The Missing Link: Organizational Behavior as a Key Element in Energy/Environment Regulation and University Energy Management

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Submitted to the Department of Civil Engineering in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE in Technology and Policy

at the

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ABSTRACT

This thesis addresses a paradox fundamental to public policy. The vast majority of organizations manage their secondary objectives highly irrationally when compared to a rational choice model. Secondary objectives are goals organizations must satisfy, although they don’t necessarily want to, to enable them to pursue their primary ambitions. They include things like energy management, child care, pollution control, and worker safety. Most social regulation is aimed at them. The paradox is that the solutions are not only irrational from the organization’s viewpoint, but they are also poor solutions to the policy problem. If no one wins, why do organizations select them?

To explore this, I compared energy management at four New England universities. I constructed histories of both energy management and the organization. Data was collected primarily by interviews, with some use of archival records.

I found surprising differences in the timing, size, level of technical complexity, and amount of user participation implicit in the options the universities pursued. While some variation could be accounted for by institutional size and relative emphasis on science, five key factors – information, skills, resources, power and incentives – appear to strongly influence institutions’ capacities to identify and implement solutions. These five components are highly interdependent and have sub-components. For example, skills and resources are separate but clearly linked. I identify three qualitatively different types of information. A key finding is that with secondary organizational objectives, these factors appear to be very sensitive to variations in organizational structure. For example, the most decentralized university was a very good implementor of behavioral solutions, which require high incentives and low levels of skill or technical information, but was a relatively poor implementor of complex technical ones.

The results help explain the problems encountered with command and control regulation and suggest that moving to market models will not resolve them. They suggest four limits to this structure-constrained model of decision making. These provide four classes of opportunities for improved decision making and better policy. Each class leads to policies which modify organizations, either by changing their structures, to change their characteristics along the five dimensions set out above, or by bolstering them in one or more of the five directions.

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ACKNOWLEDGEMENTS

A thesis writer has two objectives; to produce the document and to survive the process. Retrospectively, I'm unsure which is more important. However, surviving could be described as a secondary objective; something I had to do in order to get on with writing the thesis. Others may argue it is the primary aim. Notwithstanding, there are two groups of people I would like to thank for their assistance over the past two and half years; those who helped write the thesis and those who helped me survive. Many fall into both groups.

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How Many Graduate Students Does it Take to Change a Lightbulb?

(Answer at the end of chapter seven)
# TABLE OF CONTENTS

## Chapter 1. Problem Definition

### Introduction
- The Policy Problem 17
- The Goals of This Thesis 19
- The Research 22
- Structure of the Thesis 24

### The Organizational Framework
- Primary and Secondary Objectives in Organizations 25
- Orthogonal and Aligned Management 29

### The Problem of University Energy Management
- Energy Management as a Secondary Objective 33
- Study Questions 34
- Methodology 34
- Introduction to the Cases 38
- Comparative Energy Management 44

### Summary of Findings
52

## Chapter 2. Problem Specification

### Introduction
57

### Types of Technology
- Infrastructure and Equipment 58
- Lighting and Heat 62
- The Technological Hierarchy 63

### System Improvement
- Standardization versus Optimization 66
- Three Broad Options – Smaller, Smoother, and Less 70

### The "Nuts and Bolts" of University Energy Management
- Introduction 71
- Technology 72
  - Space Use 72
  - Space Design and Refurbishment 78
    - Architecture 78
    - Lights 81
    - Heating, Ventilation and Air Conditioning 82
    - Standards for Lighting, Heating, Cooling and Ventilation 83
    - Distribution Systems and Local Control 84
    - The Building on a Campus 85
- Maintenance 86
  - Preventative and Urgent Minor Maintenance 86
  - Envelope Maintenance 88
- Control 88
- Conclusion - Management Questions 90
Chapter 3. Secondary Objectives and Organizational Structure

Introduction 93

Structure and Secondary Objectives 95
- A Closer Look at the Input-Output Functions 96
- Building an Organization 97
- Structures of Universities 100

Universities as Process Organizations 100
- Formal (Administrative) Structure 104
- Academics and Administrators 107
- The Energy Management Organization within the University 109
  - The Energy Management Organizations in the Case Study Universities 112

Chapter 4. Structure and Decision Making

Introduction 117
- Unit of Analysis 118
- Explaining the Data 120
  - Bounded Rationality 121
  - Development of a Metric 122
- The Dimensions of the Metric 126
  - Information 126
  - Skills 129
  - Resources 129
  - Incentives and Power 130
  - Summary 135
- The Interdependence of the Bounds 135

Structural Constraints on Decision Making 137
- Size 137
- Delegation 141
- Decentralization of Authority and Responsibility 149
- Incentives 166
- External Contracting 170
- Users 174

Discussion 181

Chapter 5. Exploring the limits

Introduction 185

Raising the Importance of Secondary Objectives 186
- Reducing Peripheralness in Practice 188
- Reducing Peripheralness in Universities 190
- Evidence 190

Loose Bounds 196
Tight Bounds 201

Changing the Bounds without Changing Structure 205

Conclusion 207
Chapter 6. Policy Objectives

Introduction 209
Temporary Change 210
Gradual and Permanent Change 211
  Changes in Physical Systems 213
  Changes in Engineering Possibilities 214
  Changes in Relations between People and Objects 215
  Changes in Interpersonal Interaction through Learning and Communication 217
  Changing Social Systems Leading to Changing Physical Systems 218
Rapid and Permanent Change 219
Conclusion 220

Chapter 7. Policy Options

Introduction 221
Specialist Managers 224
Senior Management 225
Private Agents 231
Government 238
  A Critique of Existing Approaches 238
    Command and Control 238
    Markets 240
    Energy Policy Approaches 242
  A Framework for Alternative Pollution Policy 243
    Policies which aim to push back organizational bounds 245
    Policies which aim to change objectives 247
Conclusion 249

Bibliography 251
Appendix A. Energy Technologies
   I. Introduction 257
   II. Lighting 257
   III. Controllers 259

Appendix B. MIT
   I. Introduction 265
   II. History and Organization for Energy Conservation 268
   III. Current Operations 296
   IV. Housing 319
   V. Communications 325

Appendix C. Harvard
   I. Overview and University-wide issues 331
   II. The Faculty of Arts and Sciences 345
   III. The Graduate School of Education 382
   IV. The Facilities Maintenance Department 391
   V. Coordinated Activities 401
   VI. Other issues 410
   VII. Other Schools 415

Appendix D. The University of Massachusetts at Amherst
   I. Introduction 419
   II. Organization 421
   III. Budgeting 440
   IV. Housing 453
   V. Central Plant and Distribution 461
   VI. Work Orders and Facilities Control 469

Appendix E. Tufts
   I. Introduction 487
   II. Organization 489
   III. Budgeting 505
   IV. Central Plant and Distribution 508
   V. Construction 512
   VI. Facilities Control 518
   VII. Housing 521
# LIST OF FIGURES

Figure 1.1  Incentives, Options, and Prior Structure as Determinants of Organizational Choice.  21
Figure 1.2  Comparative Energy Management at Four Universities  45
Figure 1.3a  Computer Control  46
Figure 1.3b  Computer Control  47
Figure 1.4  Light Bulbs and Motors  48
Figure 1.5  Envelope Repairs and Retrofits  49
Figure 1.6  Usage Reduction by Rationing  50
Figure 1.7  Preventative Maintenance  51
Figure 2.1  The Energy System.  65
Figure 3.1  Thompson's Input, Core, and Output Model  95
Figure 3.2  Thompson's Model (modified)  97
Figure 3.3  Characterizations of Some Functions Carried out by the Case Study Universities  104
Figure 3.4  Some Contributors to Structure in Case Study Universities  106
Figure 3.5  The Structure of the Energy Management Organization  111
Figure 3.6  The Energy Management Organization at MIT  112
Figure 3.7  The Energy Management Organization at Harvard  113
Figure 3.8  The Energy Management Organization at The University of Massachusetts at Amherst  114
Figure 3.9  The Energy Management Organization at Tufts  115
Figure 4.1  Dimensions of Organizational Decision Making  126
Figure 4.2  Effect of Size on Decision Making Ability  139
Figure 4.3  Effect of Delegation on Decision Making Ability  144
Figure 4.4  Effect of Decentralization on Decision Making Ability  153
Figure 5.1  Structure of the Argument  176
Figure 5.2  Alternative Positions for Input/Output Functions  177
Figure 5.3  Effect of Change in Objectives on Decision Making Ability  188
Figure 6.1  Four Classes of Policy Objectives  209
Figure 7.1  Policy Options for Specialist Managers, Senior Management, and Private Groups  223
Figure 7.2  The Impacts of Incentive and Promotional Efforts in the BPA Solar and Heat Pump Water Heater Programs.  242
Figure 7.3  Policy Options for Government  244
CHAPTER 1. PROBLEM DEFINITION

INTRODUCTION

THE POLICY PROBLEM

Energy/environment regulation is a mess. Programs are expensive, wasteful, and often fail to achieve the desired results (Ackerman and Stewart 1985, Oppenheimer 1988). Theoreticians and practitioners from many domains claim to have 'the answers', but either they disagree with each other, or their remedies fail in practice. The heart of the problem is that none of the approaches put forward to date can explain effectively a dichotomy in the way organizations respond to regulation. Some organizations respond very effectively while the majority pursue expensive and inefficient solutions. For example, in response to new stringent regulations, one Massachusetts electroplater completely eliminated its discharge and returned its licence to the Department of Environmental Quality Engineering. Many of its neighbors, jewelry platers with virtually identical processes, spent hundreds of thousands of dollars to expand their precipitation tanks. Without understanding this dichotomy, and its cause, we cannot develop a coherent regulatory theory.

Let us start by considering the evidence for and against three major regulatory arguments - market based, command and control, and a subset of command and control

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1 Single quotation marks are used for emphasis. Double quotes indicate text from the interviews.

known as technology forcing – and a fourth class of policies which are not regulation *per se*. The economists say we should simply charge people at the marginal social cost and the market will clear at the social optimum (e.g. Ruff 1970, Burrows 1980, Schelling 1983, Blinder 1987). Leaving aside the ethical (e.g. Sagoff 1988) and practical problems with this approach, there is significant empirical evidence that it would not work. Consider waste minimization and energy conservation, two domains where organizations face a clear price signal and no regulatory encumbrances. Here, we would expect conservation levels to approach economic optimality. However, instead, we see the highly dichotomous response alluded to above with some organizations very close to their optimum and the vast majority far from it (Ross 1986, Oldenburg and Hirschhorn 1987).³ Ross observed this dichotomy between organizations in the same industry. We also see massive government programs designed to persuade organizations to pursue their best interest.⁴

Our current method of pollution and occupational health and safety regulation is commonly called command and control. Under this regime, government specifies fairly explicitly the pollution control measures, in the form of specific technologies or discharge limits based on either health calculi or available technology, an organization should pursue. As I said above, this out of favor in many camps. It is expensive, enforcement has proven problematic (U.S. Government Accounting Office 1988), and again we see a dichotomy. Some organizations pursue solutions which prevent waste

³ To argue that these organizations are not behaving rationally, we need to find examples where organizations fail to select options which offer both managerial and economic advantages. Otherwise, it could be argued that organizations are avoiding solutions that would make management too complex. We will see later that this does happen, probably with very high frequency. This provides incontrovertible evidence that these organizations do not behave rationally.

⁴ Three Massachusetts government agencies were pursuing (successful) waste minimization programs while this thesis was being written. Many electric utilities pay consumers to conserve. The Federal Department of Energy has had massive programs to subsidize energy conservation works.
production while the majority pursue solutions which often move waste from one medium to another. I estimate that over 25% of hazardous waste generated in 1983 came from either power station scrubbers, waste water treatment plants, or other treatment processes. Many businesses feel that current regulations limit their decisions and constrain them to sub-optimal choices (Bardach and Kagan 1982), and aggregate efficiencies are not realized (Nichols 1984).

A subset of command and control, technology forcing, aims to bring about changes in process or inputs rather than the construction of treatment plants. Regulators pursue fundamental technological change in the work place so that pollution is not created. To do this, regulations need to be so stringent that firms are ‘forced’ to look for innovative and fundamentally different solutions to their pollution problems. However, most experiments in technology forcing have ended in long court cases and little innovation (EPA vs International Harvester 1973, Ashford, Ayers and Stone 1985).

Finally, there is a fourth group of policy programs which do not fit into the three classes above. They work reasonably well, but are hard to justify theoretically. They appear to be simple subsidies to industry in the form of waste minimization, rebate, subsidy and information programs, demonstration projects, and the like. Advocates of small government would be justified in criticizing these programs since they are an expensive use of taxpayers’ money to subsidize inefficient industries. 

THE GOALS OF THIS THESIS

The market based, command and control, and technology forcing approaches mentioned above treat the organization as a ‘black box’ of varying intelligence and

5 The estimate is based on Table 2 of Congressional Budget Office (1985:18).

6 In fact, the advocates do not object. Quite likely, they are the beneficiaries of these approaches.
honesty. That is, they take no account of the way in which organizations interact with the stimuli from their external environment; be those stimuli energy price changes or new regulations. Rather, they assume the organization will react rationally and are surprised when it does not. Both the above critiques and the success of the fourth approach of technical assistance, subsidies, rebates, and so forth suggest that very important things, about which regulators understand little, are going on inside organizations.7

This thesis explores what happens when we lift the organizational lid and look inside. By understanding how organizations respond to regulations and incentives, we will be able to critique the various policy options that have been proposed in the literature, create a framework with which to consider new ones and, within the limits of this work, suggest new policies for both organizations and governments.

More generally, the thesis explores the way in which organizations manage what we will call secondary objectives; things they have to do, but which they don't see as vital to their functioning or growth. (This will be defined formally later.) Almost invariably these objectives call for the management of an element of the organization's institutional environment. Thus, we will be looking at organizational functions which bridge the gap between the organization and its institutional environment.

In particular we will focus on organizational decision making. However, rather than try to understand why particular decisions came about, we will focus on the way the organization limits itself to consider just a small set of the universe of economically and technically feasible options. That is, given a whole menu of options, why does the

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7 In this thesis, the term regulator will be used to refer to any private or governmental agent who seeks to influence organizational behavior. So, it includes groups such as public interest groups, congressional representatives and public servants designing subsidy programs.
organization only select from the *hors d'oeuvres*? We will not concern ourselves with which *hors d'oeuvre* the organization actually picks, be it the shrimp or the olives.

Since we are looking at input/output functions, and the way their form affects decision making, we need to focus on three variables: the form of the incentive or regulation (the structure of the organization's institutional environment); the prior organizational structure (the structure of the organization); and the characteristics of the options available to the organization (the universe of possibilities). We will explore the way they interact to constrain the option the organization will select. This is summarized in Figure 1.1. The selection process will often change the organization and either constrain or enhance possibilities for further change. We will explore that too.

![Diagram](https://via.placeholder.com/150)

**FIGURE 1.1 INCENTIVES, OPTIONS, AND PRIOR STRUCTURE AS DETERMINANTS OF ORGANIZATIONAL CHOICE.**

The thesis builds a structure-based model of organizational decision making in these types of situations. The model will enable us to explain observations in both the literature and cases carried out during the thesis research. Most importantly, it will enable us to explain the dichotomy of either very poor or very good management described above.

Structure has been used as the primary independent variable for two reasons. First, it is a much more versatile tool for policy design than some of the alternatives e.g. culture (Schein 1985) or power (Salancik and Pfeffer 1974, Hickson *et al* 1971). Structure is much easier to work with in a policy arena. Second, we will find that it is
impossible to convincingly argue for linear causation by power, information processing, or any of the other candidates, when we explain people's decision making. Rather, we will be looking at the interaction of several variables. Consequently, structure, which can be more encompassing has more explanatory power. By structure, I mean the design, formal or informal, of the organization through which it is administered. This includes both the lines of authority and communication between people and the data and information that flow along those lines (Chandler 1962:14). However, at times, we will see these other elements acting to either create or reinforce structure. In those cases, these elements will be incorporated to expand the structural argument.

THE RESEARCH

To facilitate development of the theoretical model, and to provide data with which to provisionally test it, I carried out a comparative analysis of energy conservation behavior at four New England universities.

Universities were selected for three reasons. First, they are microcosms of this society's capital base. They contain the full range of space use, equipment, and technology found in the society at large. Second, universities are not cost minimizers, so, cost reduction is likely to be a secondary objective. This is elaborated upon later in the chapter. Finally, universities are true 'life cycle' managers of their assets. They conceive, design, construct, use, refurbish, and demolish their own buildings on a campus of spatially connected structures.

This life cycle management is important for two reasons. First, we need not worry about economic distortions from third party construction or ownership of buildings. Particularly, we need not worry about people deliberately installing low efficiency, low cost equipment to reduce capital costs prior to resale. Second, the spatial and temporal inter-connectivity of structures affords an opportunity to study a complex,
dynamic and evolutionary process. Discrete buildings would be much more limiting because we expect many fewer opportunities for institutional learning. Since the dichotomous and seemingly irrational behavior by organizations has been observed throughout industry, we thought it unlikely that the fact that universities are not 'for profit' organizations would affect the generalizability of the results.

I examined energy management as a secondary objective for four reasons. First, energy is as invisible as the wires that carry it. Yet it is pervasive; nobody in the university can function effectively without it. Second, there are a smorgasbord of highly differentiated (social and technical) solutions available. These vary little between sites, and are easily understood, so real comparisons can be made. Third, utilities are probably the largest highly elastic element of a university's budget. Since they can vary so much and conservation can be used to realize significant savings without affecting academic programs, cost constrained universities are likely to see energy and water management as panaceas. Finally, an informal survey of users suggested that they generally thought it was poorly managed.

Retrospectively, energy management in universities represents the ideal combination for the theory that is developed here. The universities were a good choice because they have very high structural variation within a single industry, (Contrary to DiMaggio and Powell (1983)). Energy management was a good choice because there are literally hundreds of decisions, or non-decisions, to be explained. Each decision was relatively discrete, easy to see (as there was generally a physical manifestation), and there was enormous variation in their size, complexity, and implicit information requirements.
STRUCTURE OF THE THESIS

This thesis does three things:

1) It presents a model of organizational behavior and decision making in the management of secondary objectives and explores the policy implications of that model.

2) It explains the observations in the cases in terms of the model.

3) It presents the cases, in their entirety, to the reader.

These three aspects will be of varying interest to different audiences. Therefore, this thesis is divided three ways. The first half of each chapter presents an element of the general model while the second either expands or exemplifies that element for the case of university energy management. However, this separation is not made at the expense of either logical progression or brevity. Consequently, there is some bleed over between the two halves. Similarly, the general discussion, and particularly examples, are often written in terms of university energy management. This was done to simplify the writing. Those with more theoretical interests should emphasize the first half of each chapter. The third division is the descriptive appendices (B, C, D, E) which present the cases in detail.\(^8\) While this enables the reader to corroborate the argument, they are included principally because many people who read the draft were particularly interested in the case material. The reader should note that while the universities are identified, all individual's names have been changed. This protects them from both my misinterpretations and other facilities managers' thirst for more information.

To develop a model and analyze the policy process from an organizational perspective, we must do four things. First, we must develop both a vocabulary with which to characterize organizations' observed behavior and a specification of the problem they face (chapters one and two). Second, we must develop a framework that

\(^8\) The appendices are bound as volume two.
explains the observed behavior of organizations (chapters three, four and five). This will enable us to explain why organizations have often followed a logic other than the external rationality the regulators have assumed. We will see good solutions are hard to achieve and will identify organizational change as the vital outcome of effective policy. So, third, in chapter six we explore the policy options this creates. Finally, we can use this framework to critique the policy approaches presented in the literature and suggest new alternatives for those both inside and outside the organization (chapter seven).

THE ORGANIZATIONAL FRAMEWORK

In this thesis, we will need to distinguish and explain three different, but interrelated, aspects of organizations:

* Primary and secondary objectives
* Orthogonal and aligned solutions
* Core and peripheral activities.

The next third of this chapter aims simply to explain the differences between the first two and explore their interrelationships. The third pair is discussed in chapter three. This chapter closes by introducing the empirical study and presenting some summary results.

PRIMARY AND SECONDARY OBJECTIVES IN ORGANIZATIONS

Organizations' objectives span a continuum from primary through secondary. An organization's primary objectives are (1) its internally stated goals and purposes, and (2) management of identified threats to its survival or growth. The first group, the stated goals, is easily understood, though we must allow for the possibility of management articulating goals to the outside world, but not inward to the organization. The second,
threats to survival or growth, has two important elements which need elaboration. First, the organization must identify the threats. It won't create primary objectives to counter threats it hasn't identified. For example, the energy price rises of 1973 and 1979 fueled inflations which put people out of business. Some of these would have survived if they had understood the situation better. Conversely, organizations mistakenly identify threats that are not real. Second, the planning horizon is important. In the long run, any function may jeopardize an organization; personnel, customer support, information systems, resources supplies, waste disposal, etc. But, that doesn't make all objectives primary; they cannot be. A primary objective is long-run and significant. Examples of a business's primary objectives might include maximization of profits, product quality and market share and minimization of costs. A university may strive for the highest quality in lectures, examinations, research findings and papers, but care much less for a secondary objective like energy usage minimization.

The secondary objectives are associated with the activities the organization must carry out, products it must produce, and services it must provide so primary objectives can be pursued unbridled. These activities provide direct support for the input, transformation, and output functions.\(^9\) As such, these functions tend to mediate the relationship between the organization's core and its environment. Therefore, each secondary objective tends to be associated with the management of a particular element of the organizational environment. Secondary objectives might include legal compliance

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\(^9\) Mintzberg (1983:12) defines them as being within the operating core of the organization, while Thompson (1967) considers them outside. They are not associated with what Mintzberg calls the support staff activities, which he considers outside the core. However, the line between these activities is very grey. In chapter three, I will resolve this by describing three classes of activities; core, peripheral, and support. The secondary objectives will be associated with the peripheral activities. We can illustrate the importance of this distinction by noting the virtual impossibility of an organization going bankrupt because the cafeteria is of poor quality, while we can easily imagine waste disposal problems being very threatening. In the next chapter I will introduce the notion of infrastructural technologies; the technologies of peripheral activities.
(pollution, occupational health and safety), ethical performance, internal communications and analysis (information systems) and acceptable staff procurement and training (personnel, child care).

Even in wholly rational organizations we expect better satisfaction of the primary objectives than the secondary. If the satisfaction of each objective is constrained by those objectives which are more important, the primary objectives will be less constrained, and therefore better optimized. The reader is reminded that while lower performance is expected of the activities responsible for the secondary objectives, the empirical evidences suggests that actual performance is much worse than rational.

While overall organizational efficiency will increase with the number of primary objectives it can manage effectively, that number is limited. If we assume that an organization can embed the management of only a limited number of objectives in its core technology, we can see that not all objectives can be primary. If there are a large number of primary objectives, with the organization trying to optimize all of them, then at worst they will conflict and at best the management problem will become so complex that all of them will suffer (Galbraith 1974). For example, profit maximization and employee satisfaction can clash.

So, organizations have primary objectives. They have peripheral activities that enable the primary objectives to be pursued. Associated with these peripheral activities are secondary objectives. This thesis is about secondary objectives.

THREATS AND RESPONSES

Input/output activities change in importance with changes in objectives and changes in environmental contingencies (Hrebiniak and Joyce 1985). The latter can happen through a sudden or gradual change in the internal or external environment of
the organization followed by a recognition of that change. Examples of sudden internal and external changes are a work-place death that changes perceptions about safety and a rapid increase in energy prices which threatens the organization's viability. Similarly, gradual internal and external changes include repeated losses of key staff and gradual increases in waste disposal costs. Crises tend to be induced by unavailability or a dramatic increase in the cost of secondary 'commodities', failure of the organization to provide them with satisfactory quality or quantity, or attention drawn to secondary objectives due to crises elsewhere in the organization (e.g. a cash-flow problem yielding cost cutting as the objective, expressed through energy and other inputs). Gradual changes are either slow increases in the relative importance of a secondary activity or repeated unsatisfactory performance yielding a large effect.

In all four cases, the organization has four broad options to deal with this increased threat, 1) accept proportionately reduced satisfaction of primary goals (Thompson, 1967:23), 2) improve management of the secondary objective so that the core production is no longer threatened (Thompson, 1967:20-22), 3) change a part of its core production so that it is less dependent on the secondary 'commodity' (Galbraith (1974) sees this as one device for increasing slack), or 4) redefine its primary objectives to include management of that secondary 'commodity'. This fourth option will lead to eventual changes in the core technology.

Let's exemplify these four responses for a university dealing with a steep increase in the price of oil. The first option is essentially one of rationing. Here, the university might send people home early, or close for the month of January. The second one is the one we've seen most, namely the introduction of preventative maintenance programs and computerized control, installation of storm windows, and so forth. The third option would be to change the way in which universities perform their core activities, particularly research and teaching. While teaching in colder rooms is a trivial
example, changing laboratory techniques is not. For example, we could imagine
experiments being consciously redesigned so they consume less energy, or safety
standards being relaxed so that more fuel-efficient techniques could be employed.
Finally, the primary objectives could be redefined. One way a university could do this
would be to make the conservation ethos part of its academic agenda. That would
greatly change expectations on both the faculty and the students. Alternatively, it could
exploit the highly individualistic nature of work on campus by charging people directly
for their energy consumption.

This increase in threat can be either temporary or permanent. A rational
organization which perceived the increase as permanent would look towards options
three and four above. It would manage a temporary increase by looking towards options
one and two. However, organizational rationality generally does not prevail and option
two predominates.

ORTHOGONAL AND ALIGNED MANAGEMENT

Options two and three in the paragraph above, managing the secondary objective
better and changing the core technology, correspond to the second definitional
distinction; between orthogonal and aligned (or parallel) management. Orthogonal
management is the choice of problem solutions that improve performance without
improving the management of other objectives or changing the core technology.
Contrast this with aligned management. In this case, the improvement of a function
impacts directly and positively on at least one aspect of the way the organization
approaches its core functions.¹⁰

¹⁰ Thompson (1967:40) argues that organizations carry out their secondary functions
solely to reduce the environmental contingencies. This implies orthogonal
management (and hence only options one and two above). His analysis misses the
possibility for technological (or other) integration of the secondary function into the
core activities.
Peter Cebon (1990)

If a university incorporated energy management into its teaching curriculum with the students using the campus as a laboratory (as did Clark University in the early 1980s), the secondary function of energy management would be aligned with the primary one of education. Similarly, a production company that redesigns its process so it is inherently non-polluting is managing pollution in an aligned manner. Conversely, many physical plant departments avoid doing anything that meaningfully involves other groups on campus. These plants are restricted to energy management strategies that do not affect (positively or negatively) the activities of these other groups. Similarly, many industries control pollution by building treatment plants or paying someone to cart it away. This is orthogonal management.

When we start to build a model of an organization, we will see that some input/output activities have their own technologies to manage. They are expected to do so as well as possible given the constraints imposed by the organization. In as far as they are, themselves, small hierarchies, we can imagine orthogonal and aligned solutions within a sub-unit of the organization. So, we will see (at Tufts) an energy conservation program which operates orthogonal to the core functions of a physical plant, by not being integral to maintenance or capital replacement activities. Similarly, M.I.T. for a time had an energy conservation program which was aligned with a large portion of the plant, operations and maintenance, but remained orthogonal to the overall management of buildings, which included the maintenance of building envelopes and custodial activities.

It is worth noting that some notion of organizational differentiation is integral to any distinction between orthogonal and aligned solutions. We cannot distinguish between orthogonal and aligned management if the technology is sufficiently flexible to change in response to the changing environment. If the organization is less structured, then a
change represents an alteration in the environment with which the organization must deal, but cannot be seen as orthogonal or aligned to the organizational core.

Finally, alignment is not the same as income generating ability. There are aligned management strategies which cost more than other options, and are therefore inefficient if we consider only the objective of energy management or pollution control. For example, while possibly more expensive, fluidized bed coal boilers for power stations pollute less, are more flexible than conventional boilers in their operation and have a smaller unit size, and hence are more flexible in their timing and construction. In contrast, an orthogonal management strategy that does not improve the organization's ability to pursue primary objectives can generate income. For example, many money saving energy conservation options do not improve the organization's core.

The dichotomy in behavior described in the opening pages of this thesis corresponds to organizations selecting orthogonal solutions when aligned ones are better. The key to effective policy appears to be development of techniques for inducing aligned or superior orthogonal solutions in organizations. The problem is that organizations appear extremely reticent to acknowledge the aligned solutions available.

That individual orthogonal solutions are often undesirable is virtually self evident. For pollution, we saw waste being moved from one medium to another (air to hazardous waste, etc.). For other problems, similar partial solutions occur. However, orthogonal solutions also obstruct future aligned ones. They tend to ossify the organizational structure by creating four major obstacles to change; 1) financial obstacles in the form of sunk costs, 2) vested interests in the status quo, 3) reduced incentives since the problem is less severe, and 4) physical obstacles (infrastructure is not easily changed). As this makes the structure more hide bound, fundamental changes in the technological composition of the organization become more difficult.
THE PROBLEM OF UNIVERSITY ENERGY MANAGEMENT

Having looked at some of the broad definitional issues, let's now turn to the problem of energy management in universities. We will see there that these same distinctions can be made in this more specialized context. We will then introduce the study and look briefly at the case-study universities.

Management of U.S. universities and energy have both been important for thirty years:

- From around 1960 to 1973 (and beyond) the tertiary education sector expanded rapidly. Most universities had extensive construction programs.

- The 1973 oil embargo precipitated fuel shortages and triggered the high fuel prices and inflation that characterized the next decade. Fuel prices rose again in the late 1970's.

- In the early 1980's universities were faced with declining revenues, high fuel costs and aging capital stock (built in the 1960's).

- Now, in the late 1980's, concerns about the safety of nuclear power and the pollution potential of coal are driving up electricity prices. Simultaneously, in some regions, particularly the North East, gas availability is declining. The federal government is under pressure to tax fossil fuels to relieve the deficit and greenhouse warming. Finally, aging capital stock has made deferred maintenance a major issue.

However, in the same period technology and management tools available to deliver and control energy have improved substantially. Lighting, motors, and materials are significantly better. Energy control technology has steadily evolved from time clocks, through large simple computers controlling pneumatic actuators and pneumatic controls, to the sophisticated, highly localized, direct digital control systems available today. In addition, we understand much better the dynamics of energy use and conservation and the potential savings available through 'non-traditional' sources such as solar energy.
We could expect universities to be at the forefront of effective and innovative energy management. They contain the necessary expertise (if not within their administrations, then in their faculties and research staff); have an enormous and very expensive capital base through which savings can be generated; operate their buildings from conception through to demolition, and occupy an important position in U.S. society as 'demonstration projects', i.e. institutions from which new technologies, practices, and scientific achievements are expected to flow. Even allowing for the inevitable lag between a crisis and the emergence of technical and managerial solutions, universities are far from the energy management frontier. They have responded slowly, unevenly, and generally incompletely to the energy management task (Vine 1987, O'Hara 1986:17-19). Why?

ENERGY MANAGEMENT AS A SECONDARY OBJECTIVE

A senior administrator sees the primary objectives of a university as efficient self-perpetuation or possibly growth through the creation of a strong reputation by good research and teaching, efficient operation, and satisfaction of the needs of clients. For the faculty, the university exists so they can pursue intellectual objectives in an honest and productive environment. Neither sees cost minimization (cf. cost containment) a major priority; it is a secondary objective. But, it is still an objective. For the administrator, cost reductions increase administrative flexibility and free capital for innovative programs. Similarly, the powerful faculty cannot be offended by the provision of poor services. Finally, it makes the university more competitive either because it provides better services or has lower costs. So, administrators like universities which run smoothly and cheaply.\textsuperscript{11} The faculty face two types of costs. They control

\textsuperscript{11} All private universities and some state universities, e.g. the University of California, have a financial incentive, though it varies in strength. We will see that the University of Massachusetts at Amherst has a much weaker incentive. Therefore, energy management provides an opportunity to inject capital for improvements and
some costs within their budgets and they contribute to overhead, which generally includes energy. They have a strong incentive to control their own costs. Resources not wasted can be used elsewhere. However, they have a small incentive for overhead cost minimization. So, while it is not their principal concern, faculty and administrators benefit from cost minimization. Hence, it is a secondary organizational objective.

STUDY QUESTIONS

As I said above, this thesis is based on a comparative study of four universities in which I attempted to answer two sets of questions:

Why do universities use more energy than is economically optimal? Are the key factors organizational, financial, technological, or some relation between them? Particularly, what is the relationship between organizational structure, technology (or other approach) selection and efficiency of technology usage? If there is a correlation, what are the underlying causes; can they be related to such things as skills acquisition, information transfer, delegation and power interests?

During the study this question was refined to: Given a smorgasbord of technically feasible and economically attractive technological and behavioral options for the management of energy, what determines which ones the university considers or selects?

If so, what policy options and strategies can universities pursue to mitigate these problems? When is a wholesale restructuring called for and what problems would it solve? When can they use other devices such as market forces and other incentives? When is a change in relations with senior management called for?

METHODOLOGY

The study involved analysis of case study data from four universities; MIT, Harvard, Tufts and The University of Massachusetts at Amherst. These were preceded to control erratic fluctuations in funding from the legislature. There is no direct financial incentive however.

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12 Retrospectively, a better question would have conceded that some universities come close to economically optimal behavior. The paradox can be better understood as behavior that is either very close to or very far from optimal.
by interviews with faculty and administrators at U.C. Berkeley, U.C. Davis, and Stanford. These prior interviews were used to refine some of my questions before beginning the case-studies, and to provide an external reference frame (albeit a limited one) before beginning the research proper.

MIT, as sponsor, was interested in comparing its performance to that of Harvard. It was proud of its technical achievements in energy conservation and was extremely sceptical of Harvard's Faculty of Arts and Sciences's claim of a 50% reduction of energy use in five years. The sponsors did not believe Harvard had the technical skills for such an effort. Internecine conflicts aside, MIT and Harvard both had reputations as extremely effective energy conservers. MIT had been at the forefront of direct digital control and had realized enormous savings through its use. Harvard's 50% reduction is impressive by any standards. Retrospectively, these two sites are a very well matched pair on all dimensions except structure. Tufts was selected as a smaller private university which, like MIT, had a strong educational base in engineering. It was geographically proximate to the other sites, so there were not likely to be any weather effects. The University of Massachusetts at Amherst was selected as a state university over The University of Massachusetts at Boston because the architecture of the Boston campus was distinctly different to most universities. Being essentially one building, we felt that any quantitative analysis would be virtually impossible and there may be other effects.

I was interested in both the history of energy conservation and current practice in the context of events occurring both within and outside the university. So, I needed to understand the energy management activities as well as those activities that interact heavily with it; particularly physical plant operations and maintenance, capital renewal, and new building construction, as well as communications with and expectations of users.
Peter Cebon (1990)

Therefore, interviews were split among what I identified as the major interest groups. Central to the problem were the energy managers; they were interviewed more than once. Further removed were the facilities maintenance staff, the relevant administration, the housing staff, and faculty with a professional interest in energy management. These faculty were interviewed as both sensitive users (I assumed their professional concerns would make them more interested in activities on the campus) and because I wanted to know the extent of their professional involvement in the university's operations. Also, I interviewed the managers of two appropriate buildings on campus, generally dormitories, one built pre-1955 and the other post-1975. Other buildings were necessarily substituted on occasion. Most removed from the problem, I interviewed union representatives (by telephone), architects, an HVAC engineer, and energy contractors. Overall, a total of 74 formal interviews were conducted (including 23 at MIT, 22 at Harvard, 12 at Tufts, 12 at The University of Massachusetts at Amherst). Several informal follow-up interviews were conducted to monitor progress at the sites after cessation of formal data collection and to clarify facts.

Questions in the interviews were designed to elicit description of the major efforts at energy management undertaken to date and to understand why those approaches had been pursued. Particularly, I asked about:

* technology selection, maintenance, and replacement and the management issues surrounding it.

* organization and organizational history, particularly the relationship between energy management and other functions, especially physical plant operations.

* treatment of users and their relationship to organization and technology over time.

* the history of energy management and current energy management programs at the campuses.

Early on it became obvious that methodological and practical obstacles precluded effective quantitative comparisons of the cases. Because the buildings and plant
generally pre-date 1973, and because energy use is predicated very strongly on initial
design, there are no methods for intelligent and direct quantitative comparisons. For
example, if a building was built in 1966 with ten fume-hoods exhausting to the same
fan, it would be impossible to install computerized hood controllers. If they were
exhausted independently, it would be possible. The difference in savings would be
about $10 000 per annum for the building. Similar problems apply for virtually every
other aspect of building design. Even without methodological problems, the practical
ones are enormous. Simply, there is insufficient data to model the buildings effectively
(cf. DeCicco 1988). Even if data were available, variations in building use, possibly
excepting dormitories, would preclude useful comparison.

However, we found that after controlling for the decision making criteria, it was
possible to make comparisons between decisions in terms of their extent (how much of
the campus was affected) and their timing (when was a particular solution first adopted
in relation to the technology being introduced to the market, and in relation to the other
cases?)

At the end of the study, the findings were presented orally to staff at the
Massachusetts Department of Environmental Management, Massachusetts Department of
Environmental Quality Engineering, and Massachusetts Public Interest Research Group.
These organizations all contain people who spend time studying the behavior of
individual organizations with a view to helping, regulating, or suing them (MassPIRG
does all three, not just the last). These people gave valuable feedback on the
generalizability of the findings.
Peter Cebon (1990)

INTRODUCTION TO THE CASES

MIT

Size

Of the four cases, MIT is in the middle (second or third) size-wise. While it has second least students, (Tufts is smaller) it is the most energy-intensive. The 10,000 students (5,000 graduate) and about 5,000 staff occupy 115 buildings (9,000,000 square feet of floor space) on 130 acres. In 1987, fuel cost about $13,000,000.

Organization

The Institute has five schools and extensive support departments. The Physical Plant Department is responsible for design, operation and maintenance of all structures and non-laboratory equipment on the campus, except the dormitories. They are managed by the Housing Office and maintained by the Physical Plant at its request. The Planning Department plans the campus and the Office of Facilities Maintenance Systems allocates and plans space.

Traditionally these service departments remain very separate from the faculty and the academic departments. The Physical Plant Department is best characterized as relatively skilled and centralized. MIT itself is fairly centralized, with limited delegation of authority from the central administration.

Before the computerized energy management system was installed in 1976, the Physical Plant department had three large divisions: Utilities, Architecture Engineering and Construction, and Building Operations (responsible for cleaning and grounds as well as building envelopes and contents). At this time, the operations group was divided into three geographically-based units, each under a supervisor. Each building was run by
one of about sixty building operators who would ensure it remained operational and comfortable.

This system was generally unsatisfactory. Maintenance was often poor, so user comfort was low. Since rapid response was preferred to thorough solutions, praise and promotions were available for quick (though commonly low quality) work. Also, the highly localized teams obstructed centralized supervision and information acquisition attempts. Finally, there was significant conflict both between the various shops and between management and the work-force.

After the direct digital control system was installed, the Physical Plant Department was restructured into the current four divisions; Building Operations (all aspects of supply of mechanical and electrical services and focus for energy management), Support Services and Building Maintenance (includes envelope maintenance and custodial), Architecture, Engineering and Construction (New structures) and Utilities and Engineering (Bulk utilities, distribution, etc.) While the Physical Plant Director oversees Building Operations and the Support Services groups, the Associate Director, having had extensive energy conservation responsibilities and experience, takes responsibility there.

HARVARD

Size

Harvard's decentralized structure makes it hard to talk about size. However, the Cambridge campus (the others are in Allston and Longwood) has more buildings and less intensive energy use than MIT. About half of the 350 buildings are controlled by the Faculty of Arts and Sciences. The small professional school studied controls six. There are 22,000 people on the Cambridge campus.
Organization

Each of the university's ten financially independent faculties levies its own fees and manages its own endowment. The schools may purchase physical plant services either from the Facilities Maintenance Department or externally. However, they all purchase day-to-day operations and maintenance services and most utilities from the Facilities Maintenance Department. The study focussed on the Faculty of Arts and Sciences, a small professional school, and the Facilities Maintenance Department.

The second of the Faculty of Arts and Sciences' two major energy conservation efforts was managed by the school's Physical Resources office, which was built up for the purpose and led by the dean and an Applied Science professor. Unlike the first campaign, both of which were carried out under the same dean, the second was very successful. As part of the second program, each building assumed a lot responsibility for facilities control through energy monitors and superintendents. Elimination of Summer steam was a major source of savings, friction within the faculty, and conflict between it and the other schools. The program also precipitated the restructuring of the Buildings and Grounds Department into the Facilities Maintenance Department.

At the small professional school, an assistant dean, his administrative assistant, and a building superintendent all devote less than half their time to facilities management.

Before restructuring, the rest of Harvard saw the Buildings and Grounds Department, apparently reasonably accurately, as self serving. Apparently, it was very proprietary about the buildings and its monopoly service was perceived as poor and expensive. It also had limited technical competence, so it was never invited to review plans. At various times it had an engineering section which was never a forceful proponent or agent of modernization or change, mainly because it was very expensive.
However, it tended to be fairly aggressive toward the smaller schools. Just after restructuring, the Facilities Maintenance Department employed a mechanical engineer. He tended to be very slow and methodical, and therefore of little utility. He was not replaced when he retired three or four years later.

In the early 1980's, high costs and low opinions precipitated the restructuring into the Facilities Maintenance Department. There was large staff attrition. Structural trades (particularly painters) were off-loaded to a preferred contractor. Other functions were diminished significantly. This, among other things, was meant to show the schools that the changes were more than cosmetic, and that it had a service to offer. The faculties critically evaluated the new organization and decided to support it. Budgets were then increased and it stepped back up to a "comfortable valley".

To facilitate the restructuring, and particularly to change attitudes, those staff not brought in from outside were re-trained to be much more sensitive to the schools' needs. Also, staff for liaison roles were recruited from the schools. Communication improved significantly. In many respects they have "gone overboard in the wrong direction". The staff are very hesitant to suggest works to the schools, despite the fact that the schools feel they know insufficient to prescribe programs.

The Facilities Maintenance Department includes a director, an associate director for Cambridge, two managers, one for each half of the campus, (these four liaise with the schools) and a geographically-based operating staff. The department has a purchasing officer who negotiates prices but does not prescribe equipment. In about October 1987, the department re-deployed an engineer from the medical campus energy plant. Although employed on very short notice and virtually unintentionally, he filled a technical skills void in the organization, especially providing skills for the smaller schools.
Size

This is the largest of the case study universities. 30,000 students, including 5,000 graduates, and about 3,000 staff use 250 buildings, 140 heated. The floor area, excluding housing, is about 9,000,000 square feet. Annually, fuel costs about $11,000,000.\textsuperscript{13} However, the Physical Plant Department is relatively large since it performs a significant portion of minor capital works in-house, rather than by contract.

Organization

The campus has low capital authority, with all allocation decisions being made by the legislature and orchestrated through the central university in Boston. The central administration at the Amherst campus deals with Boston and was responsible for energy management until about 1984, when the Physical Plant Department took it on. The Plant has been restructured biannually since the current director arrived in 1984. This prevents ossification and provides challenging work for staff. While each restructuring has entailed significant movement of staff and functions, the Plant has retained its five divisions; Engineering, General Services (which runs the Physical Plant Department, including the control of work orders, inventory and ordering), Grounds and Custodial, Operations (construction and operation of all facilities on campus), and Planning (long-term deferred maintenance, construction and design). In addition, the Director's small personal staff performs general tasks including designing a new work order management system.

\textsuperscript{13} cf. MIT; 5,000 undergraduates, 5,000 graduates, 9,000,000 sq. feet, and $13,000,000/year (The University of Massachusetts at Amherst uses coal, a cheaper fuel)
The Operations Division's structure has been modified strategically to overcome organizational deficiencies. For example, in 1984, maintenance was suffering at the expense of operations, so they were separated. They were brought back closer together in 1988 when the new computer control system was about to be installed. Management hoped to guarantee maintenance by embedding a computerized preventative maintenance system in the control system. Similarly, all functions affected by the direct digital control system were brought together under the one person before it was brought into service.

As at MIT and Tufts, housing is financially separate from the rest of the university. It pays for 17.9% of the university's utility bills and occasionally purchases labor from the Physical Plant Department. However, in general it performs its own maintenance.

TUFTS

Size

Tufts is a relatively small but highly diversified university with about 7600 students on three campuses in Boston, Medford, and Grafton. The Medford campus, (4500 undergraduates, 1000 graduates, 50 major buildings (2000000 square feet) and about 110 small ones (generally converted houses)) is the focus of this study. Annual energy expenditures are about $2000000. Many of these converted houses are owned by and rented from a subsidiary of the university.

Organization

The individual schools and housing, while financially separate, buy all services from the Physical Plant Department. The Physical Plant Department has six directors; the Director, Directors of Buildings and Grounds for the three campuses, a Director of
Construction and a Director of Energy Management. Virtually all of the Physical Plant Department staff report to the Directors of Buildings and Grounds. The Director of Construction manages a small staff of project managers (five), while the Director of Energy Management has no staff and no budget. There are three professional engineers in the Physical Plant Department; two civil engineers in construction and the Director of Energy Management.

The Buildings and Grounds Division has a policy of contracting out the maintenance of new capital equipment, as it is purchased, rather than doing the work in-house. Older equipment is maintained in-house. The division provides utilities for the campus from a series of low pressure low-capacity steam boilers which do not need to be attended.

Housing at Tufts is generally of poor quality. Apparently, this is an artifact of the historical poverty of the school coupled with the methods it used to raise funds.

COMPARATIVE ENERGY MANAGEMENT

The following figures, 1.2 – 1.7, compare energy management at the four campuses for five energy management tasks; computer control, light-bulbs and motors, envelope integrity, usage reduction through use of standards, and preventative maintenance. Figure 1.1 presents a summary, while the other five look at each task in detail. In the body of the thesis we will discuss several other solutions pursued, but will keep returning to these as prototypical of particular types discussed in chapter two. For example, computer control requires sophisticated analysis and management of the system. Usage reduction requires extensive participation. Building envelopes are rarely the responsibility of the group responsible for energy management. In addition, they represent the three types of solution presented in chapter two. The first three examples represent technological changes, while the fourth is a reduction in use of an existing
technology. With preventative maintenance we run pre-existing technologies more efficiently. Similarly, the tasks deal with both infrastructure and equipment. One vital task has been excluded, namely the management of the construction of new buildings. It is difficult to graph this, and the case data is not good enough to draw strong conclusions. The appendices discuss the other solution options in detail.

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<td>Low (\rightarrow) High(^4)</td>
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<td>Light-bulbs &amp; motors(^5)</td>
<td>Medium</td>
<td>High</td>
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<td>Envelopes(^6)</td>
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<td>Usage reduction(^7)</td>
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<td>Preventative Maintenance(^8)</td>
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Notes:

1. F.A.S. = Faculty of Arts and Sciences. S.P.S. = Small Professional School.
2. Computer control represents a technological solution to a problem. It is highly complex, very expensive, and highly infrastructural.
3. These ratings are extremely summary and therefore may be deceptive.
4. Low \(\rightarrow\) Medium means going from low to medium at a specific point in time. Low - Medium means half way between low and medium.
5. Light-bulbs can be considered equipment, while motors infrastructure. These can be changed on a small scale if desired.
6. Envelopes are highly infrastructural, and tend to be maintained by a group that does have formal responsibility for energy management.
7. Usage reduction (as defined here) is non-technological, requires a lot of communication, and needs an administratively strong energy management group.
8. Preventative maintenance represents the third energy management approach, increased efficiency. Effective programs require high administrative skills and good coordination of actors.

**FIGURE 1.2 COMPARATIVE ENERGY MANAGEMENT AT FOUR UNIVERSITIES**
Figure 1.3a Computer Control at MIT and Harvard

Market

1970 1980

MIT

Number of Buildings 6 34 16 65

Harvard

F.M.D.

Computer Upgrades

F.A.S.

Number of Buildings ~100 1 1 2

S.P.S.

Number of Buildings 1 5

Hidden Timer  Centralized D.D.C.  F.M.D. = Facilities Maintenance Department
Pneumatic Control  P.C. Based D.D.C  F.A.S. = Faculty of Arts and Sciences
S.P.S. = Small Professional School
Figure 1.3b  Computer Control at U.M.A. and Tufts

Market

1970

1980

U.M.A.

~30

6

23

26 63

Tufts

Number of Buildings

50

Four Bit D.D.C  Pneumatic Control  D.D.C.  Distributed D.D.C.
Figure 1.4 Lightbulbs and Motors

- **M.I.T.**
- **Harvard**
- **F.A.S.**
- **Harvard**
- **S.P.S.**
- **U.M.A.**
- **Tufts**

*High Conflict* Delamp  Retrofit  High Efficiency
Figure 1.6 Usage Reduction by Rationing

1970  1980

M.I.T.  ![Diagram]

Harvard  ![Diagram]

F.A.S.  ![Diagram]

Harvard S.P.S.  ![Diagram] No Data on Duration

U.M.A.  ![Diagram]

Tufts  ![Diagram]

→ High Stringency/High Conflict  ← Moderate Stringency/Low Conflict
Figure 1.7 Preventative Maintenance

M.I.T.

Harvard

F.A.S.

Harvard Data Not Collected

S.P.S.

U.M.A.

Tufts No In-house Program

Some Contract Maintenance Starting About 1982

- Poor
- Below Average
- Average
- Good
SUMMARY OF FINDINGS

There are two important things to note in the figures at this stage. First, there is a lot of similarity in the performance of different tasks. For example, all but one of the schools has been unsuccessful, or has not attempted, systematic weatherproofing of envelopes. Similarly, user-based usage reduction has generally not been achieved. Second, different universities are good at different things. The Faculty of Arts and Sciences at Harvard has been successful with envelopes, while the others have not. However, it does not approach MIT in computer control. These two conclusions illustrate the broad findings of the thesis, which we will now set out.

We will see in chapter two that an organization conserving energy has a smorgasbord of solutions available to it. These solutions can be divided along three major dimensions. First, a campus contains two distinct types of technology on a campus; infrastructure and equipment. Infrastructure is task enabling, that is, it is needed but does not directly contribute to productivity. It is generally associated with secondary objectives. Equipment, on the other hand, enhances tasks and, as such, is associated with primary objectives. Along the second dimension, these can be made more efficient using three general techniques; changing technology, stricter standards, and smoother operation. Finally, different solutions have differing behavioral and technological components, and therefore different impacts on and needs from different parties. The chapter exemplifies these distinctions by discussing, in depth, the technical problem of university energy management.

Chapter three develops a theoretical argument that a rational organization will manage secondary objectives by creating specialist offices. However, we will identify two problems with this argument. First, such a conception excludes both the equipment and the users from consideration and denies the fact that responsibility for functions such as energy management overlaps other functions, such as maintenance. To get
around this problem, we will propose the existence of an energy management organization which overlies the rest of the organization. Second, we will see that these offices seem to have enormous difficulty proposing and implementing anything other than orthogonal solutions.

I observed that the solutions considered showed distinct patterns in each organization. For example, we can see in figures 1.2 - 1.7 that MIT is very good at big, highly skilled, and expensive projects but has had limited success with small projects or those requiring participation of users. In contrast, excepting the Faculty of Arts and Sciences after 1980, Harvard can be characterized as being technologically unsophisticated, but very good at small projects that require the participation of users. At Tufts, energy conservation appears to have been perpetually frustrated except in times of crisis, while at The University of Massachusetts at Amherst, the projects have all avoided users, have all offered improvements in physical plant operations, but, over time, have become more and more central to physical plant operations.

Chapter four addresses the core theoretical problem. Namely, it tries to understand why energy management organizations generally fail to implement aligned solutions which do not increase management complexity significantly. It does this by showing that there is a strong correspondence between the structure of the organization and the solutions it selects. We do this by operationalizing the problem of bounded rationality in decision making. Neglecting its propensity to take risks, I argue that an organization must muster sufficient of five core variables - information, skills, resources, power, and incentives - to make a decision and implement it.

These categories have important sub-parts and inter-relationships. It is useful to consider three types of information. First, a given change has impacts at a particular point in space. That space carries contextual information about its location, its occupants, and the tasks they carry out. Second, that same decision has impacts at other
points in space connected to it physically or organizationally. Third, there is particular technical information embodied in the solution to be implemented. Resources include labor, land, and capital. Skills are techniques to make the information useful. Obviously they vary with the information, and therefore location in the organization. Incentives and power are reasonably interchangeable. People who wish to implement solutions need either to provide incentives or have power over anyone affected by the solution, be they users or workers.

Different organizational structures around a secondary objective provide the organization with the ability to bring different amounts of these key variables to bear on a given decision. We will look at the effects of size, delegation, decentralization, external contracting, use of incentives, and definition of relationships with users. Different types of technology, infrastructure or equipment, and technological change; technical or behavioral; size reduction, quality improvement, or rationing, require different amounts of these five variables. This is why organizations tend to select options which reflect their own structures. In essence, because of zero-sum trade offs among dimensions with any structural change, the structure of the organization is a strong determinant of its capacity along each dimension. For example, effective infrastructure management often requires high skills for extensive optimization, integration, and maintenance. Therefore, centralized organizations, which tend to be higher skilled, are better at infrastructure management. Decentralized Harvard had trouble with computer control, but was very good at implementing solutions which rely on the use of incentives.

In chapter five we explore four limits to this theory. These offer the possibilities for policy alternatives. First, we note that our dichotomy between primary and secondary objectives is too rigid, and that there is a continuum. As we move along that continuum, the organization's capacity along most, but not all, dimensions did also.
Therefore, the probability of selecting aligned or superior orthogonal solutions increases. For example, from 1980-1985, energy conservation was raised in importance and was seen as vital for survival in the Faculty of Arts and Sciences at Harvard. As this redefinition occurred, the organization's capacity along most, but not all, dimensions increased. Consequently, the organization had access to a much wider range of superior solutions. Second, we see what happens if the bounds on decision making encompass all decisions. This happens with architect selection for new buildings. We find that a political model for decision making is most appropriate in this instance. Third, we consider what happens when the organization's bounds are so tight they exclude all solutions. Then, the organization either fails, or it must change the problem (alter its environment), or it must reframe in search of a new solution. Finally we note that the decision making bounds are not congruent with the structure and see that it is possible to manipulate to bounds without changing the structure significantly.

Chapter six develops, from the exceptions discussed in chapter five, policy objectives. These can be seen as temporarily altering individual bounds, temporarily altering several bounds in a coordinated or radical manner, gradual but permanent changes in organizational objectives leading to changes in structure and hence bounds, and radical changes in organizational objectives and structure.

Finally, in chapter seven we explore the options available to specialist managers, senior management, external private groups such as citizen's groups, unions, and industry groups, and government to pursue the objectives laid out in chapter six.
CHAPTER 2. PROBLEM SPECIFICATION

INTRODUCTION

This thesis aims to show how structure mediates choices when organizations manage secondary objectives. This chapter reveals the smorgasbord of choices.\(^1\) However, a simple menu would prevent easy interpretation or generalization of the data. So, in the first half of this chapter we will build from both the definitions in chapter one and other sources to create a framework for considering those options. We will see that there are both very different classes of technology and distinct categories of options. Similarly, we will explore the characteristics of different behavioral and technical solutions and relationships and trade-offs between them. We will see that these different categories of options, with their differing behavioral and technical components, suggest different organizational approaches. In the second half of the chapter we will apply that framework to the university energy management problem. We will explore the technical systems, their inherent characteristics, and the solutions available to improve them. This will enable us, at the chapter close, to develop the list of specific questions about energy management that informed the study.

TYPES OF TECHNOLOGY

In this section we carve up the hardware along two dimensions. First, we consider the difference between infrastructure and equipment. Then we discuss a

\(^1\) This thesis assumes that there is more than one technically acceptable solution to a given problem. The number of cases in energy or environmental management where this is not the case is surprisingly few.
completely separate characterization; the performance characteristics of different types of systems.

INFRASTRUCTURE AND EQUIPMENT

What is the most important difference between a centrifuge and a steam trap? Obviously, one is a piece of equipment and the other is a piece of infrastructure. These two classes of technology differ markedly in their function, the complexity of their management, and their relationship to the organization's production process. Consequently, they respond best to different internal management strategies (Chapter 4). To make the argument clearer, I will present these in terms of a university's systems before discussing the general case.

A campus contains four types of technology; task enhancing (equipment), task enabling (infrastructure), control technology, and buildings. After we have differentiated equipment and infrastructure, we will see that the latter pair, control technology and buildings, are simultaneously neither and both. Rather, control technologies are infrastructural in their design, installation and maintenance, but equipment-like in their operation. Conversely, while buildings are much like equipment in their conception, they are (by definition) infrastructural in their operation. Between the infrastructure and the equipment is an interface at which the user resides.

Equipment is what users see. It is on this side of the wall. It is everything from some lights and heaters to centrifuges and computers. In several ways, it differs markedly from infrastructure. First, it sits at the point in space that is coincident with its end-use. Unlike a fan that is used to distribute heat to another part of the building, a light is located at the point it illuminates. Second, it is possible to conceive of a single user being responsible for its acquisition. A heat recovery unit is the collective concern of everyone in a building; a word processor is not. Third, we can think, conceptually at
least, of the user being able to plug it in or switch it on. The user can make decisions about the amount it is used because these decisions are localized and simple. Finally, it can operate and is designed virtually independently of all other equipment. We can think of it as being purchased and/or operated by the user to improve the quality of the working or living environment. In sum, equipment enhances tasks. It is the technology corresponding to the transformation processes people in the organization perform. It is conceptually simple, localized, and separate.

Infrastructure is the technology and services that enable work to go on. It is task enabling technology. These services include things like space, heat, light, water, laboratory and office supplies and services, cleaning services and waste disposal. Infrastructure has several notable characteristics. First, while the technology pervades the entire campus, its very name (*infra is Latin for below*) implies that it has no effect on the structure and function of the parts of the organization not concerned directly with its operation and maintenance. Second, these services are *physically brought* into the dormitory, office or laboratory either as final services or as potential for services (like power points). Notwithstanding, the user interacts with a piece of equipment, not the infrastructure. Third, unlike equipment, energy infrastructure consists of a large number of closely coupled pieces of machinery. As such, it is generally highly complex. In fact, in terms of hardware, the technology of infrastructure provision is more complex than most other technology on the campus.² This brings us to our final, but related, point. In many organizations, productivity is inextricably linked with capital equipment. On a campus, however, all the capital is invested in the infrastructure, while the productivity rests in the relatively inexpensive equipment, the calibre of the people,

² While this complexity is easy to see for energy provision, it is a little harder for something like waste disposal. However, consider the difficulty of providing a waste disposal service which emphasizes recycling and reuse. It should be obvious that while the hardware may remain relatively simple, the organizational systems needed rapidly approach the complexity of energy infrastructure.
and the resources they can attract for their work. (Some physical sciences are an obvious exception.)

When we compare infrastructure and equipment, we see two striking differences. The first is that the equipment is inextricably tied to the university's production process (either in the core or the support activities). The process can be improved directly by improving the equipment. The infrastructure, however, is relatively independent of production. So long as the service is satisfactory, production can continue. We should note the strong similarity to the distinctions we made in chapter one. This is how we defined secondary objectives.

The second difference lies in the way decisions can be made about these elements. For equipment, it is relatively easy to imagine an individual making an independent decision. The machinery's physical and functional isolation permits individual decision making (if the infrastructure capacity is not exceeded). So, we will see in chapter four that individual incentives are an attractive vehicle to optimization. For infrastructure, however, optimal decisions about individual pieces of machinery can be made only if the decision maker is fully cognizant of other elements of the system, both now and in the future, or if the machinery is inherently flexible. The infrastructure's very complexity will suggest that concerns such as standardization of maintenance and parts will be prominent. Consequently, we may not want to decentralize the decision making.

Controller technologies, everything from openable windows through to complex computerized facilities management systems, are infrastructural in their installation decisions but equipment-like in use. The installation decisions involve questions such as to whether to install a technology, how to install it, how to convert an decision about operation into equipment performance, and so forth. If we consider the two distinctions made immediately above, they are clearly infrastructure-like. First, they have limited
effect on the quality of the work environment. While they place bounds on the amount of comfort the user may ask for, the extent of those bounds is an operational, rather than an installation decision (so long as there is some control available). Second, the installation decisions are very complicated and benefit greatly from standardization of equipment. We will see that at Harvard, where the schools are encouraged to make independent decisions, the overall university control system is considerably more complicated than is necessary and less capable of systemic optimization; a sort of tragedy of the commons.

In use, control technologies are certainly task enhancing. A student who cannot turn off the light will not sleep very well. Graduate students with overheated and under-ventilated offices are likely to sleep much better than they would like to (at that point in time). The decisions are conceptually very simple, though often very complicated hardware gets in the way of the implementation, and can be made without affecting anyone else (again if the hardware permits).

New buildings are the converse; they are approximately task enhancing in their conception but definitely infrastructural in their operation. Many of the key decisions about its final form can be made ignoring other elements of the campus and therefore are relatively simple; our key distinctions above. And, it is "enhancing" in many respects. It is a status symbol for both the donor and the tenant, it is an object of prestige for the architect, and its design determines the quality of the infrastructure it will contain, and hence the quality of the tasks it can sustain. However, it is not completely equipment like because, I will argue in Chapter five, the initial decisions are generally not made by optimization or trading off of various factors, as with most equipment, but by competing interests fighting for a pool of scarce resources. So, while this analysis is useful in this instance, it is by no means complete. Once it is built, the building (by definition) becomes a piece of infrastructure.
Production industries differ only slightly from universities in their infrastructure and equipment. In industry there is equipment, the hardware for production. There is also an infrastructure system which provides resources and takes away waste. There are, however, a couple of minor differences. First, the equipment is often reasonably highly coupled in mechanical systems. This is because the isolated 'craft like' production processes of universities are much less integrated than those in most industries. While this may make the machinery more complex, it doesn't alter the argument presented here, except that optimization decisions for a given piece of plant may be more complicated than in the university case. Second, equipment often comprises a higher proportion of the capital investment. Finally, some equipment may have dual characteristics, like the new buildings and the control systems in universities. None of these create analytical problems.

LIGHTING AND HEAT

Equipment choice constrains the infrastructure which supports it and the nature and flexibility of the control system we can use. This, in turn, constrains options on user choice. To exemplify this, consider the difference between electric light and centralized heat. While both are provided in virtually all buildings, electric lighting is generally user-controlled while heat is centralized. Fundamental differences in these types of equipment lead to differences in the infrastructure it requires, which in turn suggests different control and management strategies.

Consider the differences in service provision. Electric lighting is instantaneous, while heating takes half an hour to happen. The infrastructure for electric services are cheap and flexible, so we can put power sockets wherever they might be needed, in contrast heating pipes are very rigid. Similarly, the electric equipment can be much more portable than its thermal counterpart. The supply infrastructure for electricity is
similarly flexible an extra capacity can be provided at low cost. Consequently, most
electric control systems can ignore what is going on beyond a particular room or
building. Finally electric control systems (light switches) are very cheap and simple to
operate, while control systems for heat, even at the user's end, are very complex.

These differences are reflected in the management strategies. Electric services
tend to be user-controlled. Contrast this to the managerial hierarchies or hidden
bureaucracies that schedule and monitor the heating of buildings. Similarly, while we
would not dream of providing only one light switch for an entire building, single-zone
heating systems are common. The flexibility inherent in the technology is reflected in
the services provided.

THE TECHNOLOGICAL HIERARCHY

There is a technological hierarchy. The equipment, virtually independent of
other elements, sits at the bottom. Climbing through the infrastructure we become more
and more central to the system, and the components become more and more
interdependent. This interdependency mandates that elements can be optimized only by
considering other elements. Changing an element of the system alters the optimum point
for all those above it. Clearly, the benefit of optimizing a given piece of equipment
depends on the cost of re-optimizing those around it.

Some elements' optimization is affected only by those lower in the hierarchy.
For example, once a space has been designed and a use has been allocated, the
optimization of lighting, which is at the bottom of the tree, is independent of anything
other than the space usage and the organization's policy on lighting quality and
standards. Similarly, in reasonably robust systems, the design of a new building proceeds independent of everything else on campus.

However, the interdependence is not always purely hierarchical. Circular, multiple and temporal dependencies require iterative optimization, or more likely sub-optimal solutions. A simple example of a circular interdependency is that between the size of a pump and the diameter of the pipe on which it is placed. A fan's size is multiply dependent on the loads placed upon it and the way it is controlled. Similarly, a control system affects both the optimization of the equipment, (e.g., it allows a motor to be more tightly controlled; therefore you can run a smaller motor faster) and it also constrains equipment choice to be compatible with it. Finally, an example of a temporal dependency is a technological change which reduces loads (e.g. better light bulbs) or increases them (e.g. the proliferation of personal computers) at the bottom of the tree and requires re-optimization of things higher up later on.

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3 Space usage is taken as a given.

4 However, it is possible to imagine a situation where the design of the building is modified by an inadequate and unreliable steam supply.

5 For example, when The Faculty of Arts and Sciences at Harvard was doing its retrofits, they had the choice of re-sizing some of their fans or of putting variable speed drives on them. A simple resizing is much cheaper, and much more cost-effective unless you are using a good reliable (probably digital) control system. They chose to re-size their fans.
This network 'tree' is summarized in figure 2.1

![Diagram of the energy system]

**FIGURE 2.1 THE ENERGY SYSTEM.**

The hierarchical, circular, multiple, and temporal interdependencies, when coupled with the types of equipment and systems involved, and the quality of control and demand management systems determine the predictability of a load at a future time. The importance of this varies with the marginal cost of compensating for their impacts. Components with very high marginal costs (e.g. pipes) need to be over-designed initially to allow for changes in use (e.g. pipes). Those with a lower marginal cost can be designed to be easily augmented at a later date (e.g. packaged boilers). Others still are relatively immune to sizing problems (e.g. power cables).  

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6 A graphic example of this is in the use of refrigerators (and incandescent lights) in one of the dormitories at M.I.T.. Here there is a circuit capacity problem. The circuits overload regularly, causing blackouts until they are reset. Students using computers (who lose data immediately) undoubtedly find this frustrating.

The four principal electrical loads are claimed to be students' personal computers, stereos, refrigerators and lighting. The rise in popularity of computers is said to be causing overload problems. The physical plant has three options. Either it can let things go, creating more and more complaints as more and more students buy computers, or it can reduce demand, or it can increase capacity (by rewiring).
SYSTEM IMPROVEMENT

STANDARDIZATION VERSUS OPTIMIZATION

The rational system optimizer would concentrate first on the components that have nothing dependent on them, or that show very low scale and size economies. The more interdependent aspects would be treated next. So, for example, in a building we would start by ensuring the integrity of the building envelope, then we would look at comfort and other operational standards, and finally we would size the capital equipment. However, organizational factors, the fact that the loads are unknown before construction, the fact that changing technology and space use change opportunities and the desire to trap the largest savings first suggest a different ordering. Notwithstanding, we can optimize the equipment piece by piece while the infrastructure must be considered in the context of a whole system.

Systems consume more than energy. We must also consider the other costs associated with management, particularly the cost of maintenance. Once we do that, we are struck by a dialectic. On one hand, an organizational analysis suggests standardization of parts and procedures. On the other, economic analysis suggests optimizing the size, specification, and operation of each component.

The first obvious demand reduction step would be to ban old refrigerators by placing maximum energy use constraints on them. (Students tend to have 1960's style refrigerators when smaller modern bar 'fridges would suffice.) If that were insufficient, a move to compact fluorescent lighting from incandescent would be appropriate. Then, the need for rewiring could be assessed. However, since the physical plant has neither institutional nor organizational control over these, it has chosen to rewire some of the dormitories as a first step.

It is impossible to tell whether this approach has arisen from a feeling of powerlessness, - they would like to manage demand but don't have the power, or from bounded rationality, - they didn't even think of managing demand. Certainly, demand management is not part of the electrical shop's job specification.
Perrow (1968) looks at an organization's ability to process information. He argues that an organization does two things, exceptional things and unexceptional ones. When it strikes an exceptional situation, it will undertake a search for a solution. Searches can be of two varieties, analyzable search, where the solution can be found by methodically working through the problem, and unanalyzable search, where intuitive use of skills is required. He then argues that a given organization with given objectives will construct a hierarchy of tasks. First it will attempt to minimize the exceptions, essentially by standardization. Whenever exceptions occur, it will pursue analyzable search procedures wherever possible and will try to simplify that search as much as possible. An organization that has more search skills (more and better qualified people) will be better at searching than one with less. Similarly, an organization will be better at searching if it can coordinate skilled people effectively and provide them with information.

To exemplify Perrow's argument, a university that can standardize its steam traps (as they want to at The University of Massachusetts at Amherst), or can design its lighting systems so that all the tubes need replacing exactly annually will be more efficient. It will centralize its skills so that it can take a complicated problem like computer control and simplify it by buying only one brand of technology (as opposed to the three at Harvard). Similarly, one of the big advantages that all of the case study universities saw in the direct digital control computer systems that they installed was that they provided considerably more control over the maintenance personnel irrespective of the control over the equipment. This meant that things were fixed when they broke (rather than being by-passed) and therefore search was simplified. The efficient organization will use those centralized skills to bring the system into operation and will set about understanding the technology and optimizing the system by removing 'slack' from its operation.
The micro-economists are interested in the way organizations respond to incentives. Their argument is much more familiar and can be found in any micro-economics text. If a user has a choice over the allocation of resources, and must buy energy (and other) services, then he will consume the optimal amount given his income. That is, given a price incentive, he will choose whether or not to turn off the lights when he leaves the room, and this is how energy will be saved. So, faced with the right incentives, an organization will go about carefully scheduling times, changing light bulbs and selecting equipment that maximizes its utility. It also suggests that the organization will not standardize motors, but will carefully size them for each individual use. Similarly, it will buy whatever control system it can incorporate into its existing system at the lowest price possible. This suggests that the organization should be as decentralized as possible, so that users have maximum accountability for their use of resources.

Clearly, both arguments have merits; however, they are to some extent contradictory. Their faults lie in the assumptions they make about the problem. Perrow assumes that the cost of running the equipment is trivial when compared to the cost of running the organization, and can be ignored. So, if he had his way, the operators would leave the lights on the whole time and only install one size of motor for the whole campus. (See the quote to this effect in Section DII.B.2.b. where the energy manager talks about the operator's desire to minimize work by turning on a fan and leaving it running.) However, while he makes this assumption, it is not critical to his argument, so it provides a mediating factor, not a boundary. We would expect Perrow's argument to be more and more applicable as the complexity of the problem increases in relation to the price incentives. However, devoid of any price incentive, energy conservation following his argument can only be expected as an accidental consequence of effective equipment management. It will occur where equipment management and energy management overlap (as happens at The University of Massachusetts at Amherst).
The economists assume a perfect market. That is, the user is in an environment where he has perfect communication, instantaneous equilibrium, and costless transactions. (See for example, Hirschleifer (1984:418–419). For this problem, these terms need some interpretation. In the case of energy management, imperfect communication can be thought of as the amount of difficulty information has in travelling either from outside the organization to the decision maker, or from one decentralized decision maker to another. Speed of equilibrium is not really of concern here. Transaction costs can be thought of the difficulty the decision maker has in making the decision once all of the information is available. That is, how much trouble does the decision maker have grasping onto the relevant information and using it to make a rational decision. We would expect the decentralized structure to work best in situations where the problems best approximate these assumptions, that is situations where the information is readily available and either the decision is simple or the decision maker is highly skilled.

We can resolve this dialectic by considering the nature of the technology. Perrow’s argument applies best to infrastructural technologies. They are optimized principally in their initial selection and in their smooth operation. Their amount of operation is determined by the equipment that is installed and the way it is operated. As I said earlier, they are also highly interdependent. The amount of light determines the heating load and the electric load. The heating load determines the size and times of the motors and the fans, and so on. Because of this, their design and operation is very complicated. It requires a lot of skills in selection of components, maintenance, and tying the pieces together. For their optimal operation we require an organization that has the skills and the power to standardize them, to simplify them, to carry out sensible preventative maintenance programs, and so forth.
Equipment is optimized in its initial selection and in choices about its operation. For this, the economist’s argument applies best. While a centrifuge is a very complicated piece of machinery, its energy consumption behavior is not. A reasonably educated user is quite capable of developing an understanding of the energy trade-offs associated with one brand against another. Similarly, a user does not need to have a terribly sophisticated understanding of controls to be able to set a thermostat. Here, the user is not beset with problems of acquiring skills or gathering information. Alternatively, the skills and information needed are minimal. So, the economist’s assumptions apply. There is no reason to believe a user will not maximize utility.

From the above description, it would appear that all management involves the throwing out of old components and replacing them with better ones. So to optimize management, we would simply have users heaving equipment about and specialists throwing infrastructure around. However, this is not the case. Replacing technology is just one of three broad options any conservation manager faces. These three are presented next.

THREE BROAD OPTIONS - SMALLER, SMOOTHER, AND LESS

All efficiency increases involve one or more or three broad changes:

* installation of more efficient technologies,
* making existing technologies operate more smoothly and therefore more efficiently,
* provide reduced amounts of service with existing technologies.

For example, consider an automobile. The first strategy is to buy a smaller car. The second is to get it tuned up. The third is to drive less. It is possible to develop theoretical models which predict to what extent a person will pursue these three options to maximize utility. For example, Burrows (1980) studied the theoretical optimization of
pollution control by a firm. He examined pollution abatement as a trade-off of output reduction against technological change. In the real world of sub-optimal behavior we must also include maintenance. This categorization can be applied to all technology. Technology is just as much the choice of brick color or the shape of the eaves as it is the microprocessor that controls a pump.

THE "NUTS AND BOLTS" OF UNIVERSITY ENERGY MANAGEMENT

INTRODUCTION

We now employ the framework and categories we created in the first half of the chapter to consider the specific technical problem of university energy management; the selection and operation of technologies and the influencing of user behavior in an attempt to minimize total cost while maximizing campus system utility. We will frame the discussion in terms of the categories of options we created in the last section. Under "smaller" we will consider a university energy manager's technological options for both infrastructure and equipment. This will be organized in terms of space usage and the service demands it creates. This will let us also consider architecture as a process for converting services into loads. In so doing, we will work our way through most of the boxes in figure 2.1, more or less from top to bottom. Under "smoother" we will consider alternatives available in maintenance. Finally, "less" will be a discussion of issues around control.
TECHNOLOGY

SPACEx USE

We will assume, initially at least, that space use is a given with which the energy manager must contend. As we saw in figure 2.1, space usage, mediated by service standards, determines the primary energy requirements of a space and is a major determinant of energy consumption. It determines such things as how much light is needed in a work place, how hot it needs to be, how much variation is acceptable, and how much energy the installed equipment will use. In the first section of this half of the chapter, we will discuss the major types of space we can expect to find on a campus; laboratories, classrooms, offices, dormitories, libraries and museums, and foyers lobbies and open space. Each has its own characteristics, determined by both its use and organizational status. In the process we will introduce the types of technology we can expect to find.

Unconditioned spaces, like parking garages and store houses, are uninteresting for this study and will not be discussed. Athletic facilities have high and extremely varied loads, depending on the sport and the season. Because of their specialized nature, the study did not consider athletic facilities explicitly.

Laboratories

Laboratories are interesting for three reasons; they have lots of energy intensive equipment, they often contain fume hoods which use vast quantities of electricity and ventilation, and they require narrow deviations in conditions virtually continuously.

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More specifically, we will assume the energy manager cannot influence the way primary space is used or the partitioning of space between primary and secondary uses. Primary space is that for the building's intended uses, such as classrooms and offices. This differs from secondary space such as mechanical rooms.
Per unit area, laboratories use most energy on campus. Spatially dense energy (generally electricity) intensive equipment generates lots of heat and often needs precise control. As with refrigerators, the amount of electricity used and heat generated by functionally equivalent appliances varies considerably between models.\(^8\) Similarly, the amount the equipment is used affects its energy consumption and the heat it generates. A computer in use for an hour uses half the energy of one used for two.

Many laboratories contain fume-hoods, large boxes at a negative pressure relative to the rest of the laboratory, used to contain and exhaust noxious or radioactive chemicals. People are protected because the vapors are sucked up the flue by the fans which, when operating need electricity and a constant supply of air. Air brought in through the conditioned space increases the heating or cooling load, so common energy conservation strategy is to feed the hood with unconditioned air from a separate inlet. The fume-hood, because it is perpetually sucking, reduces the laboratory air pressure. While this keeps odors in the laboratory and out of the corridors, it can also increase air infiltration through cracks in the walls.

Fume-hoods have a sash that can be lowered when the hood is not in use. This reduces the risk of air escape from the hood into the laboratory. The energy use by a fume-hood is determined by the size of its main motor, its time in use, whether the motor can be run at a lower speed when the sash is down, whether it can be turned off when it is not needed at all, and how these various processes are controlled.

The hoods can be controlled many ways. If multiple hoods have a single exhaust system, they will have a single switch. Similarly, many independently exhausted hoods can be operated together. All must operate if one hood is in use. Singly exhausted hoods can have individual switches. Finally, there are automated technologies such as

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\(^8\) See for example Geller (1986)
timers, (which probably aren’t safe but were used at one of the case study universities), alarms which ring when the sash is left down with the motor on high, and micro computers with sensors which automatically drop the motor speed and reduce the suction when the sash is lowered. These last two solutions require the fume-hood to have a two (or variable) speed motor.

The use of micro-computer controllers, which save about $1,000 annually in electricity and heating costs (1988 dollars and prices), creates a contentious conflict between energy and safety concerns. To prevent recirculation of malodorous vapors through the building, fume-hoods often provide the sole ventilation for the laboratory. Therefore, if a chemical leaks and the fume-hoods are on reduced flow, gases can accumulate. On the other hand, the controllers continuously monitor fan reliability.

Finally, while laboratories need light, heat and ventilation just like elsewhere on campus, they tend to be supplied 24 hours daily. Except in teaching laboratories, the space is in constant use, and in some disciplines temperatures must be tightly controlled.

Classrooms

Classrooms and lecture halls are interesting in that they have neither a constant set of occupants nor a user who is generally there and responsible for the space.

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9 For example, until 1988, the protocol at M.I.T. was that hoods should run at full speed for 24 hours daily. This was under review at the time of the study and is discussed further in Appendix B.

10 It would be possible to alleviate some of this conflict by having a separate ventilation system in addition to the fume-hoods. The two could be coupled so that ventilation is reduced when the hood is in use. While the capital cost of such a system may be high, it would guarantee safety and minimum air usage. In addition, heat could be recovered from the general ventilation system. Generally heat recovery from fume-hoods is not feasible since each hood usually has its own exhaust, and therefore needs its own heat recovery unit.

11 Unless otherwise stated, "heat" refers to both heating and cooling loads.
Therefore, no user is responsible for equipment use (e.g. the temperature setting in a room). Classrooms also have more unscheduled uses than virtually any other space.

While, like other spaces, lecture halls require light, heat and ventilation, the fact that they can be very large, and therefore contain a lot of still air, and that they are not occupied continuously, has two effects on their load and control characteristics. First, they take a long time to reach thermal equilibrium. It may take an hour of heating before a lecture theater comes up to temperature. Similarly, if a crowded theater becomes overheated due to lack of ventilation, turning on the fans, though arresting the problem, is unlikely to abate it significantly. The second is that their ventilation characteristics are more complicated than for say, offices. Design codes based on air changes per hour are irrelevant for a space that has twenty-five foot ceilings, and used for only an hour or two.

This tends to make control for classrooms fairly complicated. On one hand it is desirable to give users control over the room, so they can use it freely at any time. On the other, many of the systems have significant time lags in their response, and there are no mechanisms to control the way users manipulate the system. If someone turns on the heat, will they turn it off? If the room is stuffy, will they turn on the ventilation, or will they open the window? It is not unusual to have users compensate for low temperatures by turning the thermostat to the top of the dial. The next class reduces the heat by opening the window.

Office

Offices probably have the simplest requirements of any space. Their energy use, as both electricity and cooling loads, has increased considerably as personal computers, and subsequently laser printers, have invaded the campus. (M.I.T.'s electricity usage is rising at 5% annually, probably from this source.) Offices have a constant set of users
who are responsible for the space in which they work. Most administrative and support staff offices are occupied for reasonably predictable hours. Faculty and student offices are not.

Dormitories

Dormitories tend to have relatively simple, and hence predictable, energy loads. Because they are predictable, they are often designed with little extra capacity in their systems. They generally have large kitchens in cafeterias or smaller ones for students to use. These kitchens have ovens, stoves, refrigerators, lighting, and ventilation equipment. They also need heating and cooling. There are corridors which need light, heating, and cooling, bathrooms which need light, ventilation, and heating, and bedrooms which need light and heat. While they are not great power users, smoke detectors are sometimes on the main electric circuits (which means they can be tripped by power problems).

Students' personal appliances include personal computers, stereos, refrigerators, electric jugs, hair dryers and electric razors. Stereos and refrigerators have frequented dormitories for decades. While the stock of stereos has changed, that of refrigerators often hasn't. While loads from stereos have probably decreased over time, especially with the proliferation of personal cassette players, the refrigerators are often very inefficient relative to their newer cousins. So, their annual operating cost often vastly exceeds both their capital cost and the operating cost of an adequate and efficient refrigerator. Personal computers, however, are different. They were generally an unanticipated load when the dormitory energy systems were designed. They have a reasonably high energy usage, about 550 Watts and up to 5.0 Amps.\textsuperscript{12} Unfortunately, they also require a highly reliable power supply. Power supply surges or failures corrupt

\textsuperscript{12} Most domestic circuit breakers have a capacity of 15 or 20 Amps.
data and abort program execution. Consequently, as personal computer usage increases, the demand on the electric system increases also, so that it is often approaching its design limit. Simultaneously, students are demanding higher and higher quality power supplies.

Organizationally, dormitories differ from other spaces:

* They operate twenty-four hours each day, which raises questions about operations, such as whether temperatures should be set back at night. However, they are heavily occupied for only seven or eight months of the year. With low dormitory occupancy during January, some universities move students for the month.

* Their occupants have limited responsibility, an incomparable ability to override and/or destroy any system that can be put in place, very limited tenure in both the dormitory and at the university, and very limited power within the university. Students can be mobilized relatively easily, but can be very wasteful if not mobilized. This suggests that thought should be given to invisible control devices such as motion sensors for lighting and heat.

* In private universities, dormitory construction is generally very difficult to fund. Very few donors are interested.

* In three of the four universities studied (all except Harvard), their facilities management is overseen by a different organization to the main campus.

Libraries and Museums

Libraries and museums differ from other spaces in the quality, rather than the type, of services they require. In particular, their collections need tight temperature and humidity controls. Generally, the paucity of users permits minimal ventilation rates.

Foyers, Corridors and Open Spaces

These spaces are unusual in that their excessive ventilation (i.e. open doors) often drives their heating and cooling load. Therefore, controlling air movement through doors can be a major management objective. They also link other controlled spaces, so
control of air flow across the boundaries is often important. For example, as we saw above, laboratory buildings need high corridor air pressures to contain odors.

SPACE DESIGN AND REFURBISHMENT

As shown above, the space use, mediated by standards, determines the standard of services that must be supplied. It is principally the design, or architecture, which translates that standard of service into a design load, or the energy used. The design also determines things like the ease of space control and management, ease of maintenance, the ease of retrofitting when energy technology changes, and flexibility of the space for future modification.

Architecture

The effect of architecture on energy consumption was shown graphically by a Department of Energy sponsored study where architects and engineers of 168 buildings were paid to attend a course in energy conservation and then to redesign their structures (Deringer and Misuello 1982). While artistically equivalent in the architects’ minds, the new buildings generally consumed significantly less energy. In all cases, first cost increased by less than five percent. (The rise is so low because the designs, while increasing the cost of some parts of the energy system, decreased the size of the prime moving equipment such as boilers and chillers, and often reduced the amount of duct
work.)\footnote{The economies are more ambiguous if the energy system is centralized. Savings depend on the relationship of the incremental load to the system capacity, rather than on the load itself. New buildings which precipitate major augmentations of the central plant or the distribution system carry a very high marginal capital cost. Conversely, if the system has vastly excessive capacity, then, in theory at least, the marginal capital cost is zero. In practice however, systems are generally replaced due to age rather than capacity problems. So the marginal cost is incurred in the future, not at the time of construction. Because central systems have scale economies, half a building load more or less makes much less difference to the cost of a central plant than to the cost of a building-size plant.} We can assume that care in architecture can affect things like ease of maintenance equally as dramatically.

Some energy efficiency measures are aligned with space management and maintenance. Others conflict. For example, a building with a limited need for heating, and therefore a very simple heating system, is likely to be easy to maintain. Conversely, a building with a complicated heat recovery system is likely to be very difficult. In much the same vein, an architect can design a building which derives its energy efficiency from its inherent simplicity or from a need for highly tuned operation of complex systems. Which measures predominate in a given building depends heavily on the nature and quality of its initial design.

A building's design can be thought of as having three (strongly interrelated) components. Different architects emphasize different of these and tend to specialize along these three lines. They are:

* The form, that is its external and internal appearance,
* The design of the usable space, and
* The design of the services.

These influence each other. For example, the basic design of the building envelope strongly affects the overall energy consumption, while the services design affects the energy consumption, ease of maintenance of the systems and ease of control of the internal environment.
Spanning these three is the building’s structural and mechanical flexibility. The more uncertain a structure’s final use, the more flexibility needs to be built into systems if they are to operate effectively. At one extreme would be a temporary warehouse. Contrast its short life and clearly defined services (lighting and fire protection) with a university laboratory. These are built for ascendant departments in rapidly changing fields (with changing needs). Yet they are expected to last 50 – 100 years or more, and well over 20 between refittings. Any refurbishment could accompany a change in tenants. However, flexible design costs more for a given amount of utility for the first user. So, the needs of the first user conflict with those of the university.

Space refurbishment presents essentially the same issues as new buildings, except the existing form and services limit future options. For example, the redesign of half a building may preclude modernization of the heating, ventilation, and air-conditioning system because the other half of the building needs to remain serviceable during construction (M.I.T. Student Center), or because the structural framing gets in the way (Harvard’s Bush-Reisinger Building). The magnitude of these later problems will be determined, to an extent, by the amount they were anticipated in the original architecture.

In summary, the important operational parameters for the both new buildings and refurbishments; energy efficiency, ease of operation and maintenance, and inherent flexibility, depend very heavily the design. This may depend on the university’s willingness to increase the capital cost slightly or to re-allocate resources to enhance energy efficiency. This, in turn, depends very heavily on who the architect and the services engineer are, and how they’re briefed and controlled.

While designing three things, the form of the structure, the internal space, and the services, the architect determines the technological components of the lighting, heating and cooling loads.
Lights

Virtually all tasks require space (described above) and light, in differing amounts, depending on the space use. A given amount of natural or artificial light can be provided to a space in many ways.

While, natural light, through windows or skylights, is free, it brings heat and glare and heat loss in Winter. The magnitude of this problem depends on the design. An architect who carefully chooses geometry and materials can virtually eliminate it. Poor architecture requires expensive cooling systems to remove the heat.

Artificial light comes from one of several sources, and the cost, relative amounts of light and heat generated depend, once again, on the design. More particularly, they depend on the light source, the fitting, the fitting's relationship to the rest of the room, and the shape and color of the room itself (See for example Dubin and Long, 1978). Most important for this study, however, is the historical development of some particular lighting technologies; the high efficiency electronic ballast, and the compact fluorescent light tube. This is discussed in Appendix A.I. These have efficacies of about 40–60 Lumens/Watt, compared to 11–18 Lumen/Watt for incandescent lights. In other words, an 18 Watt compact fluorescent bulb can replace a 75 Watt incandescent bulb. This results in a saving (including capital but excluding labor) of about $4.00/lamp/year. (Berman, 1985). We saw briefly in chapter one, and will see in detail later that the different universities have adopted these lighting technologies in different manners and at different speeds.

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14 For example Tungsten incandescent, fluorescent, compact fluorescent.

15 For example, a light will be brighter with a silver reflector than a white one.

16 For example, the lights at the Physical Plant Department at The University of Massachusetts at Amherst are mounted inside the ribbed ceiling. They lose light to the vertical sides of the ribs below.
So, we have a building. It has an envelope of walls, windows, roof, insulation, doors and cracks through which heat and cold pass; it has lights that generate heat; and it has lots of users breathing in and out, smoking or sweating or doing neither, and using equipment that generates heat and possibly exudes poisonous vapors (like formaldehydes in plywood) or involves poisonous chemicals (like a laboratory). Outside the envelope, there is weather; heat, cold and humidity. When all of these are combined with three standards, the standard for heating, the standard for cooling and the standard for ventilation, a heating, ventilation, humidification and cooling load can be determined.

Once we have a load, it is simple enough to design equipment to meet it. Depending on her care, the engineer can meet it closely, or over design the system. However, as well as choosing the size of the equipment, she also selects the type. Five of the most common types are dual duct, four pipe, two pipe, variable air volume, and unit heater. The technical details of the different technologies is unimportant except in two respects. First, different systems have inherently different energy efficiencies. For example, a dual duct system works by mixing hot and cold air together in the appropriate proportions to give the right temperature. This is very wasteful as air has to be both heated and cooled all year around. In contrast, a variable air volume system provides heat at a constant temperature and varies the volume to give the correct heat. Second, the different systems have different control implications. With a constant volume system, like a two pipe system, it is much harder to provide local temperature control than with say, dual duct. These differences are expanded upon in most HVAC texts, (e.g. Dubin and Long, 1978; ASHRAE, Annual).

17 The derivation of these standards is discussed below.
18 This is important because over-designed primary equipment (pumps and fans) use more energy (and generate more heat which must be dissipated) than their well designed counterparts.
Standards for Lighting, Heating, Cooling and Ventilation

Standards are values of parameters (levels of illumination, temperature, rate of change of air in a space) a system is capable of satisfying, or at which service is provided. Both design and service standards warrant consideration.

The design standard is important in both its value relative to that for service provision and in its absolute value. The closer the design standard, the actual design (which is often much more conservative than the standard) and the service standard, the more efficient the design, and the less flexible. Because of their performance characteristics, mechanical equipment (pumps, fans, and boilers) runs much more efficiently close to its rated capacity than well below.\(^{19}\) So, better suited mechanical equipment has lower capital and operating costs.\(^{20}\) For the distribution equipment, pipes and duct-work, there is an inverse relationship. That is, oversized equipment is more expensive, and, often more importantly, takes up more space. However, it is cheaper to run. Notwithstanding, theoretically at least, it is possible to optimize the design so the right sized distribution system is used.

A design standard that exceeds the service standard, and a design that exceeds the design standard, will result in excessive expense. So, we want the three to coincide as much as possible, with the design being to the design standard, which provides more capacity than the service standard. However, the closer these three become, the graver the consequences of an estimation error. For example, in one of the M.I.T. dormitories, the unanticipated introduction of personal computers led to insufficient electrical system capacity. Consequently, there are perpetual troubles with circuit breakers and fire

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\(^{19}\) Well sized boilers have the additional advantage that they cycle (go on and off) less. This reduces maintenance costs.

\(^{20}\) The differences are often dramatic. For example, it is common to retrofit 25 Horsepower fans for five Horsepower.
alarms tripping. One option being considered is a very expensive rewiring. This is an example of the cost-flexibility trade-off described above.

The service standard also determines energy consumption. If you heat to $75^\circ\text{F}$, you use more energy than if you heat to $68^\circ\text{F}$. In some cases, such as the decision whether or not to control humidity, this can be a major factor. In others it turns out to be minor. For instance, it is generally considered more important to keep the temperature consistently below $72^\circ$, so people don’t open windows in Winter, than to have it at $68^\circ$ rather than $72^\circ$.²¹

Notwithstanding, there are federal and state codes for temperature. Generally, buildings are designed to be heated to $68^\circ$ in Winter and cooled to $78^\circ$ in Summer, with exceptions for laboratories, libraries and museums. Similarly, there are ventilation standards. Some are extremely conservative, assuming the buildings are full of smoking unwashed students. It is often on the basis of these conservative standards that systems are designed. In addition there are safety standards for potentially noxious environments (like laboratories) or environments with toxic materials, (like formaldehydes in office furniture). Standards are promulgated by organizations like The American Society for Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) or by the universities themselves. Not all standards are legally binding.

*Distribution Systems and Local Control*

The service actually provided to a space depends not only on the nominal standard, but also on both the distribution and control systems. A distribution system is

²¹ This conventional wisdom has detractions. First, lower temperatures save energy. We will see later that Harvard’s Faculty of Arts and Sciences insists on setting temperatures back to $64^\circ$ at night. Second, a lower temperature reduces the cushion between what users will accept and what they are delivered. Therefore, system problems, leaks, etc are much more likely to be detected and resolved quickly. (Cf. the *Just in Time* manufacturing system. See, for example, Krafcik, 1989)
broken into zones, a room or a number of rooms with independent temperature control. A simple building with one zone generally has one air-handler blowing air through fixed ducts to individual rooms. In this building, the temperature can be controlled only by varying the temperature at the main air handler, either by varying the temperature of the incoming water or by changing the fan speed. Consequently, there is no possibility for variation of temperature between rooms or local control by occupants. Generally, buildings have at least two zones, one for each of the North and South faces. Often, however, that is all.

Different types of distribution systems offer different local control using devices such as terminal reheat, where air is heated by just the right amount before it enters the space, or using variable air volume boxes. These sorts of devices offer local control in large zones. The management decision is then whether or not to provide it, and if so, how much. The central plant can always bound users' decisions by limiting the temperature of water entering the building.

*The Building on a Campus*

All this heat, cooling, electricity, and gas has to come from somewhere. Unlike office buildings, the fact that the building is on a campus creates many more options. The designer can supply these locally; within the building or within a cluster of buildings, or supply them remotely; from a central plant elsewhere on the campus. Each has advantages. However, the combination of scale economies and concentration of equipment and fuel in one place generally favors a network of umbilical chords extending from central or regional heat and chilled water plants to the individual buildings.

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22 One seven-story dormitory at M.I.T. has only one zone. Consequently, there are large and unavoidable temperature differences between the top and bottom and the North and South faces.
MAINTENANCE

Having looked at the options for changes in technology, we now move on to the second of our three options, maintenance, or "making it run more smoothly".

PREVENTATIVE AND URGENT MINOR MAINTENANCE

All hardware must be maintained. Managers talk of preventative and urgent minor maintenance. Urgent minor maintenance is for equipment that isn't working, while preventative maintenance is carried out on equipment that is. One management task it to determine the total maintenance resources and allocate them between these two categories. Although we can predict an optimal investment in preventative maintenance, we will see later that three of the four case universities under invest. Another management task is to ensure the work is done.

The trade off between the two forms of maintenance is theoretically very simple. By increasing preventative maintenance, you increase:

* The reliability of the equipment,

* The efficiency of the equipment, and particularly the efficiency of the entire electrical/mechanical/control system. For example, a computer control system will only work with operating actuators;

* The life of the equipment

Simultaneously, you reduce:

* The cost of compound failures. Poor maintenance of one item reduces the efficiency of others or increases the risk of them failing. For example, in an induction air-conditioning system, clogging of the induction filters increases the load on the fan, which makes it run hotter. This reduces fan life.

* The number of complaints from users, and

* The cost to users of failures (e.g. data losses in power blackouts).^{23}

^{23} As people trust the system more, individual failures become more expensive. Users take inadequate precautions against breakdowns, (e.g. not backing up data regularly).
This decreases the need for urgent minor maintenance, and increases the quality of service provided.

However, increased preventative maintenance has two disadvantages. It costs money and it may increase the life of the equipment beyond its technological optimum. Consequently, capital renewal occurs later than it would otherwise. Resources that could go to capital renewal are being used for preventative maintenance, and technologically redundant equipment is still working well. The significance of this technological redundancy depends on the rate of change of 1) the technology in question and 2) the equipment a particular piece of plant is serving.

A self-interested physical plant department with optimal resources will tend to under-maintain its equipment and will maintain the wrong stuff. While it will consider its maintenance savings, and it may consider the effect on the number of complaints it receives, it will ignore the effect on users. From the user's perspective, maintenance will be misdirected. The physical plant will be interested in maintaining equipment which is expensive to operate, such as filters. The user wants it to maintain the equipment that has a high hazard from failure.

Both these problems, under-maintenance and maintenance of the wrong equipment, are often mitigated, as we'll see later, by the fact that the physical plant has a strong interest in maintaining cordial relations with users. Often, depending on the physical plant's place within the institution's structure and culture, user's concerns may override economic considerations. Bad sentiments often multiply. People affected by a problem tend to be geographically proximate and often converse. Equipment location also mitigates this effect. Key equipment, in mechanical rooms, is always visible to the mechanics and users don't need to be interrupted by preventative maintenance.

Conversely, people with very little faith in the system pay a very high price in time spent insuring themselves against failure.
Economically important but strategically unimportant equipment (such as induction filters and fume-hoods) tends to be in offices and laboratories.

This deviation from economic rationality may be minor, providing a slight excess emphasis on the maintenance of key plant, or it may be major, resulting in a complete flipping of priorities, so virtually all preventative maintenance effort is devoted to plant that will cause disruption if it fails.

**Envelope Maintenance**

It is important to note the relationship between envelope maintenance and energy usage. In theory it warrants no separate mention; the problems and trade-offs are exactly the same as for mechanical maintenance. In practice there is a need. We will see later that organizations generally define energy conservation as a mechanical problem. Therefore, it is rarely a concern of the people who maintain the buildings. They have much lower (or even negative) incentives for installation of insulation or filling of cracks than does the organization as a whole.\(^ {24} \) (See especially appendix B.)

**Control**

We now move to the third broad option, "using it less". When energy was cheap and control systems unsophisticated, the heat was turned on in October and off in May (as was done at The University of Massachusetts at Amherst until 1988). Temperatures were controlled (sort of) by altering the feed rate for the central boilers. With the energy crisis, people started turning the heat on and off daily. There are, however, better means for controlling the technology.

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\(^ {24} \) Cracking is particularly severe in the 1960's buildings which were often sealed with 'miracle' sealants. They are notorious for developing wide cracks where the sealant pulls away from the concrete or the window surrounds, letting lots of cold air into the building.
The most common, and most intelligent, controller is the user. He can turn lights on (and occasionally off) at will, adjust radiators to his exact comfort, and so forth. That is, the user is an excellent controller of the local environment, so long as it is in his interest. There are a suite of local technologies that can either serve to aid his task (task enhancing), or to substitute for his carelessness (skill replacing). The thermostat can be either. If it has user adjustment, it is an aid - the user isn't perpetually adjusting the equipment to remain comfortable; if the user cannot adjust it, it is a replacement - the energy manager decides when the user is comfortable. Other technologies include timers on local ventilation or lighting, photo-sensors which decide when it is dark enough to justify lighting a space, and motion sensors which turn off the light, heat and/or ventilation when the occupant leaves or falls asleep. In all situations, it is possible to devise a means to substitute someone else's decisions (manifested often through the set-point of a device) for the user's. In some, the user's task can be simplified instead.

These technologies all control the amount of service provided. More specifically, the thermostat turns equipment up and down to give the right amount of heat or cooling. The others turn the equipment off when the user leaves the room or doesn't need it (in its opinion). One management decision is when to give the user control over the local environment, and what sort of technological aids and substitutes to provide.

However, control does not stop at the motion sensor or the thermostat. These are the first in a long sequence of control devices available for system optimization. Some are highly localized, like feedback microprocessors that control the speed of a pump or fan so that it works at peak efficiency. Some are more global. For example, they may use information about the weather, the internal set-points (of both time and temperature), the requirements of all the other buildings and the engineering characteristics of the equipment to optimize both the hot water flow rate and
temperature into a building. Appendix A.II includes a detailed discussion of how these systems have evolved and what they do.

The reader should note some fundamental distinctions between the two main types, the original pneumatic systems and the newer, more popular, direct digital control (DDC) systems. Pneumatic controllers are significantly harder to maintain than direct digital controllers, and a lot less reliable. They are generally maintained by the heating, ventilation, and air-conditioning (HVAC) maintenance staff; that is the same people who maintain the equipment being controlled. Very significantly, they are set in the field (that is, the thermostats etc. are in the buildings themselves), and even if connected to a central computer, it is often hard to determine the set-point centrally. Furthermore, the system requires a series of pressurized control lines. These were often rubber and hence susceptible to slashing. We will see later that these characteristics lead to the failure of virtually all pneumatic systems. They were very threatening to the mechanics, who could easily subvert them. Direct digital controllers on the other hand are much more reliable. If they fail they tend to go into gross error, not to slip gradually out of adjustment, so failures are obvious. Since they require very different maintenance skills to pneumatic systems, they are often maintained by a specialist group rather than HVAC mechanics. Set points and actual performance can be read from a central computer.

CONCLUSION - MANAGEMENT QUESTIONS

This concludes our technological tour of energy management. The factors that contribute to the task vary from large, like the nature of the building’s design or the choice of fuel source, to small, such as a decision to install movement sensors in a particular space. All of these involve a complex interaction of technology - buildings, control equipment, pumps and fans - and people - architects, senior administrators, senior academics, users, the physical plant, and the energy manager.
As we look at the technological problem described above, we see a web of decisions made as these people interact. It is these decisions which differentiate universities' energy management behavior. In my field work I attempted to determine how the individual campuses resolved these questions over time, that is what decisions they made. This thesis attempts to explain why they made those decisions. The questions which guided the field-work are set out below.

**Architecture**

* Who selects the architect, using what criteria?\(^{25}\)

* Who briefs and controls the architect? What is the relationship between that person, the architect, and the architect's engineer?

* What absolute standards does the university impose on the architect?

* Who gets input into the design process and construction decisions?

* When during design are factors like services design, ease of operation and maintenance, and energy conservation incorporated? Are they integral to the conception or must they wait until the first design is produced?

**Lights**

* What lighting technology is used? When was it installed?

* What lighting control technology is used?

* How often are the lights cleaned and maintained?

* How often is the appropriateness of the lighting design (both fitting design and illumination levels) checked?

* When are lighting services provided?

**Heating, Ventilation, and Air-conditioning**

* Where and when is humidity control supplied?

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\(^{25}\) Note that functionality is rarely considered the most important aspect of 'Modern' architecture. (See Blake (1974)). It follows from his argument that architects who subscribe strongly to this style are likely to produce buildings that are difficult to operate. Certainly, both M.I.T. and Harvard interviewees talked of problems with systems in buildings designed by internationally famous architects.
Peter Cebon (1990)

* What heating, ventilation and cooling standards are used?
* When is equipment maintained?, replaced?
* What HVAC systems are used?
* How are the systems controlled?
* When are services provided?

ENVELOPE MAINTENANCE

* When were ceilings insulated?
* When were windows replaced or double glazed?
* When were cracks caulked?
* When were swinging doors replaced with revolving ones?

CUSTODIAL

* When are swinging doors locked and revolving ones left open?
* What information of interest to energy conservation (rooms that are always hot, windows that are constantly open) do the cleaning staff gather?

CONTROL

* Which users are given control over which parameters, When?
* What local control technologies are used?
* What large scale control systems are used?
* When are they purchased/upgraded?
* Who operates them?

CENTRAL PLANT AND UTILITY DISTRIBUTION

* How is the central plant configured? - are there a few large systems or is it designed for incremental expansion?
* When is central equipment maintained?
* How is it controlled?
* How is the distribution system be sized and maintained?
CHAPTER 3. SECONDARY OBJECTIVES AND ORGANIZATIONAL STRUCTURE

INTRODUCTION

The punch line of this thesis is that organizations' structures are a major determinant of the solutions they select from the smorgasbord presented in chapter two. We have to wait until chapter four to see that. However, that is virtually useless unless we establish two things. First, we have to decide that there is some logic to the way organizations structure themselves. Then we need to show that within that logic we can say something about the way secondary objectives get managed. Those are the aims of this chapter. We will consider the general theoretical problem and then contemplate the particularities of universities. This will give us an opportunity to exemplify the model for the case study universities. The multiplicity of energy conservation options, and the fact that the energy system cuts across any formal organization we can construct will create the need to define the energy management organization which will span across the formal structure. We will round out the chapter by looking at the energy management organizations in the case study universities.

As I said in Chapter 1, secondary objectives correspond to input/output functions to which organizations attribute secondary importance. While there has been extensive writing on organization on the management of input/output functions, it has tended to concentrate on those functions which organizations see as central to their mission; marketing, engineering, sales, etc. Conversely, there has been virtually nothing written on these lesser input/output functions. Consequently, we need to build a model.
Theorists treat input/output functions in one of two ways. Some, of which Thompson (1967) is the prototype, see these activities as being used by the organization to protect its central core from uncertainty in the environment. The better the buffer, the more efficiently the technical core of the organization can operate. The strategy literature (e.g. Lawrence and Lorsch 1967) describes them as matching the core of the organization to the environment. The better the match, then presumably the greater the organization’s ability to exploit opportunities that present themselves.

These two prescriptions for organization/environment interaction appear to be in conflict. An input/output function which aims to force an organization to adjust is not buffering the technical core. An input/output function which buffers the core, by definition, prevents the core from seeing environmental perturbations.

An effective model must reconcile these differences. But to do this, we must start from one or the other. A buffering model makes much more sense as a starting point, since this is the way these functions are generally managed. Orthogonal solutions act as buffers to the environment.Aligned solutions expose the core to the environment in as far as they are incomplete solutions to the problem. However, rather than treating these functions simply as walls between the organization and the environment, we will treat them as mediators of the relationship.

Thompson’s (1967) process model has two advantages over others from which we could build. First, while it is clear and relatively simple, it echoes the distinction between primary and secondary objectives presented in chapter one. This will enable us to spring from objectives to activities to structure. Second, the model sees organizations as transformers of inputs to outputs. This will prove invaluable since this thesis is concerned with the wastage (as energy, pollution, or increased risk to workers) through selection of inefficient transformation processes. We will, however make two deviations. First, we need to reconsider Thompson’s definition of core technology to incorporate
what I described in chapter two as infrastructural technology and in a footnote in chapter one as peripheral and support activities. Second, his model does not convincingly explain the irrational impact of compartmentalizing a function like energy management in a seemingly rational manner. To do so, we will need to consider the possibility of multiple solutions to a given organizational problem.

STRUCTURE AND SECONDARY OBJECTIVES

Thompson's model has two parts. The first considers the individual offices an organization is likely to create. The second considers the way it will join them together.

In the first half of the model, Thompson argues that a rational organization will create a core of offices to manage its technology (the process it uses to convert inputs to outputs) and its task environment (the suppliers, customers, regulators, and competitors with which it deals). The core's structure will be determined by the production technology. The organization will surround that core with input and output activities essential to the its functioning, but decidedly secondary in importance. The organization carries out these input and output activities, rather than purchasing services and materials on the market, (e.g. raw materials via backward integration, waste disposal through construction of an incinerator) to buffer the core from fluctuations in the environment which would otherwise interrupt core production (cf Williamson 1975). The construction of the input and output activities will be influenced by both the structure of the core and the structure of the elements of the environment with which they must interact. His model is summarized in figure 3.1:

![Diagram](image)

**FIGURE 3.1 THOMPSON'S INPUT, CORE, AND OUTPUT MODEL**
A CLOSER LOOK AT THE INPUT-OUTPUT FUNCTIONS

It is useful to divide these input/output activities into three classes. The first, the transformative input-output activities (Mintzberg 1983:12), are associated with core production and embody the organization's primary objectives. That is, they are seen as integral parts of the production process. They provide inputs for transformation and remove the transformed product. An example of a transformative input function would be the sales department in an organization which produces in response to sales orders. Sales are integral to, though not part of, the core production process.

The second class, the peripheral activities, are associated with the secondary objectives. Often, though not always, they provide inputs and outputs to other inputs and outputs as well as to the core. Often they are more important there (e.g. telephone). They have (task enabling) infrastructural technologies associated with them. We differentiated this, in chapter two, from the task enhancing equipment.

Another example of the difference between transformative and peripheral activities is the difference between a manufacturing system which buffers the core from the environment (conventional manufacturing) and one which exposes it to the environment by reducing inventory buffers, but in so doing makes quality integral to production (just in time manufacturing) (Shimada and MacDuffie 1986). In both cases, the organization has to contend with an element of its task environment, the need for quality. In one case it does so by buffering the core (peripheral activity). In the other, it defines it as part of the core production. The former is an orthogonal solution while the latter is aligned.

Finally, there are a series of services which have virtually no impact on core production. Mintzberg (1983:12) calls them support activities. Cafeterias provide a good example of these. The difference between support and peripheral activities is ill-
defined because all support activities are, to some extent, peripheral. To avoid confusion, we will tie the definition of a peripheral activity back to that for a secondary objective. That is, an activity is peripheral, rather than support, if failure to provide it can jeopardize the organization as a whole.

A modified version of Thompson's model is illustrated in figure 3.2

![Diagram](image)

**FIGURE 3.2 THOMPSON'S MODEL (MODIFIED): INPUT, CORE, OUTPUT, PERIPHERAL AND SUPPORT ACTIVITIES.**

It is important to note that the distinction between transformative and peripheral inputs and outputs is as much technological as managerial. Particularly, which input and output activities are considered transformative comes from the primary objectives. However, the extent to which those activities can satisfy the objectives, given effective management, depends on the technology actually employed, or more importantly the technological possibilities. If the technology doesn't exist, the organization can't use it. If it does exist, it still has to choose to use it.

BUILDING AN ORGANIZATION

Thompson argues that a rational organization will use two rules to guide the aggregation of people into offices, and offices into an organization. First, it will attempt, as much as possible, to buffer the organizational core from the environment. Second, it will attempt to minimize coordination costs between individuals and offices. Communication costs are minimized by letting people who must interact extensively do
so by mutual adjustment. That is, the organization will assemble them into offices. This facilitates reciprocal transmission of information. It will link offices to minimize other communication difficulties. So, for example, there is one campus police, not several in the different schools. The police have to communicate extensively with each other while the schools' needs are not highly differentiated.

So, we would see organization built up as a series of units connected either laterally or hierarchically to minimize communication costs per unit of output. At the center would be the core function. Closely attached to them would be the transformative input and output functions. Further afield would be the peripheral, and then finally the support activities. We would expect a secondary function like energy management or pollution control to be managed by creation of an office somewhere in the organization, or allocation of responsibility to one peripheral group. If we depicted this graphically, we would get a map of the formal organization. It would show the reporting arrangements and the formal communications pathways. Of course, it is not a map of all communications in the organization (Mintzberg 1983), but it does show the strongest links.

This aggregation principal and global rationality can conflict. We must consider this. Under the model, an organization will try, as much as possible, to decouple peripheral and core activities. If these peripheral activities are meant to buffer the core activities from the environment, the organization will try to keep them as separate as possible. Therefore the organization’s response to a new environmental problem, such as the oil crisis or massive increases in the price of waste disposal, will be to create a specialist office to deal with it. That office will manage the problem by maintaining a healthy separation from core activities. (e.g. buildings are cleaned at night teaching is not interrupted.) Since aligned solutions are (by definition) felt throughout the core, this always means the selection of orthogonal solutions. We would expect this effect to be
particularly strong with infrastructure management. Because it is task enabling, productivity does not vary with its efficacy, that is, it is a buffer by definition. Because it is invisible, members of the core are likely to treat it as separate.

However, there two times when a rational organization should always select aligned solutions. The first is when the solution simplifies the overall management task (facilitates all primary objectives) and removes the environmental contingency. An example would be the installation of photo-sensors on outside lights. This would reduce energy consumption and eliminate the need for people to turn on and off lights. The second is when the aligned solution reduces environmental contingencies for only a modest increase in managerial complexity. (The optimal trade-off between global efficiency and managerial complexity will depend on the organization.) For example, an electroplater who eliminates wash water and waste by recycling must manage a system with a loop in the production process rather than a once-through system. This is only a minor increase in complexity. On both occasions, to manage the aligned solution, the organization has to make the task a responsibility of people working in the organization's core or creation of a specialist office in close communication with the core production offices. That, however, contravenes the premises of the model. We have a paradox.

The paradox is that offices asked to manage contingencies have a confused mandate. On one hand their task is to buffer the organization's core. On the other, they can often produce much better solutions by pursuing options which appear to expose the core to the environment rather than buffer it. If organizations were wholly rational, this would not be a problem. The specialist office would develop aligned solutions when they were superior, and the whole organization would implement them. However, we will see in chapter four that the creation of specialist peripheral offices tends to create very large barriers to discovering and implementing aligned solutions.
However, before we look at that, we will discuss the way universities are structured and see that they follow Thompson's model fairly closely.

STRUCTURES OF UNIVERSITIES

Because universities' primary objectives tend to be highly conflictual, their structures are not quite as simple as Thompson's model would suggest. However, they don't contradict it. The model will be too limited, however, to explain managerial units which span the organization in order to bring about aligned solutions. To account for this, we will introduce the notion of the energy management organization.

UNIVERSITIES AS PROCESS ORGANIZATIONS

If we believe the Shorter Oxford Dictionary, a university is a place where degrees and other privileges are conferred and teachers and students pursue, in the same place, the higher branches of learning. So, to survive, a university would need to be little more than a place that can efficiently produce lectures, examinations, research products and literature for academic consumption. However, it must be much more.

To produce these four simple products, a university must consistently and reliably provide a vast array of inputs. To disseminate these and efficiently dispose of other unwanted residues, it must provide a string of output services. In addition, it must provide (infrastructure) services to enable inputs, outputs and the core. For inputs it must provide students, faculty, raw materials (including money) for research and teaching, a space for these to be carried out in, and facilities such as light and heat to facilitate these practices. So, there are offices variously responsible for recruiting staff and students; fund-raising; providing buildings; housing; safety; maintenance; printing; energy; food, telephone, library and medical services; and office and laboratory supplies.
At the heart of the university its core products, research, lectures, papers and examinations, are produced. To facilitate output, we find cleaning, waste disposal, career placement, commencement ceremonies, and publishing houses. Athletic facilities and counselling services vent unwanted side effects. Parallel with the first half of the chapter, we will consider the offices a university creates before considering the way it arranges them.

Which services the university provides is determined to a large part by its strategic mission (Chandler 1962), and its core technology (Thompson 1967) (the needs of the students, faculty, and staff), mediated by the demands placed on it by its external environment (Thompson 1967, Pfeffer and Salancik 1978, Tolbert 1985). Therefore, to see how different variables affect the offices provided by the case study universities we need to look at differences in their missions, their core technology, and their external environments.

If we see a university as producing four core products, lectures, examinations, research products and papers, then the things that are going to differentiate universities, in terms of their overall missions, are the relative emphasis on research versus teaching and the nature of the research. Presumably, the institutional requirements for teaching vary little between disciplines. As the emphasis on research increases, we expect the university to develop a much more sophisticated laboratory supply system. We expect this to be accentuated as the research becomes more capital intensive or potentially dangerous. We will summarize this as a single variable; research emphasis.

- **Research Emphasis.** A university which emphasizes research will have proportionately more graduate students and (if it is strong in the sciences) be much more energy and facilities intensive than one with a high emphasis on undergraduate teaching. Consequently, we would expect to see patent offices, industrial liaison offices, publications editors, and so forth. All the case study universities are reasonably research intensive, though Tufts was not in the past. Consequently, it is difficult to differentiate them.
If we consider technology, two things are important. First, how does the nature of the technology affect the way in which the university structures its core activities? With the exception of some of the natural sciences (e.g. high energy physics, nuclear engineering, astronomy, and some chemistry), the equipment used in academic research is not so large as to be beyond the bounds of one researcher (and her or his team). Consequently, we rarely expect the core technology to affect the core's structure. Second, we need to consider the way in which the core technology affects the creation of input/output offices. We expect a research university to have much more complicated input/output needs as it has to provide much more diverse materials much more reliably and must be more concerned with issues like safety. However, since research emphasis has already been identified as a variable, we don’t need to create another.

Pfeffer and Salancik (1978) suggest we should look to offices set up by the organization to meet the demands made by the interest groups which provide the resources critical to the organization's functioning. The university has the choice of either providing these services internally or purchasing them (Perrow 1981; Williamson 1975). Tolbert (1985) looked at the problem of external environment management in universities as one of resource dependency. She found that private universities have more sophisticated means for garnering private funds than public ones, and that public universities will devote more resources to securing public funds than private ones, as reflected in the number of offices devoted to the task. If it purchases them, the relevant service becomes contract administration.

Countering the resource dependence approach is the institutional isomorphism argument of DiMaggio and Powell (1983). They argue that the offices created by an organization will be determined by the expectations of the institutions with which the university must interact. Therefore, there will be structural conformity among similar institutions in a given sector. Tolbert (1985), testing this proposition for universities,
found that the resource dependency argument held only where this was the case. That is, resource dependence could not explain public universities' dependence on private funds. We will see later that one of the reasons for Harvard's trouble with energy conservation is that energy conservation suppliers expect the organization to have a different structure to that which it does. Therefore, the university has trouble obtaining and disseminating information.

* Public/Private. We expect a public university to be oriented towards a stable funding environment with the majority of funds coming from the government. A private university will have to contend with a much more diverse environment. The University of Massachusetts at Amherst, a state university which derives its revenues principally from the legislature, has a central office at Amherst which deals with the Regents in Boston who, in turn, negotiate with the state legislature. This is reasonably bureaucratic since the mechanisms for obtaining funds are fairly predictable. In contrast, the three private universities must deal with multiple sources of funding, they have a large number of less integrated offices; development offices, sponsored projects offices, and so forth. As a result of its internal differentiation (next section), Harvard, with its financially independent schools, replicates many of these functions in each school.

Finally we will need to control for size and geography. As an organization gets larger, we expect activities to be more differentiated (Weber 1947). Resources can become more specialized in their use. As an organization becomes more spread out, it becomes cheaper to replicate services locally than to provide them centrally. Since physical plant services tend to be easy to replicate, size of an individual campus is probably a better measure of size than that of the whole university.

* Size. We would expect a larger university to have more and larger offices. The University of Massachusetts at Amherst has departments for many of the life sciences, Harvard has departments for some, and MIT has only Biology.

We can categorize the case study universities according to these variables.
FORMAL (ADMINISTRATIVE) STRUCTURE

We now consider the way in which the offices are arranged. A university that was just a massive accumulation of offices would be uncontrollable. Therefore, the organizations add offices to coordinate and control the service offices and assemble them all into a structure. We would expect this structure to be reasonably functionally determined as we expect communication to be maximal along functional lines. That is, allowing for weak factors such as the expectations of the external environment, historical precedent, institutional ideology, and senior administrators wishes and ambitions for themselves and the university, we expect form to follow function. For example, the university chooses which departments it creates. We saw this with the life-science departments at three of the case study universities. Similarly, when aggregating departments, a large university may have a faculties of arts and science; a smaller one may have one faculty of arts and sciences.

So, we see a large number of offices, of various sizes, aggregated by predominantly functional reporting arrangements. The core functions are in academic departments, the input and output functions in the administration, and broadly speaking, the infrastructure functions in operations departments. Consequently, the structure of the university can be seen as the superposition in time and space of three quite different organizations. There are loosely coupled and relatively autonomous production units producing core products of the university - lectures, research, examinations, and papers - in the departments. There is a tightly coordinated and controlled series of
administrative services supporting, but virtually independent of, this activity.

Underlying this are the infrastructural departments providing operational services. Because most of the hardware is infrastructural, it has minimal bearing on organization in the academic and administrative departments. Rather, the offices are organized on the basis of the linkages between them and the expectations of the external environment.

Perrow (1984) suggests that the looser coupling we see in the academic sphere of the university derives from the highly unpredictable nature of the interactions that occur in it. Since most production occurs within a given unit, an academic at a desk, rather than at its boundaries, slack can be supplied without foregoing much output. Therefore, a need for it can be satisfied at low cost. On the other hand, the administrative functions are much more predictable, and generally involve a lot of communication with either academic offices, other administrative offices, or external organizations. Here, the university is much more interested in efficiency than allowing for perturbations. Consequently, it provides less slack for the administrative offices and their linkages. Depending on the way their tasks are defined, the operations departments generally have either very clearly defined tasks requiring limited communications through easily defined channels (e.g. routine maintenance), or they need to be very responsive to other parts of the university (e.g. repairing failed systems).\(^1\)

We can safely assume that the relationships between the academic departments is the major determinant of a university's academic structure. However, the loose coupling of academic activities makes many configurations possible, from the way people are organized into departments (Are all economists in the economics department?), departments into schools (Is economics in Management or Social Science? Does each school have its own development office?), or schools into a university (Are the schools financially autonomous?). While we could explore all the possible permutations, for our

\(^1\) They also need an emergency response function which is not addressed here.
purposes, it is important only to differentiate the case universities. Therefore, only two variables are needed to differentiate the universities: intellectual diversity and closeness of coupling of activities.

* Intellectual Diversity. Harvard, with its different schools and their different reputations and emphases pursues a highly decentralized structure with financially independent faculties. This forces it to replicate many administrative functions across schools and create a separate Facilities Maintenance Department as part of the central administration. This Facilities Maintenance Department sells physical plant services to the individual faculties. In contrast, MIT, with its strong reputation for interdisciplinary research, has a small number of relatively closely linked schools and a physical plant department which can operate without complicated internal purchasing.

* Closeness of Coupling. All the universities except Harvard have major cleavages between administration, faculty and operations. As we will see in the next section, these can be carried out virtually independently. At Harvard the primary cleavages are between the individual schools. Within these domains we see similar distinctions. For example, all of the universities studied except Harvard have financially and organizationally separate on-campus housing offices. The provision of housing services is unrelated to virtually everything else on campus. It shares only a few services, namely student support and counselling, food services, and facilities. At The University of Massachusetts at Amherst, the distinction is greater because housing is financially independent from the rest of the university.\(^2\) At Harvard, the schools provide housing.

This is summarized in Figure 3.4

<table>
<thead>
<tr>
<th></th>
<th>MIT</th>
<th>Harvard</th>
<th>U.M. Amherst</th>
<th>Tufts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intellectual Diversity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Closeness of Coupling</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>

FIGURE 3.4 SOME CONTRIBUTORS TO STRUCTURE IN CASE STUDY UNIVERSITIES

As depicted, the university would appear to consist of three independent organizations; a faculty, an administration, and operations. However, their effectiveness depends to an extent on their inter-dependence. While much of the administrative work is independent of the faculty, and much of the academic work is independent of the administration, at the edges, these groups must interact virtually continuously. Similarly,

\(^2\) While the rest of the university if funded by the legislature it raises money from service charges.
an infrastructure manager who does not interact with the users of services cannot control the environment. An energy manager who does not interact with users can do nothing other than manage the infrastructural aspects of the energy system in such a way as it remains invisible. This denies the ubiquitousness of energy. So, we round out the chapter by considering first the interaction between the faculty and the administration and then the relationship between those charged with energy management and the rest of the university. The reason for exploring the latter is obvious. The former is important because the energy manager becomes part of the administration as soon as she crawls up from the infrastructure to the structure.

ACADEMICS AND ADMINISTRATORS

The faculty is a distinct and powerful group on the campus. While formal power runs through a bureaucratic structure which rises through the administration to the corporation or the regents, the faculty has an enormous amount of informal power. This comes from three sources. First, they control production. They control the operating core. That is, lectures, examinations, research products and publications are written either by them or under their supervision. Second, while staff report formally up an administrative chain, functionally they often report to the faculty. Third, their work is premised on notions of freedom of thought and uninhibited intellectual independence which contradict fundamentally those of an administrative hierarchy (Weber 1947).

Also, the faculty and the administration have conflicting interests. While the administration is concerned with the efficient and strategic operation of the university as a whole, while not inhibiting the faculty too much, the individual faculty are interested in maximizing academic output. It is not that both parties do not want the very best for the university, it is that they have different perceptions of what is important. In a parallel case, Smith (1955) described a hospital:
"These many 'purposes' of a hospital are rarely subsumed under any single 'master symbol'; rather these many activities tend to be justified, by persons working within hospitals, in terms of two dominant values or symbols: 'money' and 'service.' And frequently these are expressed as considerations of money versus service." (emphasis in original)

Similarly, in universities, the faculty would like to maximize their intellectual productivity by minimizing the number of non-intellectual activities they have to perform, such as cleaning or procuring supplies, and minimize administrative responsibilities that are not in their interest. This may or may not include teaching. Simultaneously, they would like to maximize their personal resources, such as time, offices, computers, research students, and laboratories. Of course, they would like to pay the minimum possible for these.

To understand this dichotomy, let us consider the provision of pencils. In the manner of Perrow (1968), the central administration is charged with the responsibility of minimizing cost and maximizing efficiency on campus. By buying pencils in bulk, they can achieve significant cost savings, and they can simplify the purchasing process for the faculty. Instead of going to outside vendors for their multitudinous needs, faculty only need consult a central store. For the administration to do their job properly, they have to achieve economies of scale in both purchasing and distribution. Therefore, they would prefer to stock only a minimal number of varieties, and to dispense them at certain times, after the faculty have submitted the correct form, and not before. Without this standardization and these routines, economies are diminished. For the faculty however, it is a different story. Because of the extreme effect of pencil hardness, color and shape on intellectual creativity, they want an infinite variety. In addition, because they don't want to have to worry about keeping inventories, they need to have the supply shop open 24 hours daily. Finally, they are much too important to walk across the campus; the administration should deliver.
While this example is trivial, we can see that without an incentive structure (like a price mechanism) to regulate the faculty, the administration's task is often one of limiting the faculty's voracious appetites for anything that will marginally improve either productivity or status. However, in many instances it is unusual to use incentive structures, and in many others it is impossible to either devise them. If you can devise them, they are often expensive to administer. Consequently, the history of universities can be characterized as a conflict between the interests of the administration and those of the faculty. This conflict occurs wherever the two intersect. They intersect on big issues, such as which departments and programs should be pursued, or who gets tenure, (faculty who will advance knowledge or faculty who will bring in large research contracts?), and they intersect on smaller ones such as teaching loads and administrative responsibilities.

THE ENERGY MANAGEMENT ORGANIZATION WITHIN THE UNIVERSITY

Given the model as set out above, we have a problem. Energy is ubiquitous. It's management reaches, potentially, to every corner of the organization. However, the model suggests that the rational organization will compartmentalize energy management into a small office somewhere in the infrastructure. As we look at the case study universities, we will see that the universities realize that this is potentially very limiting. Therefore, they broaden the responsibility for the function. We will call this map of responsibility the energy management organization.

The energy management organization consists of everyone responsible for energy management. Responsibility comes in various degrees and various forms. Members include those with:

* A formal employment requirement
* A financial incentive
A moral obligation.

At many universities, including some state universities (The University of California for example) everyone has a financial incentive, though it varies in strength. At The University of Massachusetts it is extremely weak (because the university cannot retain savings from energy conservation but it can use it to improve the reliability of systems).

So, because of energy's ubiquitousness, the energy management organization theoretically includes everyone. The issue is the extent to which they are included in practice. The structure (distribution of responsibility) of this energy management organization is a function of the formal structure of the university (including things like size), the internal structure of the groups responsible for energy-using facilities, and the incentive structures the university creates for energy conservation.

It is easiest to think of the energy management organization as three concentric rings. The core comprises people with an explicit professional responsibility for energy management or responsibility for the total cost of the energy they use. This may transcend administrative boundaries. For example, at Harvard, the core comprises people from the schools, the central administration, and the Facilities Maintenance Department. In the middle ring are the people who have a reasonably strong incentive (statutory, financial, or moral) to conserve energy or responsibility for the energy consumption behavior of significant energy consuming equipment. Similarly, administrative boundaries may dissect that ring. The vast majority of people in these inner two rings are in the university's physical plant department. It is within these two rings that conservation of infrastructural energy takes place. Similarly, initiatives to spend money and changes in new building design for energy conservation generally come from within these two groups. In the outer ring are the people with a weak incentive or
whose behavior is a determinant of energy consumption. This is summarized in the figure:

Middle ring: People who have a reasonably strong incentive to conserve energy or responsible for the energy consumption behavior of significant energy consuming equipment

Core: People with explicit professional responsibility for energy management

Outer ring: People with a weak incentive or whose behavior determines energy consumption.

FIGURE 3.5 THE STRUCTURE OF THE ENERGY MANAGEMENT ORGANIZATION
Peter Cebon (1990)

THE ENERGY MANAGEMENT ORGANIZATIONS IN THE CASE STUDY UNIVERSITIES

MIT concentrates energy management in the Operations division. There is no formal energy manager position, though one engineer works in the operations center to optimize the facilities control system. Intermediate responsibility for operational energy conservation is kept virtually exclusively within that division. Energy performance of new buildings is the responsibility of the project manager, generally a senior staff member with experience in energy management. Energy conservation in building envelopes and incorporation of custodial services into data acquisition is achieved, as needed, by direct communication between the associate director and the superintendent of Support Services and Building Maintenance. Similarly for Utilities and Engineering. However, there is conflict between the imperatives to give the divisions autonomy and top down direction over energy management. Except during the ENCON program (1973–77), active participation of users has been avoided. Users were consulted during the BEAM (1976–81) and Cambridge–Electric programs (1987–89), but their input in decision making was not sought.

FIGURE 3.6 THE ENERGY MANAGEMENT ORGANIZATION AT MIT; BEFORE AND AFTER 1976
Harvard’s decentralized structure requires that energy management responsibilities be divided. The Facilities Maintenance Department is responsible for supply and conservation of bulk energy, it carries out other functions, including system control, as requested by the schools and offers solicited and unsolicited advice on energy conservation strategies. It has no formal incentive to minimize costs, though it sees this as part of its responsibilities. The individual schools have full responsibility for their energy use. They operationalize this through a facilities office which may be as small as a part of a few people’s time or in the larger schools, quite large and sophisticated. These facilities offices deal with the users as they wish. In the small professional school studied there were occasional pleas to users and organized management of scheduling. In the Faculty of Arts and Sciences, an extensive network of superintendents and energy monitors manages relations with the Facilities Maintenance Department and the users. The superintendents buy and supervise Facilities Maintenance Department services. The energy monitors use a system of pleas and incentives to elicit user cooperation. During the energy conservation initiative of the early 1980’s, much more coercive techniques were used by the dean to engender faculty support. Similarly, competitions were used to create real and symbolic incentives.

FIGURE 3.7 THE ENERGY MANAGEMENT ORGANIZATION AT HARVARD; 1978, 1983, 1988
At the University of Massachusetts at Amherst energy conservation is managed by the Operations Division of the Physical Plant Department. Prior to 1984 it was managed by the central administration. Since then it has become central to progressively larger portions of the operations division. By 1988 all mechanical services (utilities, operations, maintenance, control) saw energy management as one of their principal responsibilities. There is very limited communication of energy management imperatives to other parts of the Physical Plant Department (particularly engineering) or to the users. The very high deferred maintenance requirement ($500,000,000, 1987 dollars in 1987), principally in structures, means that energy conservation is a low priority for structural works. The housing department pays a fixed percentage of the university's energy bill (17.9%) and carries out all its own operations and maintenance. The fact that this percentage is fixed reduces considerably its incentive to conserve energy.

**FIGURE 3.8** THE ENERGY MANAGEMENT ORGANIZATION AT THE UNIVERSITY OF MASSACHUSETTS AT AMHERST; 1983, 1988
Tufts' Physical Plant Department, like the Facilities Maintenance Department at Harvard, sells the schools services. However, since the schools must purchase all services, the Department does not feel the same competitive pressures. The Department has a Director of Energy Management who has neither staff, nor budget, nor operational responsibilities. Therefore, he must raise funds externally (principally through DOE grants), compete with other parts of the Physical Plant Department for resources, or persuade members of the Department staff or people carrying out capital works (principally researchers) to pursue his ideas in Tufts' best interest, generally over their own. There is little outreach to users. Operations and maintenance are carried out as a combination of in-house work and maintenance contracts. While the energy manager has some sway over the internal workers, he cannot influence contractors. Being one of the few professional engineers on the Physical Plant Department staff, the energy manager often gives opinions on design reviews of major capital works.

![Diagram of Energy Management Organization at Tufts, 1988](image)

**FIGURE 3.9 THE ENERGY MANAGEMENT ORGANIZATION AT TUFTS; 1988**

In chapter four we will see how the energy management organization's structure mediates its desire and ability to gather, process and use information to make and implement simple and complex decisions. We will be interested in the relationship of the three rings to the university's formal structure. We will consider their form (i.e. the location of the boundaries relative to administrative cleavages) and their content (i.e. methods, and strength of methods, used to incorporate people into the energy management task).
CHAPTER 4. STRUCTURE AND DECISION MAKING

INTRODUCTION

In this chapter I present the bulk of the data. We have seen already that the organizations are very different in both the decisions they consider and implement. The appendices (Appendix B through Appendix E) suggest that the universities are selecting from fundamentally different menus of energy conservation options. For example, compact fluorescent lights were not really considered at MIT until the major retrofit of 1987-88; however, they penetrated the Faculty of Arts and Sciences at Harvard soon after being introduced to the market. In contrast, neither Harvard nor Tufts actively considered direct digital control when they purchased new systems in 1979. MIT, however, actively considered this option (and actually bought a system) in 1976.

Not surprisingly, this difference in menus of choices is reflected in fundamentally different decisions being made. We saw this in figures 1.2 through 1.7. For example, not only did MIT buy direct digital control ten years before Harvard or Tufts, but the systems the latter schools purchased were quite different in that they were much more decentralized. While Harvard will put systems in older buildings, Tufts only installs them in new ones. Furthermore, Harvard, and especially Tufts, are much less sophisticated in the way they use their systems. In contrast to the other cases, The University of Massachusetts at Amherst, in 1987, started to install a large system which was neither centralized nor decentralized in the manner of the other cases. This was fifteen years after a disastrous first attempt at computerized control.
In this chapter, we will attempt to explain the differences, particularly the differences in menus of choices from which the organizations select in the definition and solution of problems. I am suggesting a two-stage model of decision making. The first stage involves a narrowing of options to a sub-set. We would need a much more complex model (if one could be developed) and much better data to explain the differences in final choices. I will argue (as did March and Simon (1958)) that the organization acts as a set of filters which sieves the set of feasible (in an engineering and economic sense) options (and problem definitions which will lead to feasible options) to a much smaller sub-set from which it selects. We will see that in the case of secondary objectives, the filter is very systematic and has a very fine mesh, so fine that sometimes all feasible options are excluded. Other bounded rationality models (e.g. Cohen, March, and Olson 1972) also note the highly constrained nature of the decision making. However, they do not recognized its systematic nature.\footnote{The two models are not contradictory, however. In their paper, Cohen, March, and Olson are looking at decision making in a university as an organized anarchy. One of the characteristics of that anarchy is that its goals are not clear. We are looking at the way a sub-part of the organization, with fairly clear goals, tries to get its job done in the face of the rest of the organization, which is more powerful and may well not know what it wants.} The second stage involves selection from the subset. Models of this span from optimization in terms of local or global criteria to satisficing, where people select the first acceptable option which comes along (March and Simon 1958).\footnote{See March (1981) for a good review of the decision-making literature.}

UNIT OF ANALYSIS

Following arguments presented in chapter three, the unit of analysis we are going to employ is the specialist sub-unit, (the core and middle ring of the energy management organization in the energy case). Since this unit is not one conventionally used, we should consider its relationship to the more customary units of the individual, the
organization, and the organization's institutional environment. The core and middle ring of the energy management organization (or any other specialist sub-unit) comprises individuals. To expect those individuals' behavior and attitudes to be completely determined by the organization and its institutional environment would be as misguided as assuming its membership is totally random. We expect all three, the organization itself, its institutional environment, and random fluctuations due to individual skills and idiosyncrasies to determine who is in the sub-unit (energy management organization) and how they act.

Since the sub-unit spans from the organization to the institutional environment and mediates the relationship between the two, both shape its form and capabilities, contrary to DiMaggio and Powell (1983) who argue that the form and attributes of the sub-unit are determined exclusively by the expectations of the organization's institutional environment. This will become very important when we consider options for public and private policy. The private policy options will look out at the institutional environment through the lens of the specialist sub-unit. Public policies will operate, through the sub-unit, on the organization as a whole.

The majority of the chapter explores the way the influence of the organization is reflected in the attributes of the specialist sub-unit and in the organization's decision making. Therefore, a few examples will suffice. The energy management organization at the highly decentralized Harvard will have very different characteristics to that at the centralized MIT. Big universities should have bigger and more highly skilled energy management organizations.

However, the organization's environment will have an impact, which we will not address explicitly. For example, we are not surprised to find maintenance workers with limited ambition and motivation attracted to the relative quiescence of The University of Massachusetts at Amherst's Physical Plant Department. That stability is a function of
the university being attached to the state government. Likewise, we are not surprised that a large campus which must deal with a slow and unwieldy contracting system and an unreliable supply of capital, such as The University of Massachusetts at Amherst, has developed many in-house construction skills.

Finally, we also expect individual effects. For example, Frank Andrews, in taking over the leadership of the The University of Massachusetts at Amherst Physical Plant Department, used energy management to focus his attempt to reform management in general. That focus is as much a function of him and the idiosyncrasies of the committee which selected him as it is the objective structure and problems faced by the university. However, just as we expect the individuals within the energy management organization to be determined, in part, by the nature of the organization and its environment, we expect their actions to be constrained, but not determined, by things going on in the organization and its environment.

For semantic convenience, some of the argument will be presented in terms of an energy manager making decisions. This should be seen as a shorthand for "the core and middle rings of the energy management organization". As such, this energy manager is quite chameleon. Her skills wax and wane with organizational size, change with centralization of responsibility and so forth. She is not an ordinary individual.

EXPLAINING THE DATA

If we consider the data and the organizations, we can see fairly obvious patterns. For example, MIT, and The University of Massachusetts at Amherst both have fairly centralized structures, and both are fairly sophisticated in their use of computer control. Harvard, the most decentralized organization, is the most adept at using behavioral solutions. We can see a correlation between structure and decision making. Computer
control seems like a more centralized solution to the energy management problem than asking people to turn down the heat.

However, to develop policy, we need to be able to explain the correlation in such a way that it is generalizable. That is, we need a logical explanation of the causation, a theory. To develop that theory, we will first assume that people suffer from bounded rationality. Then, we will develop a metric which operationalizes that assumption in terms of the problem at hand. The metric will enable us to compare the structures of the universities and the nature of the decisions they make on the same scale. Consistent with March and Simon's theory, the metric will be the elements of decision making.

**Bounded Rationality**

March and Simon (1958) developed their theory of bounded rationality to counter inherent problems with the classical model of rational decision making. The classical model assumes that an actor approaches a decision with all the possible alternative solutions laid out and all the consequences of each option known. However, the probabilities of each likely consequence can be either certain, uncertain with known probability, or uncertain with unknown probability. Also, the decision maker has a utility function which enables the options to be ranked in order of preference. The actor selects the option which offers the highest expected utility for the certain and risk cases, or uses a pragmatic decision rule to select between the uncertain outcomes.

This rational actor model is problematic in two ways. First, the model accords with common-sense notions of rationality only in the certainty case. Second, and most important for our discussion, it makes three strong but highly implausible assumptions; 1) that all the alternatives are given, 2) that all the consequences of each alternative are known and 3) that the decision maker has a consistent and complete utility function.
However, as March and Simon point out, "From a phenomenological viewpoint, we can only speak of rationality relative to a frame of reference; and this frame of reference will be determined by the limitations of rational man's knowledge." (1958:138) Therefore, a decision maker who makes prior assumptions about the nature of the problem or the solutions, does not have time to go and get all the information available to be certain (or is incapable of getting all the information for some other reason), or does not know how to interpret the information, will not be able to make a rational decision.

It is a small leap from the individual decision maker to a decision making group such as an energy management organization. In as far as the bounds on individual decision making are caused by the objective structures surrounding the individual (e.g., national culture, organizational culture, organization-induced distortions and filters in information flows, localized distortions in incentives, time pressures, etc.), then we expect the whole group to suffer from the same bounds. In as far as the group is diverse in either task or experience, then the bounds will be less constraining, (assuming perfect communication within the group).

Development of a Metric

We can derive a lot more power from the concept of bounded rationality by operationalizing it. If decision making groups suffer from bounded rationality, then we can compare the groups if we can describe the nature of the bounds. Furthermore, if we can map the various choices the groups have available onto the same bounds, we can compare groups and the options along the same dimensions. In other words, we aim to show that MIT bears the same relationship to Harvard as a digital control system does to a light bulb, in as far as MIT's decision making capabilities map onto the capabilities needed to buy a digital control system much better than Harvard's, and Harvard's decision making capabilities map onto those needed to buy a light bulb much better than
MIT's. Furthermore, and most importantly, we aim to show that the capabilities which allow MIT to buy a direct digital control system preclude it from buying light bulbs.\footnote{We will see in chapter five that this is true only in as far as the organizations choose to allow the bounds to constrain their behavior. Once the bounds are made explicit, they need not be as constraining.}

In the following section, I will suggest that there are five key dimensions to decision making; information, skills, resources, incentives, and power. Each one of them is assumed to be important by both the rational actor and the bounded rationality models of decision making. However, in order to develop an explicit metric for comparison of energy management decision making between organizations, it is essential to delineate how the dimensions are used by the rational actor and bounded rationality models. Therefore, before defining the dimensions, I will illustrate general differences in expectations or predictions that emerge from the two models.

We will construct the metric by considering what it takes to make a decision to install a particular solution. We will do this by contrasting a real organization (our energy manager), with a hypothetical fully rational one. The first step in rational decision making is to define the problem; something like: "the selection of all technological and behavioral options which meet certain economic criteria (e.g. a rate of return on investment) and do not compromise other organizational objectives excessively."

Unfortunately, real organizations do not define their problems rationally. Rather, they define them in terms of their prior assumptions about the nature of the problem (c.f. Schein 1985). We will see very clearly in the cases, (see appendices B through E), that if the energy manager is predominantly an engineer, she will almost certainly look only towards technological solutions. At MIT, Tufts, and The University of Massachusetts at Amherst, solutions pursued are almost exclusively technological, with
the exception of trivial exercises like stickers on light switches and crisis responses of short term severe rationing. Note however that at The University of Massachusetts, at Amherst, users would not tolerate any behaviorally based energy conservation program. Interestingly, virtually the entire literature on energy conservation is written in terms of engineering solutions to the problem.\(^4\)

If the energy manager is not an engineer, there is every chance that she won't appreciate technological solutions that exist, and may even assume that energy conservation occurs through stringent rationing of heat and light. So, for example, the energy manager at the small professional school I studied at Harvard opened the first interview by asking why he should even consider energy conservation as a financial management strategy (he was director of administration) when it had enormous political costs. Similarly, the Dean of Arts and Sciences in the late 1970's (an economist) pursued a disastrous energy conservation program based virtually exclusively on severe rationing of light and heat. Clearly, neither of them was aware that technical options existed.

Given the problem, a rational organization would go out and find all the possible solutions, rank them in terms of its preference function, the way it trades off its objectives, and select the best set of solutions to the problem. It will implement that set.

Now think about what has to happen to bring this about. Unless an organizational failure has occurred, (see chapter five) this task will be taken on by the energy manager. She will attempt to do something akin to the rational actor above. She will seek information about alternative solutions, and use her skills to analyze, or have analyzed, the various options. If resources are available, she will try to implement preferred choices, either by persuading the affected parties that a proposed solution is in their interest, or by using her power to force people to comply.

\(^4\) See, for example, the proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings (Biannual).
That is, she has to contend with five characteristically different obstacles; information, skills, resources, incentives, and power. These are the five dimensions of our metric. In the next sections we will look at each of these dimensions in detail and see how they vary across solutions. We will also see that they are quite interdependent; no one can be separated or derived completely from the others. In the second half of the chapter, we will compare different organizations along these dimensions by considering different measures of organization; size, delegation, decentralization of authority and responsibility, incentives, external contracting, and the management of users. We will see how these vary between the case study universities, and how that, in turn, has led to variations in energy management behavior.

At the end of the chapter, we will bring these together and conclude that each organization and each solution has attached to it a set of characteristics along each dimension. If we ignore an organization's tendency to take risks, (i.e. to make decisions it doesn't fully understand), we will see that an organization has available to it only those options whose characteristics along each dimension fall within the bounds circumscribed by the specialist sub-unit. If the sub-unit is in a peripheral position, then those bounds are very small and very sensitive to variations in organizational structure. Hence, the organization will be limited to solutions which reflect that peripheralness.
THE DIMENSIONS OF THE METRIC

The dimensions discussed below are summarized in figure 4.1.

FIGURE 4.1 DIMENSIONS OF ORGANIZATIONAL DECISION MAKING

INFORMATION

Given a menu of options, the energy manager (or the manager of any other secondary objective such as child-care, occupational health and safety, or pollution control) has to generate some choices. To do that, she needs three classes of information. First, she needs technical information about the various solutions that are being offered which, for all intents and purposes, must come from outside the organization. This can happen in one of three ways. Either the energy manager can go out and get the information, that is, she can read the literature, read catalogues, and look for vendors. Alternatively, it come into the organization on the backs of vendors

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5 The exceptional case is if the organization has a research capability.
or through government outreach programs. Finally, it can be transferred internally from another part of the organization.

In terms of the solutions, two things about technical information are important. The first is the number of diverse sources which must get information to the energy manager before she identifies a particular solution as viable. As the number increases or the source becomes more obscure, we expect organizations which have trouble absorbing information to be less able to identify these solutions. The second thing that is important about the information is its content. We will discuss that when we look at skills.

In terms of organization, there are also two important considerations. If the information is trying to come into the organization from the outside, a key issue is how difficult for it to do so. DiMaggio and Powell's (1983) argument suggests that the external environment will have expectations about the form of the energy management organization. Typically, they would expect to find an energy management office in the physical plant department or possibly the central administration. In as far as the organization does not conform to that expectation, it may be very difficult for the external agent to find the relevant people. We will explore this further when we see the problems external bodies have had finding the relevant people at Harvard. There, the people who you would expect to be responsible for energy management are only marginally involved, and those who are responsible are often very difficult to find. Alternatively, the organization can go out and look for the information. Again, the more the responsibility is diffused, the more organizational resources have to be devoted to scanning the institutional environment.

However, energy conservation solutions don't just hang in space. They are implemented in real locations. To develop a solution for a location, the energy manager needs to know what goes on there. This gives us the second class of information,
contextual information. Would an energy manager dare install fume hood controllers if she didn't know how they were used? Will she contemplate illumination reductions if she doesn't think that people feel their work space is over illuminated? Not surprisingly, different types of solutions have different needs for this contextual information. Generally, equipment decisions need much more than infrastructure decisions. It turns out, for instance, that motion sensors are often very sensitive to the way in which a room is used as well as its geometry.\footnote{After the cessation of formal data collection, as part of the Cambridge Electric initiative, MIT installed motion sensors in some of its computer terminal rooms. This reflected a poor understanding of contextual factors. The rooms are used 20 hours daily by people who generally do not move very much. The lights go out constantly and are a source of general irritation. However, at the same time, MIT neglected to install sensors in some corridors which are, in fact, ideal for that application. In appendix C, we will see that the Faculty of Arts and Sciences at Harvard had difficulties, of a different kind, when it attempted to install sensors on an experimental basis.} We would expect the energy manager to have much more information about the spaces and people she deals with regularly than those she meets rarely. So, we would expect an energy management organization rooted in the physical plant department concentrate on the infrastructure. Conversely, if it is centered in the academic domains, we would expect most energy conservation to involve the equipment.

Third and finally, a host of people are connected institutionally or geographically to the site of the energy management works. The connection occurs through geographical proximity, the infrastructure, or the fact that many elements of a system have multiple facets relevant to multiple interests. These connected people may be affected by the solutions being proposed. If they have any power in the organization, their interests must be acknowledged. If that is to happen, the energy manager must know what those interests are. This is a different type of information. Appendix B presents a disastrous attempt by the MIT Physical Plant Department to install
microcomputer controllers on fume hoods (B-2d2).\footnote{See Appendix B, section II, subsection D2.} One of the key impediments to the attempt was the Physical Plant Department’s lack of understanding of the Safety office’s concerns about the effects of the controllers on laboratory ventilation and hence safety.

**SKILLS**

What the energy manager does with all this information depends on her skills. If she has a technical degree she is much more likely to know the difference between a smart and a dumb multiplexer than if she doesn’t. Similarly, not only will she know that there are possibilities in computer control, she will also see the managerial significance of direct digital control over supervisory pneumatic control, and so forth for every technological option. The argument could easily be extended to include skills concerning the viability of various behavioral options. Generally, because of its complexity and coupling to other systems, higher skills are needed to manage energy for infrastructure than equipment.

**RESOURCES**

Given a set of potential options, the energy manager has to determine which are viable. Given a preferred option, she needs to establish that she can attract the resources needed to implement it and that it will be acceptable within the organization.

Three resources, land, capital, and labor, are fundamental to any decision. The amounts of each available depend on what is going on both outside and inside the organization. As an example of lack of land preventing a project, Tufts had to choose between a waste incinerator and a cogenerator as it only had one site available (E-4C). Interestingly, capital can also be very constraining and differentiated between projects an organization may want to pursue. Many organizations turn to banks to finance their
energy conservation or waste management programs. Banks, however, not understanding the projects very well, often find it very expensive to calculate the risk. To cover their appraisal costs, they have to charge high interest rates which render these projects unviable. Hence, one of the reasons shared savings contractors have become popular is that they have good access to capital (often from a utility) at a reasonable rate.\(^8\) The availability of Higher Education Financing Authority (HEFA) bonds prevented this being a problem at the case universities. Finally, labor market shortages may prevent the employment of workers. Tufts claims that it has trouble attracting labor because of recent development Boston (E-2B2b) absorbs workers. However, MIT and Harvard do not seem to have the same problem.

Given the external constraints, there is still the problem of internal allocation of resources. Many authors, (e.g. Pfeffer 1977) see this as a highly political process. That process is inextricably bound up in all five dimensions, so we will not elaborate on it here.

**INCENTIVES AND POWER**

Finally, the energy manager needs to determine whether or not a project can be implemented. The core problem is that every change in technology, no matter how simple, changes the social relations between people, (e.g. Winner 1977). For example, simply replacing an incandescent light bulb for a compact fluorescent one reduces the need for bulb changers by a factor of ten. The compact fluorescent bulb lasts about ten times as long (10 000+ hours versus 800 - 1 000). Similarly, if the envelope maintenance people start worrying about cracks in walls, they must either take on extra staff or not do something else.

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\(^8\) Interview, Jim Rogers, Vice President Cogenix Corporation, April 1989. (Formerly in charge of energy management at Digital Equipment Corporation.)
In as far as there is conflict between those who make the decisions (management) and those who must deal with their implementation (labour or users), we expect opposition to change. For example, labor may suspect that any technological change is an attempt by management to increase its power (Edwards 1979). This may be happening, though not deliberately; it may be just that management will avoid changes that reduce its power, and therefore, must increase it. However, even without that fear, individual actors have a stake in the status quo and have no stakes in the unknown future.

Therefore, in as far as it is possible to sabotage a change in technology or amount of supply, everyone who is involved in the implementation of the project must co-operate. This includes the people who control the resources, the people who occupy or control the space affected by the project, and those connected geographically or institutionally to the space. Jackall (1988) suggests that some pollution projects threatened power relations in the organizations he studied. Therefore, environmental managers did not bother to advocate good, but disruptive, solutions.

People can support a project for one of two reasons. Either they can see it as being in their interest, or the energy manager can have sufficient power to ensure that they cannot object. Hence, the three things we need to consider in more depth are the robustness of the solution, the ways in which people can be made to see things as in their own interest, and the ways in which the energy manager can exert power over others.

If the energy manager has sufficient power to implement a solution in the first place, but that solution will disenfranchise particular affected groups, then the robustness of the solution will determine whether or not it succeeds. Compare pneumatic and direct digital control systems. They control both energy usage to a large extent through the control of maintenance workers (c.f. Edwards 1979). For an energy
management system to work, all the components it is controlling have to work. That is, the valves and dampers have to open and close when the system commands it to; the various pipes cannot be clogged. When they are dysfunctional, lots of energy is wasted. If an element of the system is not at its specified level (e.g. if a building is not at the temperature it is supposed to be) it shows up on a central console. Hence, the computer is constantly checking whether or not maintenance workers are performing their jobs.

I noted in chapter two that the pneumatic systems don't control workers as well as direct digital control systems. They are maintained by the workers they control (HVAC mechanics), they can move out of adjustment gradually, the set points (e.g. temperature settings) can be altered remotely without the central computer operator knowing, and the control lines can easily be slashed by disgruntled mechanics. Consequently, workers can easily subvert the technology. Direct digital control systems, on the other hand, fail grossly and obviously, are very reliable, are set centrally, and are maintained by people other than the HVAC mechanics. Appendix D describes the demise of the supervisory system at The University of Massachusetts at Amherst (D-4B1a). It is noteworthy that Harvard, in contrast, has one of the three large-scale Honeywell systems which actually worked (C-5A1). This would indicate that management at Harvard is very strong indeed. This is supported by the difficulty that the Harvard clerical workers had unionizing.

What does it take to make people see that a project is in their interest? Two devices are commonly available. The first, and simplest, is to give them an interest in the outcome, an economic incentive. Sharing energy conservation savings with users is a possibility, as is charging for individual energy consumption. The simplest economic incentive is a simple contract. "If you reduce your energy consumption for me, I'll give you so much money or so many services in lieu." However, there may be other, much subtler, exchanges. For example, imagine a physical plant department which asks
consumers to curtail their energy consumption. Those consumers may now have a legitimate expectation that, in return, the quality of physical plant department services (reliability of mechanical equipment, control over times and temperatures, etc.) will rise. By going out and asking for assistance, the physical plant department may well expose itself further because the consumers will be talking to physical plant department employees, and hence will be in a much better position to articulate their dissatisfaction.

Incentives are strongest when the user has full responsibility for impacts on secondary objectives, e.g. full cost charging for energy usage. They are zero if the responsibility is all absorbed outside the institution; e.g. if a university's energy budget is expanded or contracted by the legislature to match usage. In between, there is a weak incentive, e.g. if extra energy usage is reflected in overhead rates and tuition.

Non-financial incentives include increases in individual prestige in either the organization or the individual's professional peer group. Further, energy conservation can provide opportunities in the organization, interesting work, or possibilities of making an individual's job more pleasant in the future. These incentives are important for the energy manager.

The second device is to make everyone believe that something justifies sacrificing personal interest for the good of the organization or the society as a whole. This way, a 'tragedy of the commons' (Hardin 1968) resulting from individual selfishness can be avoided. For example, people generally believe energy conservation is a good thing. They are quite happy to accommodate minor inconvenience for what they perceive to be a worthwhile cause.

If appeals to the collective good are made successfully over time, people may begin to assume without questioning their veracity (see Schein 1985). It becomes part of the organizations culture, and members teach each other conservation behavior and
automatically factor it into their decision making. This makes the energy manager's task much easier. People will make sacrifices if they perceive something as being in the interest of the organization, in as far as they identify with it.

These appeals to the social interest should not be dismissed. Many sections of the community believe that wastage of resources is wrong in and of itself. At Tufts and The University of Massachusetts at Amherst, the energy managers were working in that field because they were committed to conservation as an ethic. At The University of Massachusetts at Amherst this doctrine (along with ease of operation and comfort) was a principal motivator for energy conservation. At MIT, interviewees talked of the need for energy conservation even though projects would take resources from their budgets. I suspect that this moral imperative may lead to the energy managers being better qualified than other equivalent people in the organizations. For example, one of the two people principally responsible for energy management at The University of Massachusetts at Amherst had a Master's degree.

Finally, we look at the use of power; making people do what you wish. French and Raven (1959) describe five sources of power; (1) Reward Power - the leader's capacity to reward followers, (2) Punishment power - the leader's capacity to coerce or punish followers, (3) Legitimate power - power that accrues in a position or role, (4) Expert power - power that accrues to a person with knowledge or expertise and (5) Referent power - the extent to which followers identify with, look up to, and wish to emulate the leader. We will consider legitimate power under delegation below. Otherwise, reward and punishment power are the most relevant. The energy manager can exercise reward power if she can ransom resources in return for cooperation. For example, during Harvard's big retrofit program, there was a belief (I have been unable to confirm its veracity) that energy conservation performance was a major precondition for the dean's support of faculty hiring and promotions, and of new construction.
Punishment power is used in the core, middle and outer rings of the energy management organization. There are many people in the core of the energy management organization whose jobs specifically include responsibility for aspects of energy management. In as far as they will be punished for not doing their job properly, punishment power is being exercised. In the middle and outer rings of the energy management organization, punishment power may be used routinely to make people work harder by making them insecure about their tenure. Given they are marginal employees, or so management keeps telling them, they are sure to come out badly from any change process. Furthermore, these workers may well protect themselves from management by building inefficiencies into the system (c.f. Thompson 1967). These people are likely to resist any change.

SUMMARY

In summary then, there are a series of preconditions which determine which options the organization will consider. Each option carries with it a particular constellation of technical, contextual, and connected information. To analyze that information requires particular skills. However, those skills may prejudice the options considered in the first place. Even if options are viable, they require resources. Whether resources are available depends partially, but only partially, on the power of the energy manager. Every option also requires different amounts of cooperation from different groups of people on the campus if it is to be implemented successfully.

THE INTERDEPENDENCE OF THE BOUNDS

Implicit in the above argument is an assertion that these bounds are not fully dependent on each other. That is, we can not explain everything using power, or power plus information. Rather, we need to consider these five variables as an interdependent network. To verify this assertion and to maintain that it holds through the rest of the
chapter, I need to show that (1) these bounds are not wholly dependent on each other and (2) the structure cannot be derived from any one of them alone.

To prove the first proposition of interdependence, consider three aspects of the decision making process described above. First, information, skills, and resources come to a large extent from beyond the organization. Hence, we cannot derive them from power and incentives alone. For example, while power may determine the skills that are available to search for information, it will not determine how hard it is for the information to permeate the organizational boundary. Notwithstanding, we expect information flows to be highly dependent on power and incentive structures. For example, as input/output functions become more transformative they obtain access to better information. This increases effectiveness. Second, I suggested above that the information used depends on the skills available as well. Technical people look for and use different types of information, irrespective of political position. Finally, power and incentives are clearly strongly interrelated. As I have suggested above, neglecting the organization's ability to develop robust solutions, it needs to find some combination of power and incentives to hold its solutions in place. However, this does not suggest any deterministic trade off between the two. Once the organization develops skills and has access to resources, we see the possibility of installing robust solutions which will substitute for both power and incentives.

Chapter three shows clearly that a structure cannot be derived without consideration of politics, the relative importance of objectives, as well as information processing. Therefore, proposition two is clearly false.
STRUCTURAL CONSTRAINTS ON DECISION MAKING

We now look at the way in which five measures of organizational structure; size, delegation, decentralization of authority and responsibility, incentive structures, and the use of external contracting affect the position of these five bounds; power, resources, information, incentives, and skills. For each, we will first consider the theoretical problem to develop some propositions, and then illustrate those propositions with the case material. Finally, we will look at the treatment of users.

We will see two things. First, the structure tends to constrict the bounds quite severely. Each change tends to simultaneously expand the organization's bounds on some dimensions but contract it on others. Second, because of this constriction, the universities have tended to favor solutions which reproduce the prior structure.

We do not expect the data to concur completely with the propositions. As we saw above, there are three important elements in an analysis; individuals, organizations, and organizational environments. The propositions are concentrated at the organizational level, to the exclusion of the others. Therefore, the role of the radically different external environment at The University of Massachusetts at Amherst, or particular individuals at The University of Massachusetts at Amherst or Harvard is ignored.

SIZE

We will consider size as a function of three variables; the number of people on campus, the area of the campus, and the energy intensity of space usage.

Obviously, we would expect the floor area to increase with the number of people on a campus. However, the usage mix changes also. For very small campuses and very large ones we would expect the mean space-use intensity to be low. Very small campuses tend to be small colleges, which emphasize undergraduate education. (Caltech
is the obvious exception.) Very large campuses tend to be state universities with hordes of undergraduates. They may have a large research base as well.

The energy delivery system increases in size with the campus. If there is central chilling or heating, there needs to be distributed steam and chilled water lines. Otherwise, there needs to be either gas lines or an oil distribution system. Similarly, the electricity distribution system increases with the campus area.

As space use intensity increases, so does the amount of equipment in use. This has three effects. First, this equipment uses energy. Second, this equipment produces heat which must be removed. Third, as a rough generalization, as equipment energy use increases, so does its demand for a controlled environment. The temperature constraints on a mainframe computer are much tighter than those on a personal computer. Research laboratories need much better temperature control and illumination than teaching ones.

Energy expenditures increase with size. A large university requires a large staff. Consequently, higher skill levels, either as a more specialized staff or a higher skill level in a diffused staff, are justified. Similarly, senior management positions become more challenging and therefore more prestigious with size. A large university is likely to attract more enthusiastic, competent and ambitious people.

However, we also expect more bureaucratization with correspondingly poorer communication, as interaction especially between users and facilities staff becomes more depersonalized, and increased problems with coordination (Weber 1947). However, since all the universities studied are fairly large, this effect is probably minor. It is also countered by the fact that larger universities can probably attract better managers. Therefore, we cannot predict a size/coordination-communication effect.

Paralleling Perrow (1968), I propose:
1. A university's ability to deal with complex technical problems increases with its size.

![Diagram: Effect of Size on Decision Making Ability]

**Figure 4.2 Effect of Size on Decision Making Ability**

**Evidence**

In this study, I have considered only the principal campuses of the universities; (Amherst for The University of Massachusetts, Cambridge for Harvard, Cambridge for MIT, and Medford for Tufts.) Therefore, The University of Massachusetts at Amherst is the largest (30,000 people, 9,000,000 square feet of academic space over 1200 acres). Tufts is the smallest (5,000 people). MIT and Harvard are about the same size. Harvard has more people (22,000 versus 15,000) and a larger floor area (9,400,000 versus 9,000,000 square feet), but MIT has significantly higher space use intensity.9

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9 As an interesting aside, Harvard's population and especially floor area were very elusive statistics. Whereas these were common knowledge at other schools, I had to chase down the right person who then had to calculate the figures for me.
After controlling for other factors, we would expect MIT to have greater
technical competence and Harvard to have less than cursory analysis suggests. MIT's
excesses come from its organizational culture. Since virtually the entire senior
administration of the Institute are either engineers or scientists, we would expect them to
be support technological prowess in the Physical Plant Department (B-1d). Similarly, the
Physical Plant Department could appeal to MIT's technological vanity. Therefore, we
would expect requests to increase the size of the professional staff would be met more
positively than elsewhere.

Harvard's shortages come from two sources. First, with the exception of a few
small boilers, it purchases all steam from the utility (C-1a2). Therefore, it does not have
to develop the expertise to run and manage a large boiler. It must simply administer a
contract. Second, because of its decentralized structure, we would expect the skills to be
diffused around the campus (Proposition 3b). Consequently, it cannot concentrate
specialists.

After accounting for these, the proposition is borne out. Using as a rough
surrogate measure the number of professional engineers on the staff, we find that The
University of Massachusetts at Amherst has the most, with seventeen. MIT follows with
thirteen. Harvard has about three, however, their distribution limits their usefulness.
There are two in the central planning office, but they aren't accessible to the Facilities
Maintenance Department except for design review, and there's one who started in the
Facilities Maintenance Department as the interviews took place, but more or less by
accident. In addition, the Faculty of Arts and Sciences has para-professional skills in its
facilities office, and, in the past, had a facilities dean and access to a conscientious
professor of Applied Science. Tufts has only three in the Physical Plant Department.
Two of them supervise construction and hence have no role in energy conservation.
DELEGATION

In a university with low delegation, a large proportion of decisions need senior management approval. While delegation occurs with decentralization (see below), decentralization is not a necessary condition. Therefore, it is considered separately. Delegation is generally achieved by senior management imposition of performance criteria or other standards, instead of participation in decisions (Mintzberg 1983). For example, The University of Massachusetts at Amherst has very limited delegation of funding decisions. The state legislature allocates funds between utilities (fuel), operations expenses (labour), capital expenses (buildings and major equipment) and other costs (spare parts, etc.) Funds cannot be moved between these budget items. Similarly, it allocates money for particular capital projects.

Two aspects need consideration. First, the less delegation there is, the more difficult it is to get projects approved (Ross 1986). While Ross does not suggest a mechanism, we can suggest three. First, it is likely that the probability of a particular project being rejected increases with the number of decision making levels. Second, we might also expect it to reduce the probability of initiation of a particular proposal since securing approval requires more work of the proposer. Proponents will probably shy away from projects of marginal attraction to themselves or with a lower probability of being approved. Third, if senior executives with broad responsibilities are uninterested in small items, which is not unlikely, smaller projects won't be proposed.

So, I propose:

2a The more delegated the authority to manage energy, the more creative the solutions to energy management problems, and the greater the profusion of small projects.

However, there is a second aspect. Senior managers coordinate. A given sub-unit with responsibility for a particular decision, will favor solutions that minimize its
need to interact and communicate with other sub-units of the organization. For example, all other things being equal, mechanics are more likely to change an old motor for an identical new one than to get engineering to study the problem and see if a better solution can be found. Similarly, a sub-unit is less likely to consider the needs of other sub-units in its decision making, so there is a greater chance that decisions will either exclude or conflict with their concerns. For example, for a building envelope maintenance group, cracked walls become problematic only when they are large enough to leak water, not when they are large enough to leak heat. Finally, a smaller unit of the organization is less able to gather relevant information for a problem. So, for example, a fully autonomous housing office is unlikely to be a sophisticated energy manager.

Furthermore, the less integrated the groups in an organization, the more likely they will pursue local rather than global goals (See proposition 4a). If other groups threaten pursuit of those local goals, by making competing claims on resources for example, then the local groups are likely to protect themselves. They will do this by hoarding information and resources. This is likely to increase division and exaggerate the boundaries between the organizational sub-units. Over time, this could easily become part of the organizational culture. As such, protectiveness of information would become a generic organizational problem. Consequently, we would expect poor communications both across organizational functions and down organizational lines to become endemic. Management can compensate for this problem by requiring (and fostering) increased communications and coordination between the sub-groups.

So, I propose:

2b If delegation excludes all the relevant actors from a decision, organizational conflict, high communications needs, and lack of information will lead to simpler (and less effective) energy management.
When considering delegation at the individual campuses, it is worth separating large and small financial decisions. At The University of Massachusetts at Amherst, there is virtually no delegation of large capital decisions. Once the legislature has allocated money to different budget lines there is nothing the university can do about it. Within the Physical Plant Department, the director delegates a lot to his associates who are relatively free to allocate funds as they wish, within the constraints of the budget. At Harvard, the corporation delegates capital sums less than $300,000 to the Vice President for Finance. The Vice President delegates capital sums less than $50,000 to the schools. How the schools deal with operations and capital sums less than that is up to them. The small professional school is very centralized because it is very small. The Faculty of Arts and Sciences is moving towards a separate operations budget for each building. At MIT, all capital expenses must go the Senior Vice President for Operations, though delegation to the Physical Plant Department is nominally the same as at Harvard. Operating budgets are delegated within the plant to the various divisions. Data was not collected for Tufts.

If we assume that people in an organization are rational, then we would expect talented people to get frustrated and leave organizations with insufficient delegation for those where they can be reasonably autonomous. If they stay in the job, we could expect there to be strong organizational incentives against maintaining or developing their skills. This creates a negative feed-back. As the organization's skills drop, senior management is likely to become less confident of staff competence. Management's natural response will be to tighten control so that it can assure itself that the sub-organization is doing a good job. However, the sub-organization's response will be to shed skills. Consequently it will still be unable to meet the central organization's expectations.
EVIDENCE

For proposition 2a we will compare The University of Massachusetts at Amherst with the least delegation, to MIT with a little more, and Harvard, which has the most. The Harvard data will be limited to the Faculty of Arts and Sciences so as not to confuse this with the very closely related issue of decentralization (Proposition 3). There is insufficient data to include Tufts in the discussion.

PROPOSITION 2A: DELEGATION INCREASES CREATIVITY AND ENCOURAGES SMALL PROJECTS

We will consider capital allocation decisions. Hence, involvement of users, which is not generally a capital problem, will be deferred. New buildings' decisions represent a special case as they always involve the senior administration. They will be discussed in chapter five.
The University of Massachusetts at Amherst only does big capital projects, with long time lags between initiation and completion. The Supervisory Data System was commissioned all over the campus in 1968 and fell into disrepair within ten years (D-6b1a). The direct digital control system was installed in 1988 with funding from the legislature on the fourth attempt (D-6b2). Of the several project phases, only the first had been designed and funded at the time of the interviews. It would control 26 buildings (including 23 dormitories) with a main computer, and 70 others with the "small system". Presumably, later phases will involve the other 40 buildings on campus and the merging of the small system into the larger. Lighting is similar. Retrofits happen with large grants from the state or large contracts through the housing office (D-4b, D-2b1). All projects are large and lumpy with long lags.

MIT is similar, though with shorter time lags. The Facilities Control System went in as one large project, was expanded as another, and was replaced as a third. (B-2b1, B2b3b) Given the nature of the technology, this is not surprising. However, we see the same thing with lighting. Until the large retrofit program of 1987/89, compact fluorescent lights were limited to external floodlighting (B2d1). Similarly, high efficiency ballasts were virtually unused. It was only when they could be combined as a large project that anything could proceed. The superintendent of operations at MIT has a capital budget which he is free to allocate as he wishes. However, in 1987 it was large enough to allow him to do about 4% of the $8 000 000 identified projects in deferred maintenance, capital maintenance, and energy conservation, and he knew there were other projects they had not identified. While he saw that he had a staff and money shortage, he said he couldn't put the package together to obtain the necessary resources to do the works. "We have a fence around us in terms of resources and available time", he said. (B3a3)
The Faculty of Arts and Sciences at Harvard is the most delegated of the three cases. There, the direct digitally controlled energy management systems go in one building at a time, rather than the large centralized systems of the other universities. In fact, the university automatically approves any capital project up to $50,000, if a school proposes it. Small energy projects that would not be considered capital, but which increase budgets, are generally approved automatically by the school. Similarly, there is a much higher diffusion of small lighting projects, with energy monitors retrofitting one room at a time, selectively changing bulbs. Also, they will de-lamp exit signs, or replace them with luminous ones; things unheard of at the other universities (C2b8a, C-2b8b).

**Proposition 2b: Delegation isolates decisions to subgroups in the organization**

This proposition will be addressed by example. At Tufts, the energy management role is explicitly one of coordination, so, we would expect there to be little conflict within energy projects that are attempted. However, we would also expect conflict to prevent many projects from being initiated. In the other universities we see a lot of projects that do not occur because of this boundary problem, or which would occur differently if the boundary problem weren’t there.

The Tufts energy manager is intimately involved in the conception and design of all new buildings; much more so than at the other universities. He is the only person at the university who appears to be thinking about the problems of coordinating maintenance, preventative maintenance, and operations, or doing any sort of systems analysis. Therefore, it is not surprising that the energy manager is conceived, by the other people on campus, as the person with the coordinating role in the Physical Plant Department. Hence, coordination of projects is not a problem so long as the energy

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In theory, there is as much delegation at MIT. However, in practice, Harvard’s budgets appear to be much more flexible.
manager is not threatening other people's resources (E2b1a). Once that happens, there appear to be big problems. The energy manager described perpetual problems procuring resources for projects.

There are also problems when projects go outside the Physical Plant Department, i.e. into equipment. The best example is the installation and retrofitting of fume-hoods at the medical campus. The Physical Plant Department was unable to persuade the researchers to install microcomputer controllers even though the hoods were being replaced. The controllers were of no use to the group mandating the retrofits, the safety office, and went against the direct interest of the group that was paying for them, the researchers (E2b1c). Fume-hood retrofits met a similar fate at MIT, where there are about 600 fume-hoods on the campus, of which it is probably sensible to retrofit about 300 with microcomputer controllers (the other 300 are used for radioactive chemicals, have inappropriate exhaust systems, or have insufficient face velocity). However, of these 300, only about 100 or 150 were likely to be retrofitted. There had been considerable friction between the Physical Plant Department which reports to the Vice President for Operations, and the Institute Safety Office which reports to the Provost (B-2d2). In contrast, at Harvard, the safety office, as part of the central administration, acts in an advisory capacity only. However, it can intervene and veto the schools' actions it feels put Harvard at risk. There we find almost universal use of microcomputer controllers on the hoods\textsuperscript{11} (C1b3, C2a2c). No data was collected about fume-hood retrofits at The University of Massachusetts at Amherst.

Another example of this coordination problem is in building envelope maintenance. At Harvard, where the schools have responsibility for the envelopes, and

\textsuperscript{11} I am not suggesting that the outcome at MIT is better or worse than that at Harvard. The debate over whether these controllers increase or reduce safety is extremely complicated, and is not being addressed here. I am suggesting, however, that the different power relationships between the offices has resulted in a different outcome.
instruct the Facilities Maintenance Department to carry out works, the Faculty of Arts and Sciences put a lot of effort went into sealing cracks in walls and ensuring that internal pressures were high enough to prevent infiltration. Similarly, every building was carefully assessed to see if it would benefit from insulation (C2a2c).

At MIT in contrast, the superintendent of operations is responsible for energy conservation, while the superintendent of support services and building maintenance is responsible for building envelopes. The building services people dislike retro-insulating roofs because the insulation obstructs maintenance access (B2b2b). Similarly, one building (Building 13) has been retrofitted twice since construction (once under the BEAM program and once under the Commonwealth Electric retrofit program.) On neither occasion has there been any move to dramatically reduce infiltration and increase comfort in the main lobby by changing the doors from a swinging door to a revolving one, or adding an entrance alcove. Similarly, the building service people aren't interested in stopping infiltration which doesn't bring water into a building. This is particularly evident in the dormitories, which are the responsibility of the Housing Office, and not the Physical Plant Department (B-4b).¹² Finally, we find that the custodial staff often lock the wrong doors in the buildings. That is, the revolving doors are locked and the swinging doors are left open late at night. While some swinging doors need to be left open (for disabled access), for energy conservation we would want predominantly revolving doors open.

¹² In Tang Hall (not studied explicitly) there are large cracks alongside many of the windows. From informal interviews with residents, it appears that cold complaints result in the heat being turned up. This is not surprising. It is much easier for the Operations Center staff to change the thermostats for the building than it is to initiate a memo to the housing office suggesting that the dorm rooms should be inspected. In the Faculty of Arts and Sciences at Harvard, in contrast, a cold complaint always results in a room being inspected before the heat is turned up (B-2B5).
At The University of Massachusetts at Amherst this coordination problem has not arisen. Energy conservation is pursued to increase operational efficiency, not the other way around (D-3a). Therefore, they will generally avoid these problems since there is no operational advantage in reducing infiltration or insulating, and it creates more work and coordination difficulties. They expected they would have to sort out those problems that inhibited the operation of the energy management system (such as cracks) when it came on-line. So, they expect an assault on infiltration in the dorms as well as the heating systems themselves (D-6b2d).

Finally all sites of replace failed components from the nameplate. This exemplifies the proposition. Efficiency gains can presumably be made by re-optimizing the sizing of that particular component whenever it is replaced. However, none of the campuses do this. Instead, replacements are generally virtually identical (B3a3a, C2b2, D3c1, E2b2c).

DECENTRALIZATION OF AUTHORITY AND RESPONSIBILITY

In this context, a decentralized organization gives multiple actors responsibility or authority for the same function in different geographical locations. Responsibility is decentralized when smaller groups must make decisions about carrying out particular tasks. Authority is decentralized when separate sub-groups of the organization become financially accountable. So, for example, The University of Massachusetts decentralizes authority and responsibility by having separate physical plant departments at each of its campuses. Similarly, a university can decentralize responsibility by having work groups in the same physical plant department assigned to different geographical areas. Harvard decentralizes authority. That is, the schools are financially independent.

We will discuss decentralization of responsibility by considering the problem of providing engineering services and HVAC mechanics for a university. At The
University of Massachusetts, each campus; e.g. Lowell, Amherst, and Boston, has its own engineering department. This is sensible because the campuses are large and geographically spread. In contrast, Tufts' three campuses, Medford, Boston, and Grafton, share engineering services. The university isn't large enough to support multiple groups of engineers. Since mechanics are reasonably interchangeable, a university gains little by pursuing non-geographical (e.g. by specialization) divisions. Geographical allocations, (i.e. to specific buildings as at Harvard and MIT until 1976) however, offers the advantage of increasing local knowledge and staff accountability.

Decentralization of responsibility without decentralization of authority, e.g. assigning maintenance workers to individual buildings, offers economies of scope by localizing accountability. Obviously, there is a trade-off between aggregation of technical skills and accumulation of local (contextual) knowledge. However, once the work-force exceeds a certain size for a given task, it may be sensible to partition it geographically. One of the key determinants of this will be the cost of moving information or people from a central location to the periphery in the two situations (Galbraith 1974). The other key determinant is the extra information or accountability that can be gained from regionalizing. While it is of intellectual interest that MIT went from a regional to central system or mechanics when it could automate centralized data acquisition, the decentralization of responsibility is of limited interest except when it is compared to decentralization of authority.

By decentralizing authority, irrespective of responsibility, each sub-group of the organization becomes a decision center. Advantageously, this provides a stronger price incentive for the sub-group, because any change it makes is internal to its operations.

So, I propose (as would an economist):

3a Decentralization of authority in an energy management organization, increases the incentive for energy conservation, and hence the tendency to undertake energy conservation projects
However, decentralization of authority reduces economies of scale. Since each element of the decentralized organization must reproduce the decision making apparatus for energy conservation several times over, no one element will be able to develop the in-depth skills they would have had they pooled their resources, unless that element is large enough to develop all the requisite skills internally. Furthermore, a rational decentralized organization will purchase skills until they have zero marginal utility. Consequently, decentralization will lead to more aggregated skills on the campus (if skills could in some way be added), but less ‘skilled people. I do not have data to test the second half of this proposition,

so, I propose:

3b Decentralized of authority in an energy management organization, reduces the technical competence a given group can accumulate, and therefore its ability to deal with complex technical problems.

However, since each group must perform certain functions, decentralization will lead to a duplication of administrative functions not called for by the scale. For example, each school at Harvard needs to have full accounting skills. Similarly, if each group can make independent decisions, economies due to standardization cannot be achieved.

So, I propose:

3c Decentralization of authority is in an energy management organization, increases the cost of running that system because of inefficient reproduction of administrative functions and losses in economies due to standardization.

A decentralized organization makes two types of decision; those the individual parts make individually, and those they make collectively. We expect collective decisions to carry high communication costs. This would lower the tendency to undertake large and complex collective projects. As a proposition, this would be a virtual restatement of
proposition number 2b. The reader should note that that proposition applies in this instance also.

If the parts of an organization make the decisions individually, then the organization must make multiple and similar responses to an external stimulus. So, for example, if a new product comes onto the market, each part of the organization must find out about it. One of two things can happen. Either the central organization can provide extra staff to disseminate the information, (proposition 3c), or each part of the organization must find out about it for itself. In addition, external sources of information must find the key people in each of the sub-parts of the organization. This will be difficult if they do not expect the organization to be decentralized (DiMaggio and Powell 1983).

So, I propose:

3d Decentralization of authority in an energy management organization, reduces the rate of diffusion of information both within and from outside the organization.

In the decentralized organization, we do not expect the individual parts to be the same size (as defined under proposition 1). Using the same logic, we would expect smaller sub-units to have less skills. In addition, the larger actors are likely to have significant power over resources. That is, larger parts of the organization could force pooled resources to be tailored disproportionately to their interests (unless the central administration of the university intervenes) or they could develop skills internally and make it uneconomic to provide those skills centrally for the smaller units.

So, I propose:

3e Smaller parts will exhibit relatively worse energy management than the larger in an energy management organization with decentralized authority.
It follows from these propositions that centralized organizations will have high skills and low incentives. We would expect them to focus on technical energy management solutions, mainly in the infrastructure, with little emphasis on management of demand. Conversely, we would expect decentralized organizations to concentrate on optimization of equipment and demand management.

![Diagram of Skills, Resources, Incentives, and Power]

**FIGURE 4.4 EFFECT OF DECENTRALIZATION ON DECISION MAKING ABILITY**

**EVIDENCE**

These propositions are best tested by comparing Harvard, which is decentralized into financially separate schools, with the more centralized MIT. Both schools are approximately the same size, about the same access to funds, fairly similar space use, and virtually identical weather.

MIT is very highly centralized, except that the Housing and Food Services Department is quite separate from the rest of the Institute. In contrast, Harvard is
Peter Cebon (1990)

decentralized to the school level. After that, the level of centralization is at the
discretion of the dean. However, Harvard has a culture of decentralization. Several
interviewees told me of the advantages of Harvard having "every boat on its own
bottom" without realizing that the Faculty of Arts and Sciences is about the same size as
MIT, and therefore MIT is an equivalent "boat".

There is a problem with presenting an argument about a decentralized
organization like Harvard. People may object to the analytical framework and argue
that the university should be considered an amalgamation of small schools with a shared
name and a few shared resources. Therefore, it is inappropriate to analyze Harvard as a
large decentralized university. I reject this. Harvard has distinct educational resources;
a certain number of faculty, students, and buildings. It arranges them as it wishes.
Separate small colleges lack that choice. As such, this proposition looks at the effect of
choosing the decentralized structure.

**Proposition 3a: Decentralization Increases Incentives**

As we consider this proposition, we have to be very careful to separate the task
of collecting information and identifying projects (propositions 3b – 3e) from the task of
acting on information at hand. This proposition focuses on the incentive to act on
information in hand.

First, energy managers at Harvard are prepared to do many things that those at
MIT are not. For example, at Harvard, the Dean of Arts and Sciences was prepared to
turn off the heating in particular buildings after certain times at night (C2a1, C2b8b).
People could provide their own if they wanted to work late. Dean Nankin was prepared
to move resident faculty and graduate tutors out of dormitories over the mid-Winter
break (C2a1). Also, temperatures are set back strictly in the Harvard dormitories (C–
2b5). Similarly, the small professional school controls scheduling carefully (C3c3). Also,
when Susan Hill was in charge of scheduling in the School of Design, she would regularly refuse to cool it if there were insufficient people there (C7c).

Second, let us compare the Harvard retrofit program to the MIT BEAM program. Harvard carefully assessed and retrofitted every major building (C2a2). In contrast, the BEAM program covered only ten buildings, and was terminated before contracts could be let on four of them (B2c). The reasons for cancelling the BEAM program are complicated. It could be argued that the quality of people involved is a significant determinant here, though that could be related to the quality of the work environment. Notwithstanding, given the technical problem and the incentives in place, there is no reason why MIT should not have retrofitted the entire campus as did Harvard.

The final difference between the two programs is that MIT considered only technological options. There was no suggestion of changes in operation of the buildings or creation of administrative structures (like the energy monitors at Harvard) to change user behavior or to create a framework for an ongoing program.

**PROPOSITION 3B: DECENTRALIZATION REDUCES COMPETENCE**

We would expect Harvard to have more skills than MIT (in aggregate), but that they would be diffused and of lower quality (on average). In comparing the two organizations, there is absolutely no doubt that MIT has more specialist skills (e.g. thirteen engineers to three). The question is the extent to which that is determined by MIT's technical self definition. The reader should keep this bias in mind.

The easiest way to see this skill differential is to consider the proliferation of direct digital control computer systems. MIT installed its first system in 1976. By 1979 it was upgraded to include another sixteen buildings (B2b1). In 1979, three years after MIT had shown that direct digital control was a superior option, and at the time it was upgrading, Harvard upgraded its computer to be a more sophisticated pneumatic system
Given that the industry was in transition at the time we cannot conclude that the university should have invested in direct digital control. However, it was an extremely attractive option by that time and was obviously the next step if not the current one. At minimum they should have considered, if not invested in a new system that would support direct digital control in selected buildings. However, they upgraded the old supervisory system. Furthermore, when the interviews were carried out in 1987, the F.M.D. staff spoke as if D.D.C. technology were brand new. It was, in fact, twelve years old. Clearly, information was not getting into the organization from the outside, (proposition 3d) or, if it was, the Facilities Maintenance Department did not know how to make sense of it.

In 1987, the small professional school was considering options for control of its library when its shared savings contract expired (C3c3). No doubt, the best overall solution is a direct digital control system. However, at the time of the interviews, the school saw problems, particularly with scheduling and operations. The people involved appeared to be having trouble grappling with the problem. Logically, either these problems are non-existent, or if they do exist, the skill level in the Facilities Maintenance Department is significantly lower than would be expected at a university the size of Harvard. So, either the small professional school or the Facilities

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It is possible to eliminate other possibilities such as being overly influenced by a supplier (they went to a new company) or the decision maker choosing an easily understood system because he was about to retire (he is still there).

We should note, however, that direct digital control did not offer the Facilities Maintenance Department the same benefits as Harvard as a whole. For the Facilities Maintenance Department, the principal advantage of a computer system was that it saved maintenance people from perpetually opening and closing valves in buildings. The Staefa did that admirably. They had spent a lot of time getting the Delta 2500 on-line in 1975, and probably weren't looking for more trouble. In this sense, proposition 4 (incentives) could explain this behavior better. However, the interviews indicate fairly clearly that direct digital control wasn't even considered at the time.
Maintenance Department (or possibly both) does not have the skills to deal with this problem. We see something similar in the Biochemistry building in the Faculty of Arts and Sciences (C5a1). There, the school wanted to install a direct digital control system, but was reticent about giving the Facilities Maintenance Department responsibility for the programming. They feared it lacked the necessary skills. They would rather contract that out, even though, in theory, a contractor cannot optimize the system nearly as well.\(^\text{14}\)

We would expect a similar thing to happen with the design and construction of new buildings. Here, however, the evidence is more ambiguous, as we would expect this with a decision involving a lot more intra-organizational interaction and greater possibilities for importing skills. An architect who has worked with both universities suggested that MIT is much easier to deal with, and has a much better idea of what it wants, one test of skill. MIT certainly puts a lot of emphasis on having project managers who have a broad view of the technical problems; generally the Director or Associate Director of Physical Plant, or someone equivalent (B3c2). However, with two very strong qualifications, it appears that MIT buildings are not as good as those at Harvard. The first qualification is that since MIT is so much more energy intensive, any problems are likely to be magnified. The second, and probably more important, is that as an MIT student I hear more about the MIT’s problems than Harvard’s. Notwithstanding, there are complaints of a building which gets wet on every floor if it rains, (Chemistry). This building also has fume-hood exhaust fans that require the maintenance personnel to work in a potentially dangerous environment. Another has air

\(^{14}\) Through very sensitive operations, risk taking, and lots of ‘playing’, MIT used the facilities control system to reduce energy consumption for the campus by about 10% between 1985 and 1987. A contractor is likely to be much more risk averse, and is much more likely to program the computer, bring it on-line, and walk away than take time to fine-tune it. Also, a contractor is likely deal only with individual buildings’ systems, not the whole system including the steam plant. Again, savings will be lost.
inlets in front of loading bays, fume-hood exhausts, and bus stops (so fumes are sucked into the buildings) (Electrical Engineering and Computer Science). In addition, the Physical Plant Department staff talk of battles with architects over whether windows should be openable, or whether a new building should have pneumatic or direct digital control (when the rest of the campus is direct digital control) (B3c3).

It seems that MIT, for various reasons, is not very good at selecting architects who will design operable buildings. A footnote to Chapter two suggested that the 'modern' architecture school tends to de-emphasize building functionality. It also appears that MIT likes 'modern' architects, for various reasons. Until recently, MIT's architect selection was highly centralized. The decision was made by the senior administration and one or two staff (as opposed to being made by a committee now and at other universities). The Physical Plant Department could not influence this part of the process. However, I might add that some of the buildings at MIT which were designed by engineering/architecture firms are not terribly successful either. This contradicts the analysis.

At Harvard we appear to see the opposite. There, it seems that they are much more capable of putting flexibility into the architecture selection process (C2b4c). The caveat I place on that is that donors, and the faculty they sponsor, tend to be very influential in selection. However, within those constraints, Harvard appears to be more creative. For example, the Sackler Museum had two architects. James Stirling designed the visible parts and a local firm designed the services. This appeared to be an innovative way of having an international architect and well designed services. While it was an innovative solution, it appears (though ambiguously from the interviews) that

15 It appears that as a technological 'leader', MIT wants its buildings to be at the architectural 'cutting edge'. Note, however, that an alternative, and equally valid, desire would be to have buildings at the technological frontier of "user friendliness", energy efficiency and ease of operation.
Harvard had a lot of trouble managing the project. The reader should note that coordinating and dealing with two architects on the one building is probably a management problem an order of magnitude more difficult than dealing with one! This would appear to indicate a skills problem in the Faculty of Arts and Sciences. This is not so much in managing the project but in setting up a project they couldn’t manage.

Similarly, Canaday Hall was either an ill-conceived experiment in low-cost construction or a poorly managed project (depending on who you ask) (C2b8c). Either way, Harvard made a fairly expensive mistake with that facility. It would be reasonable to conclude that in some way, mistakes like this come from skills deficiencies. Note however, that Canaday Hall is very good compared to some of the dormitories at Tufts (E-7) and The University of Massachusetts at Amherst, (D-4b1). They, however, are resource constrained.

Finally I will exemplify this skill deficiency problem by considering critically the highly successful energy conservation initiative in the Faculty of Arts and Sciences. In particular, I would like to contrast it to what preceded it and what happened in the other schools. Before the major energy conservation initiative, energy management in the Faculty of Arts and Sciences is generally acknowledged to have been extremely poor (C2a1). Not only did the initiatives not save very much energy, but they had also embarrassed the Dean and disenchanted most people involved. Also, it is generally agreed that the Faculty of Arts and Sciences approached the problem poorly. Clearly it had insufficient skills to deal with the problem. It was only when Professor Poole, a professional engineer and member of the Applied Sciences faculty, presented a solution that the initiative began (C2a1). The administrative officer for his department, had a PhD in Engineering. The significance of Poole being a member of the faculty will be discussed under proposition seven. However, note that the Faculty of Arts and Sciences

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16 Peter Dixon (He was later promoted to Assistant Dean)
possessed these skills by virtue of its academic mission, not its administrative structure, and therefore they were skills that the other schools did not have.

Hence, it is no surprise that energy management in the other schools has not been nearly as good as in the Faculty of Arts and Sciences (C7). From what I understand, the Medical, Government, Dental and Business schools have done very little. Public Health has recently gone completely to a shared savings contract. Design has been reasonably successful, and Education and Law have done only things that are either very simple or in response to the Faculty of Arts and Sciences initiative, particularly to do with Summer Steam. It would appear that one of the principal things that differentiates the Faculty of Arts and Sciences from the other faculties is the possession of an Applied Science department.

Proposition 3c: Decentralization Increases Administrative Costs

Consider the organization needed to run Harvard. The Facilities Maintenance Department has people who do maintenance, and people who run the energy management system. There are people who supervise them and others who, in turn, manage them. In addition, there are people who read meters, aggregate readings, make bills, send them out and process the internal transfers. There are people who negotiate the budgets with the schools, and people who negotiate the operations and maintenance programs. The schools have a mirror organization. In all the schools that use the Facilities Maintenance Department there are people who supervise the Facilities Maintenance Department mechanics (generally called superintendents) independent of Facilities Maintenance Department supervision. Also, there is a facilities office of some description that must negotiate budgets and works programs with the Facilities Maintenance Department. That office needs technical expertise; it must either purchase

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17 Of course, some people have multiple responsibilities
from consultants o- develop in-house. In addition, the Faculty of Arts and Sciences, because it wants to decentralize further, has a series of energy monitors. Over the top of this, there are people in the central administration who have to coordinate these interactions to make sure things happen smoothly.

In contrast, at MIT, things are much simpler. The people in shops who do the operations and maintenance work are supervised and managed. One group operates the facilities control system while another operates the central plant. An engineering and architectural department provide advice. Finally, there are people who deal with finances and people who manage contracts.

Clearly Harvard's structure is more complicated and more susceptible to repetition of responsibilities than MIT's. There is some suggestion that the total number of people involved may be fewer. However, given the diversity of the people and the number of partial employees at Harvard, e.g. part-time energy monitors, it is very difficult to work out how many people to include in a head count. Similarly, the universities have significant differences in their self-defined tasks. For example, MIT must operate a large central plant, is more energy intensive, has extensive training and preventative maintenance programs, and has relatively limited contracting of maintenance and other tasks.

The technological systems show the same thing. Consider, once again, the energy management systems. MIT has a United Technologies system. It is well coordinated and was integrated with the system which preceded it (B2b). At Harvard, in contrast, the individual schools are purchasing direct digital control systems on a building by building basis. They feel that if the university goes with only one manufacturer that limits their choices and creates opportunities for monopoly pricing. Therefore, they want to purchase from any manufacturer they choose (C5a2). Unfortunately for the Facilities Maintenance Department, the schools also insist that their systems tie back into the
Facilities Maintenance Department main computer. Unfortunately, these interfaces are not easy to bring about. If the Facilities Maintenance Department had only to worry about one manufacturer it would be simple. They would just buy a main computer that matched. So, as a compromise the Facilities Maintenance Department has agreed to support three different protocols (C5a1.) While it is deciding what sort of main computer to purchase to support the system, they have a cumbersome set-up of telephones and modems connecting the building systems with the current main computer. When they do purchase a computer, the choices will be limited to the manufacturers who offer multiple interfaces. The computer will also cost more because the interfaces are proprietary, and therefore expensive.

This presents an interesting 'tragedy of the commons'. The individual schools derive all the benefits of making their own decisions, while the Facilities Maintenance Department absorbs all the externalities. It must be able to cater to the needs of all the different schools. Consequently, its job is much larger and more complicated than if the schools cooperated. Therefore its services are more expensive. This does not mean that in the long run this isn't better. That depends on the cost of the extra flexibility in the Facilities Maintenance Department compared to the savings the schools make. However, that calculus does not enter the schools' decision making. This complicated arrangement would not matter terribly much if Harvard were a small college, but as its size increases, so does the bureaucratization of its functions. This extra flexibility becomes more and more expensive.

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Irrespective of operations, they would need to do this if there were any sort of computer generated preventative maintenance program, in the manner being developed at The University of Massachusetts at Amherst.
PROPOSITION 3D: DECENTRALIZATION INHIBITS INFORMATION FLOWS

MIT and Harvard's differential responses to the Cambridge Electric rebate program shows starkly that decentralization inhibits information flows into the organization. MIT found out about the program within days of its April 1987 announcement (and eventually decided to participate) (B2d). Harvard is the utility's other major customer. I spoke with the Assistant Deans in charge of facilities at the two schools with least capital and skills, and therefore best use for such a program, (Divinity and Education) in September 1987 and April 1988 respectively. They had not heard of the program. So, clearly, there are blocks to information transfer within the university.

However, to make matters worse, when I discussed the program with a representative of the utility, he told me how, twelve months after it started and just before the initial finishing time (it was extended another twelve months), he had finally secured a meeting at Harvard, which he was hopeful of enlisting. The only problem was that while he thought he was going to see "the facilities people at Harvard", he was in fact going to see the engineering staff in the central administration. They play virtually no role in energy management. The same undoubtedly applies for other external suppliers. They would be quite justified in thinking that if they have spoken to one person at Harvard, then they have spoken to Harvard. They would also be wrong, and whoever they have not spoken to would miss out.

Not only are the schools quite separate, but they receive individualized services from the Facilities Maintenance Department. Three managers act as liaisons for three geographic regions of the campus. Each has his or her 'favorite' suppliers. Why shouldn't a supplier working through the Facilities Maintenance Department think that she has access to all of Harvard, when in fact she has access to a third of one campus?
There are also problems of internal information transfer. Consider the Faculty of Arts and Sciences retrofit program in the early 1980s. The program was very unpopular with the other schools (the Law School in particular) in part because it forced up the price of Summer steam, dramatically, at least a year after the program began. While they understood that the program was going on, they didn't appreciate the implications for them (C2a2d). This important information took a long time to cross the campus. Similarly, the other schools have not realized the savings that the Faculty of Arts and Sciences made by retrofitting lighting. This internal transfer problem is discussed at length in Appendix C.

**PROPOSITION 3E: DECENTRALIZATION AFFECTS SMALL UNITS ADVERSELY**

This proposition is best tested by comparing the Faculty of Arts and Sciences with the small professional school. We would expect to see the Faculty of Arts and Sciences with more specialist skills than the small professional school. In addition, we would expect the Facilities Maintenance Department to direct its services overwhelmingly to the Faculty of Arts and Sciences. The interviews bear out both of these predictions, though towards the end of 1987 the Facilities Maintenance Department was aware of this, and was trying to change its services to be less biased.

The skills differential between the schools' follows from proposition one. Therefore, it should be no surprise to the reader that one small professional school refused to participate in the study. The administration felt it knew so little about the problem that the study could be threatening (Not in appendix). Similarly, in the small professional school studied there was a long history of uncertainty. Again, not surprisingly and through absolutely no fault of his own, the Director of Administration thought that more energy conservation meant lower temperatures and less light, much as

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19 For example all the external light 'poles' at the Business School are incandescent, when compact fluorescents would do the job just as well at much lower cost.
Dean Nankin had fifteen years earlier. The school cannot afford the staff that would enable it to think otherwise (C3b). Given this, it is no surprise there is no ongoing energy conservation program in the school.

Using its market power, the Faculty of Arts and Sciences has managed to get Facilities Maintenance Department services that match its requirements. The Facilities Maintenance Department staff are quite open about this. As one interviewee said:

"The F.A.S. drives the organization and staffing. If the F.A.S. doesn't need a coordinator, we don't do it." 20

Later, the same interviewee discussed the problem of providing technical input into design review for new buildings. A week earlier they had discussed it with Faculty of Arts and Sciences staff, who were keen to have Facilities Maintenance Department input. However, when told of the cost, the Faculty of Arts and Sciences staff baulked and decided they could probably obtain a better service with in-house resources. This was unresolved at completion of the study.

Furthermore, the Faculty of Arts and Sciences is large enough to support its own technical staff. Therefore it asks for little technical assistance from the Facilities Maintenance Department (C1b1). Without the Faculty of Arts and Sciences as a client, the Facilities Maintenance Department cannot justify technical services to meet the needs of the smaller schools. That is, the technical resources you would expect for find in the Facilities Maintenance Department are in the Faculty of Arts and Sciences, and are inaccessible to the other schools. To overcome this problem, the new Facilities Maintenance Department director, who started just before the interviews took place, wanted to negotiate an explicit services contract with the individual schools. They would pay fees for those services. That way, the Facilities Maintenance Department

20 Thomas Risbey
could justify aggregating those wishes and increasing the technical staff, or whatever. It had not yet been implemented, so people were unsure how well it was going to work.

If we compare the Housing Office to the rest of MIT, we see the same thing. The housing officers I interviewed were unaware of many of the technological options they had available to reduce costs, particularly with lighting (B-4a, B-4b). This is most unfortunate because while the Physical Plant Department feels it cannot intervene in areas like dormitory room lighting, the house managers appeared quite willing to do so. Similarly, the MIT building services superintendent was quite explicit about being less vigilant about building envelope problems in the dormitories since they weren't his responsibility.

INCENTIVES

In the first half of this chapter I suggested that everyone affected by an energy conservation project must be incorporated through the use of power or incentives. The university's accounting system leads to a distribution of incentives which are not necessarily the same as that of the university as a whole. Consequently, the energy management organization also has an incentive structure which is not the same as that for the university as a whole.

It follows that:

4a An energy management organization will respond to its preference function, not that of the organization as a whole.

A specific example of this is the relationship between capital and operations budgeting. As discussed in Chapter two, some of the most effective energy conservation, and some of the cheapest, occurs during capital construction. Therefore, it is important that the funder of capital programs has a marginal incentive equal to that faced by the university. Often capital budgets are concentrated while operating costs are
distributed (through the use of uniform overhead policies). This leads to tragedies of the commons. If people cooperatively conserved energy, they would see handsome returns. However, their marginal incentives are very low. Energy conservation incentives are blunted as decision making is centralized (proposition 3a).

There are two ways of overcoming this problem. The central administration can inject capital for investment specifically in savings programs like energy conservation. Alternatively, the organization can impose standards which ensure people consider the organization’s, rather than their own, when allocating capital. For example, it could require units to install all energy conservative technologies that had a rate of return of more than (say) 20% when carrying out works. However, as the discussion of the building redesign experiments in chapter two suggest, these opportunities may be hard to identify.

So I propose:

4b In any organization where the accounting system gives weaker incentives for capital investment than for operations, energy conservation will suffer, unless the university creates mitigating standards.

EVIDENCE

PROPOSITION 4A: ACCOUNTING DISTORTS INCENTIVE FUNCTIONS

Consider The University of Massachusetts at Amherst and MIT. At The University of Massachusetts at Amherst the prejudice is explicit. The university only performs energy conservation projects that will increase its efficiency of operation or its quality of service. At MIT, it drops out of the capital allocation process.

In Appendix D, we see that The University of Massachusetts at Amherst’s incentive structure is motivated by several things, virtually none of which is saving
money (which is presumably the legislature's and therefore the university's incentive).\textsuperscript{21} It will use financial savings as a sweetener to attract capital from the state (D3d). Its objectives, however, include increasing the ease and flexibility of operation of the physical plant and therefore increasing user comfort, reducing maintenance needs, creating technical challenges for the professional staff, exploiting opportunities for the staff to increase their status, and satisfying moral concerns for the world's energy resources. It will also pursue energy conservation to save scarce resources such as people. So, for example, when the new energy management system (which is being installed to increase the quality of operations and maintenance by increasing control in addition to saving a lot of energy) comes on-line, they will drop temperatures from 76° - 80° to 72° (D6b1c). However, they will not go to the 68°, as required by law. They don't see it as being worth the fight.

At MIT, the process is much more subtle. The Superintendent of Operations allocates his annual capital budget by sitting down with his senior staff, none of whom has explicit responsibility for energy, and going through the major components of the buildings one by one to decide what needs doing. They place the resultant list of projects in order of priority and select the first 4%, which is about all the senior administration believes their current staff can manage (B3a3). Admittedly, some of those projects are explicitly for energy conservation. However, without energy conservation explicitly 'at the table' when the decisions are made, then, in the face of capital shortages and in a situation where the Physical Plant Department has no direct incentive to save money, there is no doubt that projects that make the plant easier to run will be favored. Similarly, projects which have dual benefits, part operational and part energy, are unlikely to be implemented unless the operational benefit alone justifies its

\textsuperscript{21} The Physical Plant Department has a very weak incentive because it fears legislative cutbacks in its utilities budget. By continually reducing its consumption, it can insulate itself.
place at the top of the list. The staff were not surprised when the Cambridge Electric
shared savings initiative offered about $1 400 000 in annual savings (B2d1).

The decision to spend the $1 150 000 windfall from the drop in oil prices on an
up-grade of the facilities control system was made at more senior level (B2b3).
However, MIT sees the computer as a facilities control system, and not an energy
management system, so the upgrade wouldn't have been justified on the basis of energy
conservation.

**Proposition 4b: Saving incentives for capital investment should be at least those
for operations**

Since this proposition is virtually self-evident, two examples will suffice. At
Tufts, researchers pay for energy in proportion to the floor area of their laboratories.
So, with about sixty laboratories, a given researcher can expect to pay less than 2% of
his marginal energy consumption. However, each researcher is responsible for his
laboratory's capital program (E2b1c).22 He must pay for new equipment, including new
fume hoods. Situations have arisen where laboratories were retrofitted, for safety
reasons, and the Physical Plant Department has wanted to install microcomputer
controllers on the hoods. However, the researchers have refused because these devices,
which cost $2 000, will only nett them about $20 annual savings. Unfortunately, the
university as a whole would save about $1 000 annually.

We can expect similar occurrences at The University of Massachusetts at Amherst
where the housing office pays a fixed proportion of the utilities bill (17.9%) but pays all
of its own capital costs (D4b).

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22 The only exception to this is when the university bears the cost of bringing in a
new senior faculty member.
EXTERNAL CONTRACTING

Coase (1937) argued that there are only two fundamental ways of constructing an economic exchange. He said you can have either a market or a hierarchy. The two are interchangeable. For example, a university could employ its own architects or it could purchase their services externally (as most do). Similarly, Tufts is increasingly purchasing maintenance services on contract rather than provide them as a direct physical plant function. Finally, all of the universities, at one time or another, have participated in shared savings, or third party financing, energy conservation initiatives. This contracting parallels Williamson's (1975, 1985) argument for transaction cost economics. Tufts believes it is cheaper, in the long run and given their current operating environment, to contract out these services than to perform them in-house. This contracting out does not overtly change the incentive structure anywhere in the university other than within the physical plant itself.

Three questions need consideration. 1) Is contracting cost effective in this instance? If so, why? 2) Why do the universities enter shared savings contracts when they are all big enough to develop the necessary expertise in-house and have good access to finance? 3) How does contracting, in the manner of Tufts, affect energy management both in a given time period and through time?

A university of a given size can afford to maintain only a certain quantity of skills. For example, only an exceptional university could sustain an office of architects. Similarly, there are institutional costs associated with the maintenance of particular skills. For example, labor is unionized in universities. Certain industries, like painting, have sufficiently simple technology that small external operations can exist, and not be unionized. These external operators are cheaper. In other areas, like environment rooms, the skills needed to maintain the equipment do not match the university's skill structure. Again it is cheaper to contract the work out as only one external service
person is needed where the university would have to provide two or three. Finally, there are institutional costs associated with overcoming the problems outlined in hypotheses 1 through 4.

So I propose (paralleling Williamson and Coase):

5 A university will contract out services when it lacks the resources to provide them or it is cheaper to do so than to provide them in-house. It will enter a shared-savings contract when the institutional costs obstructing internally managed energy conservation exceed the contractor's profit. 23

Finally, we turn to the impact on energy management of Tufts contracting HVAC maintenance. HVAC maintenance is different from the other functions generally contracted out (e.g. painting) because it is central to facilities operations. There is insufficient data in the cases to test any hypotheses I could make, so I will limit myself to some speculative comments. If these comments are correct, they could be incorporated into proposition 5. However, as comment three below suggests, there are also inter-temporal issues which would need to be addressed.

First, an energy management organization has a finite resource base. This consists of capital budgets, operating budgets, and professional and trades staff. The more that the university contracts out, the more it diminishes its resource base, and therefore, the less flexibility it has for effective energy conservation. So, we would expect this practice to change the skills base of the university from people who are expert in maintenance and operations to people who are expert in contract administration. Simultaneously, those people who are charged with energy conservation will have very limited resources to work with. This organization is less likely to be able to carry out effective energy conservation.

23 MIT and Harvard had to use a shared-savings contractor to participate in the Cambridge Electric rebate program. To incorporate this, we have to modify the proposition to include the extra benefit of the shared-savings rebate program.
Second, the university's capital stock is divided into two parts; that under a maintenance contract and that not. While the comments above apply most to the equipment not under contract, it is virtually impossible to do any energy conservation work on equipment that is under contract, short of complete replacement by retrofit, as that would violate the contract. Similarly, it is very difficult to negotiate energy consciousness into the maintenance contract itself, unless it is also a shared savings contract. This is obviously an impediment to energy conservation.

Third and finally, we must consider the effects of such an approach over time. As I see it, there are two. The first is that the institution fails to learn about its resource base. Therefore, any systems oriented improvements over time are much more difficult to achieve. Similarly, it is much harder for it to gather information about the equipment it has to see where improvements can be made. The second is that the organization de-legitimates itself on the campus by turning from an operation and maintenance organization to a contract administrator. This diminishes its standing and competence to negotiate with other groups about issues like new facilities.

Please note that while these three comments are critical of the contracting practice, I am not saying that overall it is not beneficial to the university. Contrasting these problems is the real difficulty small universities have aggregating skills (proposition 1). Therefore, at some size it is presumably more efficient to buy in specialist external skills and pay for the service and suffer the other efficiency losses. It is impossible to tell if Tufts is below that size.
EVIDENCE

PROPOSITION 5: EXTERNAL CONTRACTING MAY BE COST EFFECTIVE. SHARED SAVINGS CONTRACTS GET AROUND INSTITUTIONAL CONSTRAINTS.

In many ways, the first part of this proposition is self-evident. We see that the different universities contract out different services. The principal motivations are often either cost or skill deficiencies. So, all of the universities contract out the servicing of their environmental rooms. Similarly, Harvard laid off its structural trades when its unionized labor could not compete with non-union labor elsewhere (C4b). Harvard’s decision to contract out steam supply was not studied in depth, so we can not see if it accords with the proposition.

However, the second part is much more interesting. With the exception of architecture, all of the universities studied are big enough to manage virtually any technical problem that arises. However, we see them taking out contracts that from the outside appear to be irrational. This seems to be a clear confirmation of the core argument. It appears that the organizational structures are putting up barriers in power, resources, information or skills which make it easier to purchase these services than to supply them.

If we ignore the rebate aspect of the retrofit initiative, there is no reason why MIT should be participating in the Cambridge Electric program (B2d). It easily has the skills and financial resources to do the work in-house (B2b2b). The task is easily large enough to take on an extra staff member, or hire consultants, to do the analysis. Instead, MIT takes on expense by forfeiting the contractor’s profit. However, the effort required to procure the resources appears to be very high (C.f. Pfeffer 1978). Many

It is interesting to note that the reason non-union painters can out-compete union painters is because the nature of their ‘technology’ being very simple and very localized is such that the non-union painters derive no ‘home ground’ advantage in terms of skills, coordination, learning, or availability in emergencies.
interviewees talked of difficulties simply raising funds, and of simply not bothering to go for funds for small projects. Staff would presumably be an order of magnitude harder to procure.

Similarly, The University of Massachusetts at Amherst enters shared savings programs which are the most expensive possible option for capital works, as far as the state is concerned (D3a2). The University is starved of capital and can only influence the legislature in unusual circumstances (such as a potential disaster if the South West steam line failed) (D3a). This is a way of raising money. Furthermore, because the state often takes several years to process and approve capital requests, the cost of entering the shared savings contract is often less than that of deferring the works.

Finally, since Tufts needs several HVAC maintenance mechanics, it seems unlikely that it is cheaper for it to contract, though it is possible (C2b2b). A much more plausible explanation is that Tufts has trouble keeping staff. Given that none of the other universities appear to have this problem, the problem appears not to be at the industry level. Similarly, there appears to be nothing extraordinary about Tufts' organizational structure or staff responsibilities, so we can eliminate the organizational level. Therefore, it would seem that the problem lies at the personal level, possibly in personalities or management styles.

USERS

Users may participate in energy management either by helping determine the solutions pursued or participating in the solutions' implementation. Every management choice has both a technological and a participatory component. Interestingly, virtually all of the energy conservation literature ignores the participatory elements and discounts approaches that do not have very small participatory aspects (e.g. Vine 1987). That is, it is seen as a purely technological problem.
Participation in finding solutions generally requires a reason to participate, such as an incentive. If users do not participate, solutions with which require them are effectively excluded from discourse. It is not clear that users should always have a say in management choices. For example, we may be interested in standardization that may cost the user more in the short run.

Similarly, different solutions require more or less user participation for implementation. For example, users are involved deeply if buildings are closed late at night or for the month of January, or if lights are switched off manually. Conversely, motor retrofits, control system installations, etc. involve only minor disruptions.

In terms of our five bounds of decision making; information, incentives, power, skills, and resources, users have three important characteristics. First, they possess all the contextual information about equipment and the possibilities for equipment use and change. From the equipment flows sizing and operation of the infrastructure (given a control system). Second, many energy conservation works can disrupt their work space. Changes in infrastructure (e.g. motor changes) can prevent work from going on. Changes in equipment (e.g. fume hood overhauls) can disrupt the space. If, as is often the case, users are more powerful than the energy managers, their cooperation needs to be enlisted. Third, they generally have very poor access to both technical information and information about things going on in physically or organizationally connected spaces.

If users are not incorporated sufficiently along all five dimensions, we expect very conservative decision making. Energy managers selecting lighting without relevant contextual information will be conservative. They can't afford to make mistakes. Users who lack incentives will discount operating costs in their decision making. Why should an academic buy an energy-efficient laboratory freezer? Similarly, students will use the cheapest possible light bulbs in their desk lamps. Office staff leave computers on all day because of a myth that turning them off can damage the hard drive. We cannot
incorporate users completely with incentives. They lack technical and other information. We cannot avoid them completely. Their cooperation and support is needed for effective decision making.

Therefore, we expect the way users are incorporated into the energy management organization, as decision makers or recipients, commissioners or commissionees, will have a big impact on the management of equipment and infrastructure. However, for operations at least, control technology is, to an extent, a substitute for users. Therefore, we need to focus on the interplay between users and the way they are incorporated into the energy management organization, the control system, and technology (equipment and infrastructure).

Consider control. An organization uninterested in conservation will never turn off the lights. Similarly, until 1973 (1988 at The University of Massachusetts at Amherst) the universities turned the heat on in October and off in May. Perrow (1968) suggests that an organization will simplify the task as much as possible. This achieves that. Such an energy management organization would be very simple. It would contain only the middle ring of maintenance personnel. The core would be unnecessary (without energy conservation there is no need for specialists) and the outer ring (users) could act as it chose. An organization which chooses to conserve constructs it energy management organization in part when it makes choices about provision and control. Services can be provided centrally or locally. People or machines can make control decisions. This yields four possible combinations; central provision and human control, central provision with automatic control, local provision and human control, and local provision with automatic control. The nature of the control technology with its economic and institutional price, reliability, flexibility, and so forth, is central to the choice of the best combination.
Central provision with human control requires people to telephone a central energy provider and ask for light. Lights are then turned on for a negotiated period of time, after which they go off. By automating the control, using computerized switches and regular schedules, this process can be simplified. However, the organization is still relatively complex and communications intensive. The third option involves placing a switch in each room. Here, the communications required for service provision are much more simple; the user simply has to be taught how to flick the switch. However, the communications for conservation are much more complicated. Persuading people to turn off the lights involves an extensive organization. The final option involves the use of sophisticated local technologies such as motion sensors, light detectors, and timers. Now, the communications required to turn on and off the lights are extremely simple. The user turns the lights on and they turn themselves off. Consequently, the outer ring of the organization can be ignored since user participation is no longer needed.

Again, using Perrow's argument, we would expect organizations to go to automated local control as much as possible. By far the most attractive are the photo sensor and the motion sensor. They are automatic and silent. Timers are a second-best alternative. They are cheaper, have been around longer, and are conceptually much simpler but are more obtrusive. Several of the case study universities attempted to install these devices. MIT put timers on ventilation and lights. Similarly, Harvard put timers on ventilation and lights, and attempted to install motion sensors. However, this was very disruptive. For example Harvard needed three attempts to install one motion sensor (C-2b2). MIT removed most of its timers because they ticked. When they were in place they would disrupt classes if the time (and therefore the lights) ran out in the

26 While this seems unrealistic for light, it is in fact how heat is provided. The difference between light and heat stems from the underlying technology. There is a time lag associated with heat provision, and it requires much more control of the infrastructure, generally back to a central plant.

26 While this is simple for a light-switch, it is not necessarily for a thermostat.
middle of a session (C-5b1). Only recently (1987/88) did motion sensors become cheap and reliable enough to warrant reconsideration. The universities are starting to install them.

However, it is insufficient to say that users need to be incorporated. There are three ways of doing that. Users can be compelled through the imposition of standards. They can be given an economic incentive, or they can be asked to co-operate in a cause that is assumed to be worthwhile (Paralleling the types of incentives above). Different universities use different devices at different times. In this section, we will limit ourselves to looking at the effect of different modes of incorporating users in operations. We will consider the broader questions of balancing the organizational bounds in chapter five.

We can make three propositions:

6a Incorporation of user through use of standards (coercion) is effective, though difficult to accomplish as it requires overt use of power.

6b Incorporation of users through economic incentives is effective, though administratively expensive.

6c Incorporation of users by persuasion is both time consuming and of limited effectiveness.

EVIDENCE

PROPOSITION 6A: COERCION IS EFFECTIVE THOUGH HARD TO ACCOMPLISH

The first part of the proposition is self-evident. So long as an organization can enforce a rigid standard, it will be effective. If it cannot maintain the standard, then the policy won't work.

There are four areas where coercion is commonly used:

* Regulation of times (scheduling control)
* Regulation of temperatures (the amount of heat)
* Regulation of the amount of light
* Regulation of construction features.

Regulation of construction is needed only if the user has significant control over construction. So, for example, under proposition 4b we considered the problem of an experimenter who wishes to upgrade his laboratory and has to pay for it out of his own budget.

Harvard is the only university of the four that is willing to place scheduling control on users. For example, the Faculty of Arts and Sciences reduced the hours of service in the William James building, despite an uproar from the faculty (C2b8b). Clearly, a lot of administrative pressure was needed to make the policy effective. Similarly, the Faculty of Arts and Sciences religiously sets back temperatures in the dormitories, despite the fact that this involves a lot of work by maintenance operators whenever students complain (C2b5).

As a contrast, consider temperature control at The University of Massachusetts at Amherst. Here, the Physical Plant Department has extremely little control over the faculty, staff, and students. Therefore, it is no surprise that the campus tends to be heated to about 76° - 80° for the entire Winter, and that the Physical Plant Department can do little to reduce it (D6b1b). After they bring the energy management system online, they hope to drop the temperature to 72° (D6b1c) bringing them much closer to the legally required 68°.

It appears from the interviews that the temperature in the laboratories at The University of Massachusetts at Amherst are as poorly controlled as the rest of the university. Therefore, it is interesting that while the faculty at MIT and Harvard can
demand laboratories at 68° all year around, those at The University of Massachusetts at Amherst are satisfied with much higher variations.

PROPOSITION 6B: INCENTIVES ARE EFFECTIVE THOUGH EXPENSIVE

The big problem with the use of incentives is that they often require metering. Metering is difficult and expensive. There are three examples of the use of incentives in the case studies. Two are the inter-dormitory competitions at MIT and Harvard. The third is the movement to internal 'shared savings' at Harvard. The first two illustrate the proposition. Discussion of the third will be deferred until chapter five.

The inter-dormitory competitions at MIT and Harvard were not terribly successful (B2a2, C2a4). The one at Harvard was carried out principally to attract people's attention to energy conservation, and to try to modify their behavior (C2a4). However as one interviewee said:

"Those ended up not being terribly successful, basically because of a lot of the accounting and the metering of it. ... The meter's shared between the house and the dining hall, so who gets credit, so that didn't work out as well as it might as an incentive to the students, but there's lots of information shared. People know what energy their building's used, and a fair amount of them pay attention to it." 27

Generally, metering problems are brought up as soon as any incentive based system is mentioned. At The University of Massachusetts at Amherst the possibility of metering carries with it additional political implications about cost allocations to users (D-2b2e).

27 Thomas Risbey (who worked with the Faculty of Arts and Sciences at the time of the energy conservation initiative.)
PROPOSITION 6C: PERSUASION IS BOTH TIME CONSUMING AND OF LIMITED EFFECTIVENESS

The veracity of this proposition is demonstrated by the paucity of out-reach programs in the case study universities. I came across one person in the cases who was doing anything in this area for its own sake; an engineer at The University of Massachusetts at Amherst had included in a specification a requirement that the contractor put stickers on lights and thermostats (C2b3). Everyone else I spoke to felt that out-reach programs were a waste of time in the current environment.

However, out-reach is often used as a mechanism to enforce standards. For example, Susan Hill at Harvard spent a lot of time explaining why there would be no cooling for a handful of people in a building (C6c). Similarly, the Facilities Maintenance Department operators spend time showing students how to keep their rooms warm and explaining the set-back policy to them (C2b5).

It is interesting however that at Stanford and U.C. Berkeley, where generic energy consciousness is higher, there are very active and creative outreach programs. Neither campus had any idea how effective the program was, since it is immeasurable, but their overall feeling was that it was worth it. I had the impression that the outreach program was very important to legitimate the rest of the work they were doing and was an attempt to foster an energy-conservative culture on the campus.

DISCUSSION

The argument I have set out above is that decision making is bounded in five dimensions; information, skills, resources, incentives, and power. If we characterize both the various solutions and the organization along these five dimensions and neglect risk taking, we would expect the organization to only be able to consider solutions whose characteristics fall within the envelope described by the organizational bounds inscribed
by these five variables. Organizational risk taking is the selection of solutions outside the bounds.

We can classify the solutions within the dichotomy we created earlier. Infrastructural solutions tend to require little input from users but often require detailed technical information, high technical skills and (sometimes) large amounts of capital. Therefore, they are more common in organizations which have good access to technical information and the skills and large amounts of capital; centralized organizations with low delegation. Conversely, equipment modification and change and localized control requires large amounts of highly contextual information, low skills, and often little marginal capital. Therefore, we expect an emphasis on equipment in organizations which provide incentives to users; decentralized organizations with high delegation.

In as far as these bounds are determined by the organization's structure, we would expect the structure to be a predictor of both the variety of options the organization can choose from and the actual decisions taken. If the sub-unit responsible for the management of a secondary objective is in a peripheral position, these bounds are very constrictive. This is because any structural change which increases an organization's capability along a particular dimension penalizes it in another. For example, decentralization increases incentives and contextual information but decreases skills and access to technical information. Delegation increases access to capital but simultaneously fragments the decision making process by isolating subgroups in the organization. As as result, the organization will tend to select orthogonal solutions which reproduce the prior structure.

It is worth noting that an organization lacking both skills and technical information could easily delude itself that it was managing energy very well, even if it wasn’t. It has no way of knowing that it is not considering a multitude of viable solutions. Conversely, an organization which has a lot of skills and information but
which lacks resources could think it is doing very poorly, even though it is objectively in the same position.

It is easy to imagine a situation where the bounds become so constrictive that there are no viable solutions within the envelope of possibilities created by the organization. If this occurs, then the organization fails. The failure can be dramatic if the contingency becomes critical to organizational survival. We will explore the implications of this in the next chapter.

As the input/output becomes more transformative we expect all the bounds to expand, and hence more varied solutions to be considered. For example, we will look at energy conservation in new buildings in chapter five. There we will see that the bounds do not create the principal restriction on decision making.

We might expect consistency among the bounds within industries. For example, very large corporations are unlikely to face an external resource constraint as they can finance many of their projects internally. Conversely, the power dynamics within the corporation may be very important (Jackall 1988). In contrast, family-run electroplaters will have good contextual knowledge of their processes but may know very little about their technical options. Hence, we may well be able to discern differences in behavior at the industry, organizational, and individual level, just as Miles and Snow (1979) have suggested that strategic action by organizations can also be viewed as a series of three overlays.

Finally, it is important to note the relationship I have specified between organizational structure, bounds, and decision making. I have described the structure as an intervening variable which creates obstructions to decision making. However, it is these obstructions which inhibit the decision making, not the structure. If the bounds can be overcome despite the structure, either because of individual action, clever senior
management, or changes in the external environment, the bounds can be overcome. That will be the third topic in chapter five.
CHAPTER 5. EXPLORING THE LIMITS

INTRODUCTION

All is not lost! Chapter four seems to suggest that all organizations are highly constrained in their management of secondary objectives. In chapter three we deduced the almost inevitable creation of a specialist office, which, we suggested in chapter four, led to crippling bounds which constrain the organization to solutions which are as much an adjunct of its technical system as the specialist office is an add-on to its social system. This is not necessarily the case. In this chapter we will explore the limits of the theory. This will comprise four parts.

In chapter one we noted that organizational objectives vary from secondary through to primary rather than being one or the other. However, we assumed the binary distinction when we looked at the way these objectives were translated into the organization's structure. There were transformative offices and peripheral offices, but nothing in between. The first of the four things we will look at, therefore, is what happens as we move from a very secondary objective in a highly peripheral office through to a primary objective in a transformative office.

Having set up an analytical structure, in chapters two and three, we examined its implications in chapter four. We argued that the structure creates bounds which constrain solutions. However, at the chapter's end we saw two limits to this. First, at one extreme, there is the possibility that virtually all viable decisions are within the organization's bounds. The problem of constructing new buildings on a campus is a good example of this, so this will be the second of the four things we examine. At the
Peter Cebon (1990)

other extreme, it is possible for the bounds to be so constraining that there are no viable solutions in the envelope described by the organization. We will look at what happens then, third.

Finally, we noted at the end of chapter four that the fact that the bounds are an intervening variable, as summarized in figure 5.1, creates one more very important possibility.

![Diagram: Organizational Objectives -> Organizational Structure -> Bounds -> Decisions]

**FIGURE 5.1 STRUCTURE OF THE ARGUMENT**

I have argued that organizations' choices in structure lead to the creation of bounds which affect decision making. However, it is the bounds which inhibit the decision making, not the structure. Therefore, while structure has a very strong tendency to dominate decision making, it does not have to. An organization which can manage its bounds despite its formal structure, generally through local modifications, can have both effective decision making and maintenance of a structure which reflects its objectives.

**RAISING THE IMPORTANCE OF SECONDARY OBJECTIVES**

As I said above, organizational objectives vary from secondary through primary. In accordance with our model, we expect the position of the input/output function to vary from peripheral through transformative. This is illustrated in figure 5.2
As we saw in chapter three, an input/output function in a peripheral position can be expected to buffer the organization from its institutional environment (after Thompson 1967). Lawrence and Lorsch (1965) posit that the role of an input/output function is to match the core of the organization and the institutional environment as well as possible. Transformative offices do this. Consistent with these two prescriptions, we expect the peripheral offices to produce predominantly orthogonal solutions to problems while transformative offices will attempt to produce aligned solutions where technically feasible. As an office moves from peripheral to transformative, we expect the probability of aligned solutions being adopted to increase. That is, we expect the chances of solutions which match the organization to the environment to increase relative to those which buffer it.

The theory we developed in chapter four suggests that the less peripheral an office becomes, the less constrained decision making is on four dimensions; resources, information, power, and skills. Key actors will become more powerful and more central to decision making, and therefore will have better access to resources. Because they perform a more important function, we expect them either to be defined as part of the core of the organization or to spend more time dealing with people in the core. Therefore, they are likely to have better access to contextual information. They are
likely to have more resources and therefore greater skills. They will be able to procure extra resources more easily. Incentives do not change automatically, however. Similarly, power over workers is likely to decrease as they will have control over a critical contingency (Hickson et al. 1971).

Therefore, depending on the technological possibilities, the movement from a peripheral to a transformative office is likely to correspond to an increase in the proportion of aligned (or superior orthogonal) solutions developed by the organization.

![Diagram of skills, resources, information, etc.]

**FIGURE 5.3 EFFECT OF CHANGE IN OBJECTIVES ON DECISION MAKING ABILITY**

**REDUCING PERIPHERALNESS IN PRACTICE**

In the above discussion, the movement of functions from peripheral to transformative is very abstract. It is worth considering what it means in practice. The two domains to explore are organizational process and organizational structure. In terms of process, we expect it to be accorded greater priority relative to other objectives. That
is, we expect it to figure more heavily in people's incentive structures for capital allocations and performance evaluation. (See Zmud and McLaughlin (1989) for a discussion, from a groups perspective, of the problems of managing organizational process for secondary objectives.)

In structure, the key distinction is whether or not the function is a line or a staff responsibility. As the function becomes more transformative, we expect it to move further and further into line decision making. Once in the line, we expect it to be defined as relevant to progressively more parts of the organization's activities. Eventually, it will encompass all truly relevant activities. That is, we expect the manager responsible for the objective to take on more and more of a coordinating role. There are three reasons for this. First, the more important a function is perceived to be, the more senior is likely to be the person responsible for it. Senior people are likely to be more trusted, more powerful, and more experienced (technically and politically). Second, as the importance of a function is raised, people are likely to realize that it is relevant to progressively more aspects of organizational life. For example, we will see that at The University of Massachusetts at Amherst, energy management was originally seen as a central office function. The new physical plant director saw it as intimately related to management of the physical plant. Consequently, the energy manager was moved to the Physical Plant Department (D-2b1). Related to the second point is a third, namely that aligned solutions, by definition, cut across organizational boundaries. If they stayed within a sub-unit, they would be orthogonal to the rest of the organization. We noted in chapter four that all technological change brings with it changes in social relations. Further, those changes in social relations often bring conflict with them. If that conflict appears as one organizational sub-unit imposing its will on another, the second sub-unit may well oppose it. That opposition is likely to be effective if authority does not rest with someone who coordinates the two activities.
The possibility of less structural coordination, through appeals by senior management and other informal devices, exists in all organizations. However, we expect these to be much less effective in highly bureaucratized or unionized institutions like state universities or in organizations where the divisions between groups are accentuated for other reasons, e.g. intense politics.

Reducing Peripheralness in Universities

In universities, with their three sub-organizations (faculty, administration, and operations), this process is a little more complicated. A change in the relative importance of an input/output function can be restricted to the physical plant functions, or it can involve the academic and administrative spheres.

If we restrict ourselves to the physical plant department of the university, the energy manager can be in a staff position, as at Tufts or MIT, or in a line position, as at The University of Massachusetts at Amherst. In either case it can be relative to a small part of the organization, such as operations at MIT (with senior management taking on responsibilities beyond the Physical Plant Department), or relative to the whole Physical Plant Department, such as at Tufts. Alternatively, responsibility can be moved right into the academic sphere, as at Harvard. However, in general;

7 As the energy management task becomes more transformative in nature, the energy manager position will span more parts of the organization. If energy management extends beyond the physical plant department, energy management will become more central to all capital allocation, promotions, and other incentives for users.

Evidence

We will look at the evidence two ways. First, we will examine the four campuses over time and see that there is a strong correlation between the types of energy conservation they were pursuing and the coordination devices in place. The dates below are extremely approximate. Then, we will look more closely at each site to see the way
in which coordination (and control) was essential to the success or failure of critical projects in the universities' energy conservation histories.\(^1\)

From about 1973 to 1976, the universities emphasized service reduction. They removed lamps, cut back temperatures, reduced service quality, and constrained schedules. These activities were generally very visible, often controversial, and affected the whole campus. The energy manager's technical task was one of extremely simple design, supervision of relatively unskilled labor, and persuasion of the campus to cooperate. The tasks made no serious demands and created no serious conflicts within the physical plant departments. However, the conflict with the rest of the university was severe. The universities which chose to confront users had the symbolic head of energy management in a very senior position.\(^2\) These included Harvard's Dean of Arts and Sciences and The University of Massachusetts at Amherst's Eric Hartley, a member of the central administration backed by a faculty and administrative committee (D-2b1). MIT kept the function within the Physical Plant Department and was extremely ginger about upsetting users (B-2D3). From the interviews it is very hard to work out what happened at Tufts. It appears the initiative came from the Physical Plant Department which, among other things, de-lamped in the Medical School and offended the faculty sufficiently to have the Physical Plant Department still scared of them fifteen years later.

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\(^1\) It is important to note that the data does not permit direct examination of the proposition. The data suggests that changes in the position of energy management in the structure corresponded to changes in coordination which in turn was correlated with changes in the nature of the solutions implemented. At two sites, Harvard and The University of Massachusetts at Amherst, the change in coordination was associated with a change in the relative importance of energy management as an organizational objective. At MIT and Tufts, it remained secondary. Note also that the correlation between coordination and solutions does not suggest causation (which is why this is not in chapter four). There is good reason to believe that the solutions were identified before people were placed in coordinating positions to implement them. However, this does not contradict the proposition.

\(^2\) The actual work may have been done by a more junior employee, however.
Peter Cebon (1990)

(E-2B1b). In all these cases, energy management came, symbolically at least, from senior management, or failed.

From about 1979 onward (after the second oil price rise) the universities took a different tack. In this stage they undertook selective retrofits of different buildings (MIT) (B-2C) or sets of buildings (Harvard) (C-2A2, C-3C1). The same thing happened when they carried out electricity retrofits in the late 1980's (B-2D)(D-3D1). In this case, the energy manager spent time carrying out or supervising reasonably complex designs and administering contracts with external parties. In this instance, the energy manager's role was one of attracting capital resources, carrying out or supervising relatively sophisticated design, and administering and supervising external contracts. We generally see the energy manager in a staff position in the physical plant department.

More recently, energy managers are looking at preventative maintenance and selective retrofits as mechanisms to facilitate cost minimization in the physical plant department. In this case, the energy manager, who is intimately concerned with the operation of the plant itself, is generally in a coordinating position, except at Harvard where it is a budget controlling position. Relevant actors are the superintendent of operations at MIT (B-2B), the Director of Physical Operations in the Faculty of Arts and Sciences or the Director of Fiscal and Administrative Services in the small professional school at Harvard (C-1B1), and Eric Hartley at The University of Massachusetts at Amherst who is responsible for all operations except custodial and grounds (D-2B).

We now look more closely coordinating roles at each site to see the way in which coordination (and control) was essential to the success or failure of critical projects in the universities' energy conservation histories.

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3 I use the term cost minimization, rather than energy conservation, because labor and capital cost control are included in the strategy.
Given its bureaucratization and the attendant problems that brings, we expect the greatest need for formal coordination for energy management at The University of Massachusetts at Amherst. There is considerable evidence in the interviews that this is the case. Consider for instance the problems bringing in the new work order system appeared to be engendering (D-6a). People at the university seemed very sensitive to the way in which the new system would change people's access to information. For energy, the university has overcome constraints by promoting the energy manager so he always controls all the resources he needs.

Eric Hartley joined The University of Massachusetts at Amherst in the central administration (D-2B1). There, he wrote grants, audited buildings, and carried out works. None of these really threatened existing interests. They were financed with grants in excess of annual appropriations and were performed under contract or using overtime. They included things like insulating buildings, changing lights, and installing heat timers (D-2B1). However, when Hartley started to make changes in areas beyond his control, acrimony developed between the administration and the Physical Plant Department. He moved to the Physical Plant Department and concentrated on projects well within his area (including the steam trap program and the resurrection of the central utilities plant). Although money for the energy management system was allocated in about 1986, the specification was not finished until the end of 1987 (D-6B2a).\footnote{One interviewee felt that the design should have taken only about three months.} The functions they planned for the system included running their operations and maintenance programs; operations that extend well beyond Hartley's original sphere of influence. They were also worried that the machine would be sabotaged as was the Supervisory Data System that preceded it. In the time it took to write the specification, Hartley was promoted progressively until he controlled all the staff affected directly by
the new technology (See quote in (D-6B2d)). When asked if he thought this was a coincidence, he said, "No ... Someone's done it that way. We've worked it out that way."

If we consider the energy conservation program in the Faculty of Arts and Sciences at Harvard, one of the things the interviewees emphasized repeatedly was the fact that Professor Poole was a senior faculty member. It appears that this was vital for faculty cooperation (C-2A4). Without their support, the program could not have been sustained. At all the other schools, (B-3A1 [footnote]) (D-2B1) (E-2B1c) for various reasons, people have not been prepared to intervene in offices and laboratories. It appears that at Harvard a facilities dean would not be able to do this without faculty support. Again, this suggests that the energy manager (Poole in this case) needed control (through the dean) over the actors (the other faculty) to make changes. The program represented a significant change in the power relations of the university. For the first time, it gave members of the administrative staff power over some of the faculty's activities.

The Faculty of Arts and Sciences initiative also precipitated the restructuring of the Buildings and Grounds Department into the Facilities Maintenance Department (C-4B). As such, this should be considered while discussing this hypothesis. Although this change was precipitated by questions of competence, attitudes and pricing, and not by a change in technology, the hypothesis is borne out. The change was initiated by the Vice President for Administration on his first day in office, clearly a controlling position, undoubtedly with the complicity of the President.

Third, we consider the installation of the facilities control system at MIT (B-2B). When installed, it almost failed, with sections of the Plant refusing to operate it. Quickly, the plant was completely restructured around the technology from a geographically oriented and locally based operation to a highly centralized one. Not surprisingly, the commissioning of the system was overseen intimately, and apparently
with the use of a lot of power, by the then director of the Physical Plant Department. Clearly, this supports the hypothesis.

At Tufts we see how lack of coordination led to failure. There, the energy manager has no supervisory responsibilities (E-2A). At Tufts, virtually all energy conservation initiatives that involve the staff of the Buildings and Grounds Section have been frustrated. This goes from big things, like the energy manager's and the shop supervisors' inability to persuade the senior management to increase staff to initiate a preventative maintenance program (E-2B2c), to small ones, such as not having heat recovery because it is labor intensive (E-2B1c). Similarly, the energy manager has had little support for his training initiative (E-2B1a). However, the reader should note two things. First, he feels that these problems go beyond his lack of influence; he also sees staff shortages as part of the problem. Second, in such a small and isolated case it is very difficult to separate the people from the positions. i.e. is the lack of influence a reflection of lack of ability or would anyone appropriate to the position have the same problems.\(^5\) Notwithstanding, his job is clearly frustrated by his lack of control over resources.

We can also see a contra-example at MIT. In the shared savings program of 1987/88, virtually the entire campus is being re-lamped except in the dormitory rooms (B-4A, B-4B) However, illumination levels are not being changed. (B-3A1 [foot]) This presents two examples of an organization shying away from this 'boundary-spanning' behavior. The administration is not prepared to intervene in the student's bedrooms in any way, even though it represents a potential saving of about $25 000 per year.\(^6\)

Similarly, by not discussing illumination levels with people, MIT is missing many

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\(^5\) Realize that the position is only capable of attracting a certain calibre of person.

\(^6\) 4000 students using 100 Watts for four hours per day, six days per week for thirty weeks at $0.10 per KWh = $30 000 per year. If they converted to fluorescent light, the cost would be about $3 000.
Peter Cebon (1990)

savings. Clearly, MIT doesn’t want to include the users any more than it absolutely has to, and is prepared to forego some savings instead.

LOOSE BOUNDS

In the vast majority of cases examined there is a tension between the five bounds of information, incentives, power, resources, and skills. That is, as we have seen, it is very difficult to get enough of each in one place at the one time to select good solutions to problems. However, these bounds are not always so constricting. All the cases we have examined so far have involved either retrofits of pre-existing plant and buildings, with the attendant need for highly contextual information and often skills and technical information, or the selection, maintenance, or replacement of very sophisticated infrastructure and computer systems, a highly skilled task needing resources and technical information.

New building construction is different. As we saw in chapter two, the selection and supervision of the architect is probably the most important variable in a building’s energy consumption. There, we found that architects who had had a brief introduction to energy conscious design produced much more energy efficient buildings with no increase in capital cost. Clearly, the two important elements for this are architect selection and architect supervision. Of these two, selection is clearly more important (assuming the architect is competent). However, the information someone needs to select an architect is fairly limited and readily available. No resources are needed for the actual selection. Low skills are required.

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7 Casual discussions with many users indicate they often feel their space is over-lit. Significantly, they often comment that this is a sign that MIT is profligate with energy, so the Physical Plant Department loses out in both respects.
In such a situation, a political model might be appropriate. We have already seen that new building design is important to the energy manager. However, it is also important to the donor, the head of the department building the building, the architect, and the senior administration. The central administration is interested in more than operations. It also wants buildings that symbolize the university, satisfy the donor, and don't cost too much to build. For the faculty, the building reflects their power and status and represents an opportunity to increase their academic productivity. The energy manager wants a building that is well designed, energy efficient and easy to maintain. In addition, there is the architect outside the system who's agenda may be slightly different from all three groups. In as far as these interests conflict, we expect conflict, and hence a political process.

In as far as the interests can be aligned, we expect movement towards economic rationality. For example, consider a new laboratory building. The donor, the architect, and the occupant of the building all have a large interest in the building being an attractive status symbol. They will oppose energy conservation if they perceive that will make their building look ugly. However, if the president of the university has recently taken an active interest in greenhouse warming and acid rain, and therefore is keen to see energy consumption reduced on the campus, the department chairman who wanted an attractive building is also going to solicit the energy manager's advice. If it turns out that the low energy building is going to be more comfortable and make it easier to control laboratory conditions accurately, the department head will be even more enthusiastic. Finally, if utility bills were charged directly to the building, instead of being included in overhead, the department chairman may take the energy manager to dinner.

So, the relative salience of energy management, or the other skills and unique information the energy manager can bring to the table (Hickson et al 1971, Hinings et al
1974), are likely to be major determinants of whether or not she is allowed to participate in architect selection, and how influential she will be in the decision.

Once the architect has been selected, the building has to be designed and constructed. It is customary for the design to be overseen by a committee of interested parties, generally people from the relevant academic departments, the physical plant department, the administration, and sometimes the principal donor.

The place of energy management in this process can vary from chairing the committee to non-participation. At MIT, the committee is often chaired by members of the Physical Plant Department with significant energy management experience. At Harvard, in the Faculty of Arts and Sciences, energy management had a place at the table in its own right until the new dean came into office. While, the same people sit on the committee at Harvard, they find they have less sway in decision-making compared to the faculty and that energy has suffered the greatest relative decline. At The University of Massachusetts at Amherst, the energy managers are actively involved, while at Tufts, the energy manager's participation went only as far as plan reviews. Finally, the Facilities Maintenance Department at Harvard (not surprisingly) has had very little input into building design and plan review.

Three factors seem to be determining how close the energy manager gets to the table. First, the importance of energy management as an organizational objective is an obvious determinant and needs no further elaboration. Second, energy management can come to the table on the coat-tails of another function. For example, MIT has started to emphasize operability of its buildings. Therefore, senior members of the Physical Plant Department are very active on construction committees. In as far as they have energy management experience, they bring it to the table. Finally, the energy manager's proximity to the table depends on her reputation. If the people on the committee feel that their buildings are managed by a group of incompetent fools, they will respond
differently to requests to if they are impressed by the fact that they don’t notice their buildings being run at all. That is, reputation is a measure of the alignment of the energy manager’s solutions and the perceived interests of the users. Therefore, the informal status of the energy manager, as measured by the effectiveness of the management of other functions associated with energy management such as physical plant operations, is likely to be the third determinant of her influence. Put differently, the energy management organization’s behavior in times of stasis is one of the determinants of its ability to influence change. Unfortunately, users are much more likely to notice when things go wrong than when they go right.

At The University of Massachusetts at Amherst the operations department has had more influence over design as its competence has increased, even though the entire process is internal to the Physical Plant Department. Before the operations division employed engineers to design the new energy management system, operations had virtually no input into the design process. Now, in addition to specifying, if not designing, the control systems for the new buildings, they have broad influence over the design of all operational aspects (D-6B2a).

To understand why participation in architect selection and supervision should matter, we have to explore two aspects of the building design process. First, we should see how the committee works. From interviews at all four sites it appears that the design process begins with everyone presenting the architect with a wish list of building features. The architect goes away and produces an initial design which is almost invariably over budget. At this point, either the relatively finite pool of financial, temporal, and spatial resources are expanded, or elements of the building are slashed. Expansion requires fund-raising skills or ingenuity. Ingenuity implies the ability to secure grants or modify the design to reduce lifecycle cost and persuade the university to take out loans to cover the financial expansion. Similarly, energy efficient buildings
tend to have a smaller plant than less efficient ones and therefore increase the physical space. However, slashing is the norm. Given that the process is framed as a distributive loss rather than an integrative gain (Walton and McKersie 1965), it is no surprise that the features removed depend on relative political strength. Furthermore, it should be no surprise that the invisible energy-efficient infrastructure is among the first things to go.

After the design is reasonably complete, it is often sent out to various interested parties for comment. Just as the future of an organization is determined largely by the events and interactions that occur as it is framed, it is at the (structural) framing stage that a building's characteristics are determined. By the time an energy manager reviews a design, only minor changes will be possible. The energy manager will face both the real boundaries of budget and bricks presented on the plans, and the cognitive boundaries in the minds of the architect and other parties to the construction.

Consequently, the energy manager's input is limited by her formal and informal power. If formal power is limited, informal power is needed. To gain informal power, she must appear competent to both the senior administration and to the users who end up on building committees. This implies that the operations and maintenance of the campus have to be both at a higher standard than cursory analysis would suggest, and visibly at that higher standard.\(^8\) If all the major decision makers are senior administrators, the need to appease users is reduced somewhat. However, senior management are also users. They are undoubtedly the recipients of many of the more significant complaints. The performance measures they use include maintenance costs. So, again, influencing senior management probably requires high quality and visible operations and maintenance.

\(^8\) This does not mean all users' desires should be satisfied. Rather, I am arguing that their every desire for operations and maintenance should be satisfied and that they should be aware of the difficulties that are being encountered.
For new buildings there is a vicious cycle. It is the energy manager's influence that gives her the standing to bring about changes in design that will make the building cheaper and easier to operate. If the building is easy and cheap to operate, the job will be easier. This in turn will increase the energy manager's influence, and so the cycle will go on.

**Tight Bounds**

At the other end of the spectrum, the bounds may be so constrictive as to envelop no solutions. This is most likely in organizations which are either poor or which have made the relevant office highly peripheral. In both cases, the relevant office is likely to face shortages of resources and skills. Therefore, the bounds are likely to be very constrictive. In the limit, when the problem is too difficult for the office, there will be no viable solutions. At this point, the organization fails. It now has two choices. Either it can go out of business, or it can solve the problem. Since the input/output office spans between the core of the organization and its environment, some of the options lie in the environment, while others lie within the organization. Those in the environment involve changing the problem or the bounds. Those in the organization involve changing the bounds.

If the organization is very powerful, it may seek to change the environment. For example, in the face of emissions controls which they felt they could not meet (but

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9 It is important to emphasize two things. First, I am not suggesting that well endowed organizations are free from this problem, just that poorer ones are more susceptible. Second, the invisibility of a feasible solution does not mean that there is no one in the organization who is aware of it. It means that that solution is not included inside the bounds constraining the peripheral office. For example, many organizations have found that some production problems disappear when workers are involved in decision making. In as far as the workers were aware of both the problem and solution before they were asked, the solution was in the organization. However, management practice excluded it from discourse and hence consideration.
which the Japanese and the Germans could), U.S. automobile manufacturers successfully sued the E.P.A. to stall and weaken regulations (U.S.A. 1973). If the problem is unchangeable, the organization may reach into the environment to relax critical bounds. For example, consultants could be brought in to provide skills and technical information.\textsuperscript{10}

Alternatively, the organization may look inwardly to solve the problem. If the problem cannot rise up and threaten the organization’s survival within its planning horizon, it may ignore it. So, for example, high energy prices may simply mean that production costs rise. Those increases in prices can be passed on to the customer. Shortages of energy, on the other hand, may represent a critical contingency. Production itself will be threatened. In the latter case, a solution must be found.

The difficulty an organization has finding a problem will depend on the bounds which are constricting the viable solutions, assuming one exists. If the problem is simply that relevant specialist (e.g. energy manager) has a solution to the problem cannot attract organizational resources, we would expect those resources to become available as soon as the contingency becomes threatening. We expect similar things to happen if the energy manager has insufficient power over people whose help is needed in the creation of solutions. We saw that in 1973–1976 the leadership of the universities often made strong appeals to users to cut their demand for energy.

However, there will be times when the organization cannot see viable solutions. That is, the various components of skills, information, resources, power, and incentives cannot be brought together in the one place at the one time. If the contingency truly is

\textsuperscript{10} This is not necessarily a good solution, however. From personal experience, consultants make money by reproducing prior solutions to problems. That implies that the consultant’s solutions will require a minimum of contextual information and minimize disruptions in the client organization (unless the consultant is engaged during a crisis). Therefore, the consultant is also likely to have available only a small repertoire of solutions.
critical, then we expect a crisis to occur. The organization's future is being threatened by its inability to manage this particular element of its environment. Given a crisis, senior management is likely to get involved, and in so doing redefine the contingency as critical. That is, this function is no longer an appendage to the organization but is spotlighted as vital. Consequently, access to resources and power are likely to be liberated; people throughout the organization are likely to have big incentives to solve the problem; and flow of information will be much less constrained.

We saw this at Harvard and MIT. Harvard's dean of Arts and Sciences redefined energy management as the measure that would prevent programs from being cut in the face of a budget crisis. A faculty committee was created, technical specialists were employed, resources were made available, and incentives for hiring, promotions, and capital allocations were changed to ensure cooperation. At MIT, something different happened. In this case, the Physical Plant Department selected a solution outside its prior bounds. The installation of a direct digital control computer system was seen as a minor addition to the physical plant (B-2B2a). However, it was far from that. The operators of the central supply facility appear to have been the first to recognize its significance. They filed a grievance when asked to monitor the system. The director of Physical Plant became involved and moved the monitoring station into the plant headquarters. Eventually, the whole Physical Plant Department was restructured around the new technology. (See appendix B for details)

In some cases, this crisis induced dissolution can extend outside the organization to an entire industry. If all organizations are struck by the same critical contingency, they may look to each other for help. For example, Tyre (1989) has studied the responses of printed circuit board manufacturers to a pending regulation that they dramatically reduce the amount of CFCs (Chloro-Fluorocarbons) they use when cleaning their boards during manufacture. She has seen a dissolution of organizational boundaries
and the creation of an informal meta-organization of board manufacturers, chemical suppliers, cleaning equipment manufacturers, and other parties. She described the way in which they have gone from looking at simple solutions which reduce the amount of CFCs used (a highly orthogonal solution) through alternative CFCs and alternative solvents to fundamental process redesign so that the boards need no cleaning.

The above scenario of events; creation of a crisis, redefinition of the problem, dissolution of organizational boundaries in the search for a solution, and finding a solution, is congruent with the process of organizational reframing (as described by Bartunek 1988). She defines organizational frames as shared sets of schemata, where schemata are "generalized cognitive structures, frameworks, or templates people use to impart structure on, and impart meaning to, some particular domain." She adds that "Based on this description, reframing primarily refers to the imposition of a qualitatively new framework or template on some particular domain, an new 'lens' for seeing and understanding it."

In her paper, she describes reframing as a four stage process. In the first stage, a crisis indicates that present shared understandings are no longer appropriate for the problem at hand. The crisis must be strong enough to unfreeze dominant organizational members' present understanding by presenting a major challenge to their validity. The second stage is a period of "experimentation" in which new information is developed. She notes that in organizations, different information will be developed in different sub-groups. In the third stage, new possible frames are generated from the information developed earlier. Finally, a synthesis occurs and a new creative understanding is developed.

This strong parallel suggests that two things are going on when the organizations are struggling through a contingency induced crisis. On the first level, there is a redistribution of power. The crisis empowers the specialist manager (energy manager)
and creates opportunities for others within the organization. The converse is that entrenched interests are likely to be threatened. On the second level, it is a cognitive problem. People need to develop new understandings about the nature of the problem. We noted above that Dean Nankin redefined energy conservation as the thing preventing programs being slashed. In another study I found that one of the things which enabled Dow Chemical to dramatically reduce its waste was the fact that it redefined waste as forgone product (Cebon 1989).

We expect both the political and cognitive aspects of this reorientation to be very stressful. The political trauma has been noted (Bartunek 1984). Bartunek (1988) discusses the strong feelings that are likely to come with cognitive reframing. She cites other authors who describe feelings such as sequences of deaths and rebirths, crisis, shock, defensiveness, and a strong sense of loss of formerly shared frames in the first stage. The preparation stage is often accompanied by ambiguity and confusion. This and the third stage often feature tension and conflict between groups which hold different perspectives. It is only in the last stage that people start to feel good about the process.

Given this, it should come as no surprise that technology forcing, a regulatory approach which seeks to deliberately induce restructuring and reframing in organizations so that they will produce aligned solutions has been unsuccessful. A discussion of that will have to wait until chapter seven.

**CHANGING THE BOUNDS WITHOUT CHANGING STRUCTURE**

We now come to the final limiting case. The core argument of this thesis has been that the creation of specialist offices for the management of secondary objectives leads to the presence of bounds which constrain decision making. In this section, we
examine the fact that the bounds are merely a product of the structure; they do not equal it. A manager who recognizes that good decision making is being prevented by a series of constraints may be able to push back the bounds without significantly altering the structure.

The simplest device available is to develop power through informal means (c.f. Bachrach and Lawler 1980). We discussed this a little when we looked at new building construction. However, it is worth making the general statement that a manager may obtain power through strategic alliances, being seen to be useful, and so forth. So, it is not surprising that the energy manager at Tufts, who has very little formal control over resources (although he is in quite a senior position) spent a lot of time trying to develop informal influence. For example, he discussed building plan review and program input in terms of the entire building engineering system, and not in terms of just energy interests. At the time of the interviews he was involved in more than twenty projects. That is, he devoted a lot of effort to making building operations easier for the shops, even though this was beyond the requirements for his job. He alluded to building strong ties with the shops (which the supervisors confirmed) through lobbying for a preventative maintenance program (E-5A).

Furthermore, organizations can try to use informal means, for which they have no power, to try to induce people to behave in certain ways. For example, outreach programs, including things like signs on light switches, (e.g. B-4a)(D-2b1)(C-2b8a) appeal to people’s consciences much more than to any formal structural means.

However, there are formal mechanisms available which are probably much more effective. It is often possible to develop programs which push back all the bounds without changing the structure. Consequently, the organization has access to the full smorgasbord of solutions without having to create a primary objective. This will prove very important when we consider policy options.
The Faculty of Arts and Sciences at Harvard provides an excellent example of this. In the Faculty of Arts and Sciences, each building has an energy monitor (or energy monitors) responsible for energy management in their area (C-1b1). As well as having energy responsibilities in their buildings, often including budget control, the energy monitors act as a conduit of information to and from the energy office (C-2b1d). As part of the most recent stage of the energy management initiative, the facilities office has started to share savings with the individual buildings. (The building can keep 20% of all savings.) This gets around the incentive problem created by the School’s uniform overhead policy without changing it. The facilities office also provides them with analyses of savings options they might choose (skills and specialist information). The buildings then decide if they are interested in any of them and suggest modifications (contextual information). If the buildings are interested, the facilities office writes the proposal into the budget (resources) and lobbies to have it funded (power). This organization has overcome all the structural barriers without altering the structure.

**CONCLUSION**

This ends the analytical part of the thesis. In the first four chapters we have seen how an organization which attempts to develop a rational structure for the management of secondary objectives is likely to limit itself to orthogonal solutions to its problems.

In this chapter, we have looked at four limits to that theory. First, we discussed what happens as an organization increases the importance of a secondary objective and saw that that is likely to increase the amount of coordination and boundary spanning involved in management of the objective. Second, we looked within the decision making process to see whether or not there were some problems which were not constrained so
Peter Cebon (1990)

much by organizational bounds. We saw that some problems, such as architect selection and supervision for new buildings, do not suffer from these problems, and hence are much less constrained. In these cases, a political model of decision making seemed more appropriate than a structural model. Third, we looked at the possibility that the bounds could be so constraining that there were no solutions available to the organization. In this case the organization either had to push away the problem by changing it, ignore it, or adjust to solve it. Depending on the nature of the constraints, that adjustment could be either relatively easy or extremely stressful. Finally, we noted that the organization’s structure does not necessarily rigidly prescribe the bounds. Skillful managers may be able to push back the bounds without significantly altering the structure.

In the next chapter, we will explore the policy objectives which come from these findings. In chapter seven we will consider policy options.
CHAPTER 6. POLICY OBJECTIVES

INTRODUCTION

The previous five chapters showed us that organizations make bad decisions in the management of secondary objectives because their prior assumptions about the nature of the problem lead to the creation of structures which, in turn, lead to bounds which severely constrain decision making. The aim of policy, then, is to push back those bounds.

In this chapter, we examine the four objectives a policy directed at pushing back organizational bounds can have. The first two types of policy aim to push them back temporarily, one by pushing back a few bounds and the other by pushing back all. The third and fourth aim for permanent change. The third aims at gradual but permanent change, while the fourth aims for rapid and permanent change.

In chapter seven we will consider the options available to different actors, specialist managers, senior managers, external agents and governments, who want to pursue these four agendas.

This is summarized in figure 6.1:

<table>
<thead>
<tr>
<th>Stressfulness of Change</th>
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<tr>
<td></td>
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<tr>
<td>Permanence of Change</td>
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<tr>
<td>Low</td>
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<td>Class 3</td>
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<td>Class 4</td>
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FIGURE 6.1 FOUR CLASSES OF POLICY OBJECTIVES
TEMPORARY CHANGE

There may be occasions when it is appropriate to pursue temporary changes in an organization’s decision making capacity. For example, in the introduction to chapter one we saw that an electroplater managed to completely eliminate its waste stream by recycling wash water. The relevant decisions, to explore and then implement minor process redesign, were made in a short period of time. In any situation where the problem can be virtually eliminated in a short time, a temporary change may be appropriate. Further, some problems may be of very short duration. For example, an organization may be at a critical juncture in its development. Decisions made at that time may have big implications for management of particular secondary objectives. Building a new facility provides a good example. Again, short term changes may all that is needed. Given that temporary changes are not terribly disruptive in the long term, and therefore relatively easy to achieve, both organizational actors and external agents are likely to be prepared to pay a financial surplus for effective and permanent solutions that can be achieved relatively rapidly.

For short-term changes in bounds, there are clearly two options. The most obvious is to attract a lot of attention to the problem; create a crisis that can be resolved in a short time. The problem of removing CFCs from cleaning operations for printed circuit boards, described in chapter five, is such a case (Tyre 1989). The organizations recognize the problem. They are devoting a lot of resources to it. For example, people are being seconded from other areas of the firms to concentrate on finding solutions. When it is resolved, those resources will be taken away.1 The second option involves pushing back the organization’s bounds for a short period of time without fundamentally

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1 This does not mean that the actual solution (rather than the solution process) will not require a big infusion of resources. If the manufacturers decide to eliminate cleaning operations completely, they will need to redesign and replace the equipment which places the chips on the boards and solders them in place.
changing the structure. If one or a set of bounds are inhibiting good decision making, then it may be possible to construct a policy which overcomes them for long enough to achieve policy objectives. For example, it has been common for the Department of Energy to subsidize energy efficient building works in schools and hospitals. Given that energy efficiency is cost effective for the institution itself (projects awarded subsidies generally have returns on investment of about 200%), and given that some of the awardees are can raise external capital (some state institutions cannot), we can conclude that these programs are often designed to attract the attention of senior management of these institutions by dangling a carrot at the institutional boundary.

GRADUAL AND PERMANENT CHANGE

Gradual and permanent change is a very attractive option if it can be achieved. Conflict is not highlighted, few people's jobs change radically, and there is minimal disruption to organizational life. Therefore, in the best of possible worlds, it is by far the preferred option. The idea is to exploit every organizational event which changes the decision making bounds so that the bounds change in one direction, rather than randomly oscillating or wandering about as would happen in normal circumstances.

This is not always possible, however. Such a strategy needs a lot of time, power and a mechanism to intervene over that period of time. Organizations in relatively turbulent environments may well not have a lot of time. Others, such as The University of Massachusetts at Amherst exist in a very stable environment, and therefore can pursue this strategy. Long-term strategies are available to a surprisingly large group of actors. For example, the Clean Water Act, by itself, is clearly short-term in orientation. The organization must respond once to a very specific series of interventions. However, if seen as one plank in a national environmental platform with a stream of uncertain legislation into the future, it is one of a series of pushes to reorient organizations.
Sometimes, a gradual strategy is the only viable one. If a system is more inertial than a change agent is powerful, given the benefits of the change and investments in the status quo, gradual change is probably the only permanent change option. However, to prescribe gradual change is insufficient. We must understand the process by which it occurs.

A campus is a very complicated place. It houses a large number of buildings, each with different functions, ages and needs. Each of these buildings is at a different point in its lifecycle. Some are yet to be conceived; some are in construction; some are operating smoothly; others are being refurbished. Many share resources or are delivered them from a central plant. While a part of each of them may be changing at a given time, all require constant operation and maintenance. That is, within the various buildings all the different energy systems at all different levels are being operated (by someone) to stay the way they are. Every so often, either in the name of energy conservation, as a product of physical plant’s functions, in the interest of other activities like new academic programs, or as a result of a change in the external environment beyond the energy management organization, something needs to be changed. That is, either something within the energy management organization changes, or a change in the external environment makes its way into the energy management organization and causes an internal change event.

This change can be obvious, such as a new building; subtle, such as a new light fixture; or barely perceptible, such as a person’s decision to turn off a light they’ve normally left on. However, these changes invariably represent a change (or non-change) in the behavior of the campus energy system.

If we look closely at The University of Massachusetts at Amherst case, (see particularly D-2B1), we see that energy management has changed in importance over time. While Frank Andrews accorded it a high priority from the time he joined the
university, that increased priority has been reflected in the technology (as work practices, equipment for operations, and university infrastructure) of the Physical Plant Department only gradually. However, the changes in behavior appear to be quite resilient. The new energy management system will ensure that maintenance is done, the relationship between operations and maintenance has changed, and the new work order system will add another durable element to the new organization. The gradualness is quite understandable in this particular instance. Probably, rapid changes in work practices would be disrupted and opposed. This can be seen in the energy management system's very careful introduction and sale throughout the plant (D-6B2d) and the care that is being taken to construct the new work order system (D-6A2c).

We can think of events at The University of Massachusetts at Amherst as a series of discrete change events. That is, events which alter relationships in the Physical Plant Department and have been used to slowly ratchet the organization around to its new orientation. At a more abstract level, with each of these events, two things have happened. First, there has been a change in the physical systems. Second, every such change has been accompanied by a process which involves interactions of people with each other and with hardware. In the next two sub-sections we will explore each of these in turn. We will begin by examining the way that changes in the physical systems alter the potential for further change. Then, we will look at the way in which the process of managing the secondary objective creates or inhibits the possibility for further change.

CHANGES IN PHYSICAL SYSTEMS

Two things alter with changes in the physical systems in a setting. First, the possibility (in an engineering-economic sense) for future change alters, and second, the objective relationships between people and objects within the system change.
Changes in Engineering Possibilities

Any change can enhance or diminish the potential for future change. A simple and graphic example of a change which enhances further change is a window with a crack at the side. Before the crack is plugged, storm windows which do not cover the crack are probably not cost effective. Afterwards, they may well be. We expect this result to be repeated wherever there are parallel (as opposed to serial) causes for failure of secondary objectives.²

In the (much more common) serial case, each improvement in the system reduces the marginal incentive for the next improvement. For example, if double glazing windows, it is probably cost effective to use low emissivity glass on the inner pane.³ However, it is never cost effective to replace a second pane with low emissivity glass. We saw a much subtler example when the Faculty of Arts and Sciences at Harvard chose to not install variable speed drives on fans, but rather to simply change the impellers (B-2A2c). The variable speed drives were much more expensive and had little marginal benefit. However, if, at a later date, Harvard decided to install direct digital control in the buildings, the variable speed drives would need to be retrofitted on the motors at a greater cost. This could easily alter the viability of direct digital control. Here, the serial dependence occurs through time as well as through space. That is, a decision in 1981 to install variable speed drives would need to be made on the basis of a projected cost of direct digital control five or ten years later. Finally, a waste management example. One of the big advantages of waste reduction programs is that they eliminate

² Parallel means that there are several alternate routes for wastage (or other objective failure). If wastage does not occur by one route (through the crack in this case) it can occur by another (through the single glass window). Serial, on the other hand means that one process follows another. That is, each new operation acts on the same set of waste. Going from double to triple glazing is an example.

³ Low emissivity glass has a silver coating on one of the panes. This alters its ability to transmit and reflect light and heat. It makes a big difference to the thermal characteristics of the window.
the need to treat waste. However, once the capital has been sunk in a treatment plant, the returns from waste minimization drop dramatically. The capital is sunk and the operating costs don't necessarily drop significantly.

The technological hierarchy we set out in chapter two is a different kind of serial system. Here, every management decision made at a particular point restricts the possibility for savings further up the hierarchy. That is, the savings potential at a given point is defined by what is going on, or what is projected to go on in the future, further down the hierarchy. A change in lighting affects the potential for change in heating and cooling, and so forth.

However, not all systems in a large institution are heavily interlinked like this. In fact, we see many independent systems replicated across a campus (e.g. lighting) both across space and through time. For these independent projects (and probably for the dependent ones as well) it is the social changes wrought by a change in technology that limit future options. We discuss them now.

**Changes in Relations between People and Objects**

Every change in hardware or work practices alters the power relationships between people (e.g. Noble 1984, Edwards 1979, Thomas 1989, Bachrach and Lawler 1980, Dalton 1950). Consider the simplest possible case; replacing incandescent light bulbs with compact fluorescent fixtures. At one level, this is very simple. The bulb changer screws out one bulb and screws in another. At another level, the impact is major. The new bulbs last ten times as long. Therefore, only one tenth the labor is needed to change light bulbs. If building superintendents change bulbs as one of their many duties, they simply don't have to work as hard. However, if an organization employs people just to change bulbs, then 90% of those people are now redundant. In
the face of technological change which alters people's work, it is not surprising that conflict can arise.

This conflict over changes in technology pervades the data. The most dramatic cases surround the introduction of computer control systems. Here, the tensions between management and labour in a quest for control of the work-place seem to be played out (Edwards 1979). At MIT, management won. At The University of Massachusetts at Amherst, labor did. Conflict needn't be up and down the hierarchy (Thomas 1989, Bachrach and Lawler 1980, Dalton 1950). At MIT, we saw conflict between two staff groups. The introduction of controllers onto the fume hoods led to a major conflagration between the Safety Office and the Physical Plant Department. At Tufts, the same conflict was played out between the administration and the faculty. The faculty were not prepared to pay for fume hood controllers which would benefit everyone collectively but not them individually. Clearly, every change in technology changes the power and incentive relations for future changes in technology.

Since energy management function tends to be fairly heavily embedded in the physical plant department, it is worth exploring its relationship to the other parts. There are two ways of measuring the output of a physical plant sub-department. One is in terms of the systems' efficacy. Does the roof leak? Is the fan noisy? The other is in terms of money. How much money does it save? Irrespective of the operational benefits, energy management is almost invariably measured in terms of money, the language of the rest of the organization. Other physical plant functions cannot be measured this way. Furthermore, unlike other functions, energy management can often get resources from outside the organization (as loans, grants and subsidies, shared savings programs etc.). Similarly, it can make deals with the faculty or take out special loans from the university itself. If set up so it can retain savings, it needs to make fewer trips to the senior administration for funds. Finally, because energy management is generally
perceived as seen as more noble, and probably more interesting, than physical plant
management, it is probably attracting relatively better people. Therefore, energy
managers may be disproportionately powerful in some physical plant departments. Their
projects may well generate friction. This could lead to initiatives being sabotaged by
other members of the physical plant department.

CHANGES IN INTERPERSONAL INTERACTION THROUGH LEARNING AND
COMMUNICATION

Projects change more than the physical environment of the organization and
people’s relationships to each other. In implementing the projects, people have to
interact with each other and with the systems being installed. This interaction changes
people’s understandings, through both learning and communication.

By carrying out a project, the people within the specialist office learn two things.
First, retrofit projects lead to the possibility of better retrofit projects. That is, they
increase skills, access to technical information, and the database of contextual
information (Dutton et al. 1984). There is a learning curve. Second, by carrying out
retrofit projects, specialists learn about the possibilities for change in the way they
design entire new processes (Arrow 1962). We saw at Tufts that one of the big
objections to the policy of contracting out the maintenance of major building systems
was that it obstructed this learning (E-2B2b). In contrast, at one chemical manufacturer,
aste reduction projects clearly benefit both the process being modified and future
processes into which that learning could be incorporated (Cebon 1989).

During these change events, several of the bounds move. By doing, the managers
acquire new skills and accumulate a database of technical information. In addition, the
managers are learning more about detailed processes, and are therefore accumulating
contextual information, both about the work–place and the sorts of people who occupy
it. So are the users. In addition to learning about the specialist managers themselves, users are discovering the size (or lack thereof) of the impacts of management of the objective on their work and the potential for future benefits. This changes their incentives for further change.

However, underlying this is not just exchanges in objective data. Because people are interacting with projects and each other, their assumptions about the nature of the projects and each other will change if the data conflicts with their prior assumptions. If information is sufficiently discordant for long enough then reframing can occur (Argyris and Schön 1978) and fundamentally different understandings will emerge. By the same token, repeated projects which reflect prior assumptions about relationships can reinforce those notions about the impact of projects and the nature of the other party.

CHANGING SOCIAL SYSTEMS LEADING TO CHANGING PHYSICAL SYSTEMS

The above section has been written as if the changing physical systems operate as the lever for changes in an organization’s social systems. The argument could, of course, have been written in reverse. In fact, we are more likely to see the opposite, as we did at The University of Massachusetts at Amherst. There, a managerial decision was made to change the orientation of the plant, and that led to changes in the physical systems, which, in turn, increased people’s confidence in the operation of the plant which enabled further change to occur. However, most importantly for our purposes, we can see that through either random good fortune over a number of projects or careful manipulation of the bounds, it is possible to bring about a gradual movement in an input/output office from a peripheral to a transformative position (or make it transformative for progressively more of the organization). Accompanying that transformation will be an alteration of the organization’s bounds.
We can see two broad policy options. The first is a commitment to slowly lever the organization to a new set of objectives, and therefore to a new set of bounds. The second is to slowly lever the physical systems of the organization in the hope that it will lead to learning and changed perceptions which, in turn will lead to a reorientation and a new set of bounds. Both approaches could be pursued simultaneously. For example, an external body could sponsor demonstration projects and then lobby for managerial reforms.

RAPID AND PERMANENT CHANGE

The final change process is a rapid and permanent change in organizational bounds caused by a change in organizational objectives. This approach is desirable if the change agent has sufficient power to pursue it. For example, the federal toxic waste management statutes are very aggressive and appear to have pushed many organizations to view their waste differently. The government has a very strong mandate for toxic waste management.

In chapter five, we suggested that this change occurs through organizational reframing. We suggested there that a crisis is needed to initiate the process. That occurs when the organization is cast a problem for which no solutions reside within its bounds. That is, it is threatened by a critical contingency (Hickson et al 1971). The organization dissolves its prior structure and searches for a solution. A new structure emerges with the new solution. For that new structure to have intrinsically larger bounds for the input/output function of concern, the organization’s objectives have to change as well. That is, there has to be a reconceptualization of the nature of the problem. The secondary objective must become primary. Waste has to be redefined as foregone product. Energy conservation has to be seen as a substitute for slashed academic programs. Otherwise, we have the temporary crisis case at the start of this
chapter, and all that will result is a single change in technology leading to a minor change in organization and no guarantee of better management of equivalent problems in the future.

An example of this sort of objective change found in the data was Dean Nankin’s change in the objectives of the Faculty of Arts and Sciences at Harvard. The crisis was the school’s financial woes combined with the energy crunch. The dean decided that cost minimization was to be a primary concern in the organization, and set about, somewhat awkwardly at first, to see that that new vision was embodied in virtually all the school’s programs.

CONCLUSION

Hence we have our three broad options for a policy which aims to push back organizational bounds. On one hand, if the problem is short lived or can be solved with one decision, we may want to push the bounds back temporarily, either by targeting individual bounds or inducing a short-term crisis. Alternatively, if the organization is inertial compared to the policy agent, we may want to push them back slowly. Finally, if the policy agent is strong or a crisis looms, rapid and permanent change may be called for.

In the next chapter we will look at the options available for actors inside and outside the organization to pursue these objectives.
CHAPTER 7. POLICY OPTIONS

INTRODUCTION

In chapter six we laid out four classes of policy objectives for pushing back organizations' decision making bounds. The first two aimed for temporary expansion of bounds to make one or two key decisions, while the second two aimed for permanent change. The first class involved "nourishing" organizations along particular dimensions, e.g. outreach programs which provide skills. The second class involved inducing short-term crises which temporarily dissolved organizational constraints. These approaches would be appropriate for short-lived or completely soluble problems. The third class involved gradually induced, but permanent, changes in organizational objectives and structure. This is difficult to achieve because it requires an appropriate change agent who can pursue a sustained effort. Such people cannot always be mustered or there is not always time. However, if possible, it is the preferred permanent change option since it minimizes conflict and disruption. The fourth and final class of policies would pursue rapid and permanent changes in organizational objectives and bounds.

There are four distinct groups which have an interest in effective management of secondary objectives. Inside the organization are the specialist managers (energy manager or physical plant department head) and senior management. Outside the organization, there are private agents (such as public interest groups, unions, and industry groups), and finally, government.

In this chapter, we will lay out various actors' options to pursue the four classes (two temporary and two permanent) of policy objectives. We will also present a rough
indication of their likelihood of success. Simultaneously, we will critique alternative proposals found in the literature and practice. Note, however, that the aim, at this stage, is not to lay out a new, integrated, policy strategy. That requires extensive research into organizational change and the dynamics of interaction between external parties and the organization. Both of those are beyond the scope of this study. Rather, we present some possibilities within our framework.

In a few cases, two options, relating respectively to gradual and the rapid change, will look very similar. For example, public interest groups will be implored to lobby outside directors about opportunities in waste reduction in some companies, while boycotting and generally embarrassing others. On one level these are the same; both involve pressuring a company to act. On another level, they differ markedly. They exploit people's abilities to create two virtually opposite cognitive frames to interpret a mismatch between an organization and its environment. (Thaler 1985, Tversky and Kahneman 1981). For example, imagine a company which decides to stop being profligate with energy. On one hand, it could see energy conservation as an enormous unrealized opportunity. Therefore, profits could be increased by redirecting efforts. This would call for our first or third approaches. Alternatively, the organization could perceive it is very wasteful and that, in the face of rapidly rising energy prices, it will soon suffer at the hands of its more efficient opponents. Therefore, without an immediate response to this crisis, its very future will be threatened. This is the domain of classes two and four. Note, however, that the objective situation may vary little between the two cases, if at all.

The options for the first three groups; specialist managers, top management, and external parties, are summarized in figure 7.1.
<table>
<thead>
<tr>
<th><strong>Temporary Changes in Individual Bounds</strong></th>
<th><strong>Specialist Managers</strong></th>
<th><strong>Senior Management</strong></th>
<th><strong>Public Interest Groups</strong></th>
<th><strong>Unions</strong></th>
<th><strong>Industry Groups</strong></th>
</tr>
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<tbody>
<tr>
<td>Technical Analyses, Internal Competitions, Internal Rebates, Technical Assistance, Outreach etc.</td>
<td>Programs which Exploit Opportunities in Environment, Recognize and Exploit Crises, Counter Specific Organizational Constraints</td>
<td>Citizen Suits</td>
<td>Workplace Participation</td>
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<table>
<thead>
<tr>
<th><strong>Temporary Changes in All Bounds</strong></th>
<th><strong>Carefully Designed Combinations of the Above</strong></th>
<th><strong>Gradual and Permanent Changes in Objectives</strong></th>
<th>As Above, with Status Enhancement through Outreach and High Quality Services in Related Activities</th>
<th>Programs and Decisions which Oppose Structural Obstacles. Symbolic Reinforcement of new Objectives.</th>
<th>Lobby Outside Directors, Insurers, Creditors etc. Use of &quot;Right to Know&quot; Laws. Plant Tours</th>
<th>Participation in Strategic Decision Making</th>
<th>Informal Pressure through Industry Groups, Interlocking Directorates, and Social Interaction</th>
</tr>
</thead>
</table>

| **Rapid and Permanent Changes in Objectives** | **Enact Crises and Emphasize that they Represent Permanent Shifts in the Environment. Appropriate Delegation** | **Attack Management and Obstruct Inputs during Organization-Induced Crises. Citizen Suits with High Fines.** | | | |

**FIGURE 7.1 POLICY OPTIONS FOR SPECIALIST MANAGERS, SENIOR MANAGEMENT, AND OUTSIDE GROUPS**
SPECIALIST MANAGERS

Under this conception, the technical manager's task is twofold. One element, the familiar one, is the bringing of technical skills and information into the organization. The other is determination and elimination of other bounds. We will concentrate on that.

Most of the specialist manager's temporary change options are fairly obvious and need little elaboration. Generally, they involve the manipulation of individual bounds by such things as internal competitions to create incentives and liberate contextual information, internal rebate and technical assistance programs, outreach programs to transfer technical information and incentives, hiring of consultants to increase skills, and so forth. An effective program will attack all bounds simultaneously. If this can be done without the fanfare of competitions and the like, an ongoing program is possible.

It is very difficult to imagine a specialist manager in a low powered peripheral office reorienting an entire organization through gradual change. The only possibility is to develop programs which overcome organizational bounds without threatening others or requiring large amounts of extended senior management support. If such a program were sustained, it may well become institutionalized in the objectives and both the physical and organizational structures. The facilities office in the Faculty of Arts and Sciences at Harvard put in place a program which by-passed each organizational bound without threaten other interests. If the incoming dean had supported this approach, rather than changing priorities so much that the people at the core of the initiative (the facilities office) no longer had time for this effort, it may well have become institutionalized. A manager who develops high informal influence through outreach programs or a high standard of other services (such as prompt and effective maintenance) is likely to be more successful with this sort of strategy.
Specialist managers cannot induce rapid organizational change.

SENIOR MANAGEMENT

It is unclear how much senior management can influence organizational decision making. Chandler (1962) argues that in a successful organization, senior management develops an appropriate strategy and embodies that strategy in an organizational structure. His argument implies that management is very powerful and can ignore constraints and obstacles to change. Child (1972) attempted to reconcile that argument with others found in sociology, namely that technology, size and the organization's environment were the determinants of its structure. He argued that, while these were major determinants of organizational action, organizations whose performance was better than satisfactory (relative to objectives) would have spare resources available for allocation. It was in the allocation of that 'slack' (Cyert and March 1963) that power holders in the organization (often senior management) had discretion in the structure creation and resource allocation. Further, as we have seen in chapter two, organizations have more than one choice in the selection of technology to satisfy a particular objective. Therefore, in as far as structure is at least partially determined by technology, there is the possibility of multiple equivalent configurations based on different technology.

Subsequent researchers attempted to observe the effect of leadership in organizations. Their findings were far from clear. Salancik and Pfeffer (1977) tried to determine whether new mayors could alter the behavior of cities. They found little effect and concluded that leaders were relatively impotent. Lieberson and O'Connor (1972) found that 98% of the variance in sales, 96% of the variance in income, and 83% of the variance in profits, between 1946 and 1965, of 167 companies could be explained by the company, the industry, and the year. This left little to be explained by
leadership. In contrast, Smith, Carson, and Alexander (1984), looking at the
effectiveness of United Methodist ministers, found a leadership effect. However, given
that churches are voluntary organizations with the leader as star attraction, this is hardly
surprising.

These studies fallaciously assume that the effects of organization, environment,
and leadership are independent. A senior manager who guides an organization through a
turbulent environment is not considered a leader if all other leaders in the sector do the
same. On the contrary, leadership skills may be needed just to keep the organization on
course. As such, these studies measure the difference between leaders (i.e. the variance),
not leadership in an absolute sense. For example, if all manufacturers in an industry
simultaneously made pollution prevention a priority, possibly as a result of a particularly
effective regulation, these studies would measure no effect. If, however, one firm did
not respond, the effect would be large.

Notwithstanding, the main point I wish to make is that the available literature
gives virtually no guidance as to when managers should pursue which policies; both
temporary approaches, gradual, or rapid change, or how successful they are likely to be.
Consequently, we must be a little speculative.

Temporary changes in objectives and structure, by the temporary elevation of a
particular secondary objective, are very attractive to, and undoubtedly quite achievable
by senior management. They leave only minor residual changes in the organization's
structure, and hence have only a marginal impact on the power distribution.
Management has two options. The first involves recognizing an opportunity and creating
a program, with a short-term shift in bounds. This will succeed in as far as
organizational politics and institutional inertia permit. The second option involves
creating a temporary crisis out of a change in the internal or external environment
(Weick 1969), marshalling people to stem it, finding a solution, and returning to normal.
This is expensive and disruptive but relatively painless. Only people directly affected by
the solution must change the way they do things, and the problem can be forgotten once
the solution is effected. Note, however, that raising the importance of the objective is
necessary, but not sufficient. As we saw at Harvard, all the decision making
components have to be brought together as well.

The best approaches involve changes which oppose problems created by the
organization's structure. For example, an administratively centralized school like MIT
would need to increase the flow of contextual and connected information and reduce
incentive barriers. Therefore, it would probably need to involve users and other interest
groups. Such, a program would be consistent with others at MIT; large, temporary,
initiatives receiving a lot of managerial attention. A decentralized organization like
Harvard would do best to enhance skills and technical information as well as ensuring
that the small schools have adequate access to resources. Either could occur in the
context of a crisis or recognition of an opportunity. A conscientious senior manager
would attempt to leave a residual change in the organization which would facilitate
future change.

Furthermore, the balance between the organization's needs in infrastructure and
equipment may guide decision making. If the needs are centered on the equipment,
decision making should be centered on the users. If the needs are centered on the
infrastructure, decision making should be centered on the specialists.

Any leader can pursue gradual and permanent change given an infinite tenure
and opportunities. Unfortunately, both are limited and each orthogonal solution
potentially constrains future aligned ones. Therefore, the key question is not so much
when to pursue a strategy of gradual change, but rather, how big a step can be made
each time. We saw the outer limit with the installation of the first direct digital control
system at MIT. Management only just won the stand-off with labor. In contrast, the
Peter Cebon (1990)

Physical Plant Department management at The University of Massachusetts at Amherst lost the same battle over a much less robust technology eight years earlier. The gradual transformation at The University of Massachusetts at Amherst, beginning in 1984, where energy management was slowly brought from something irrelevant to the Physical Plant Department to centrality to its operations, appears to have been relatively painless.

The key variables to consider when estimating the size of the step are 1) the characteristics of the change relative to what preceded it, 2) the leader relative to the people affected, 3) the organization, and 4) the environment. People are less likely to object if asked to do something like what they've done before. For example, I found elsewhere that a major chemical company could place a high emphasis on waste reduction because it is very similar to hazard reduction. The company's religious concern for safety since the 1930's, enabled the additional responsibility to be accommodated easily (Cebon 1989). The relative position of the leader, as we saw in chapter four, can be reduced to a concern for increments in power and incentives, given the robustness of the solution. If those affected see the change as small, then less power or incentives will be needed. Flexible organizations will require less of a kick. Therefore, organizations which are tolerant of error, encourage innovation, and have open communication will probably be better gradual movers. Finally, the more severe the environmental contingency, the larger the individual moves the organization will tolerate.

Quinn (1989) discusses cases of gradual change in very large organizations. He emphasizes that gradual change is best achieved in an environment with long planning horizons, pro-active management, and a backdrop for analyzing short-term decisions against long-term strategies.

We saw in chapter six that radical change is the problem of creating individual and organizational schema compatible with the new structure. Rapid schema changes
require crises (Schein 1985, Bartunek 1988, Allaire and Firsatro 1985). That is, the
people in the organization who are concerned with the change must perceive that
environmental contingencies threaten the organization. Furthermore, they must perceive
a permanent shift in the environment (otherwise it would be a temporary case). Such a
perception has two components. The first part is the objective environment. A real
shift must have occurred if the leader is to have legitimacy. The second is the
organization's enactment (Weick 1969) of that environment. That is, it responds to its
mental model of the environment, not to the environment itself. Therefore, to a large
extent, but obviously not completely, the perception that a threatening change in the
environment 1) has occurred, and 2) is permanent, is interpretive.

Clearly, the two variables important in creating a crisis are the level of the
objective mismatch between the organization and the environment and management's
ability to interpret that mismatch and create a crisis. So, for example, Dean Nankin at
Harvard created a financial crisis which threatened academic programs. Dow Chemical's
reorientation began when an entrepreneurial manager managed to show that its poor
public image was devastating morale (Cebon 1989). Allaire and Firsatro (1985:197)
advise organizational leaders to "make a looming crisis tangible and to make known the
dangers the corporation faces. The leaders must make the case vivid and persuasive.
Corporate management must also develop a sense of control and responsibility for the
firm's performance."

Once the crisis has been identified, Allaire and Firsatro see five further steps in
managed change. They are 1) formulating a meta-strategy for radical change, 2)
assessing the organization's present culture and structure, 3) defining the goals of the
organization's culture and structure, 4) proposing a broad agenda for radical change and
5) stabilizing the organization once change has occurred.
While all of these subsequent stages are important, for our purposes, the proposition of an agenda for radical change is pivotal. Allaire and Firsatro argue that this requires structural change, backed with technical argument, political action to remove obstructions, and symbolic management "to channel the complex social processes through which symbols, meanings, and values are created" (Allaire and Firsatro 1985:202). Bartunek (1988) cautions against over specifying the nature of change. She notes that people must make a cognitive investment or else they will only pay it lip service. Allaire and Firsatro suggest a political agenda of 1) broadening the political support for radical actions, 2) raising the level of dissatisfaction and discomfort with the present situation, and 3) sensitizing key actors to the need for change. Their symbolic agenda includes 1) communicating forcefully a new image that captures the external strategy and proposed culture to be implemented and 2) using all available media channels to disseminate them. Finally, they emphasize the need for change agents who are favorable to the new orientation and will explain and propagandize it and suggest 1) they should be recruited, trained, and disseminated throughout the organization and 2) liaison relationships should be maintained with them.

One outcome of such a process would be the delegation of authority for management of the objective to the appropriate managerial level, within the line organization. For example, at Dow Chemical the plant superintendents are responsible for environment and safety. This is the first administrative level at which all the nine elements of decision making come together. To keep the incentives high for managers, senior management encourages the public to request plant tours and uses the "right to know" laws to require managers to release emissions statistics into the local community. (In fact, they only have to be submitted to the federal government.)
PRIVATE AGENTS

We will consider three groups of private agents: public interest groups, unions, and trade associations. Each may, for various reasons, want to change organizational behavior. However, they are unlikely to be interested in temporary changes. For them, permanent changes in behavior are much more important.

PUBLIC INTEREST GROUPS

Public interest groups (e.g. the PIRGs, NRDC, etc.) act as private representatives of the public's concern over particular issues, such as energy conservation or pollution control. They generally do two things. First, they lobby. They traditionally target government for certain legal provisions in relevant laws. Second, certain legislation (e.g. the Clean Water Act), allows them, through the use of citizens' suits, to act as private enforcers of the law. They can sue agencies for failing to promulgate regulations or for promulgating regulations of insufficient severity, and they can sue individual licensees for failing to comply with the law.

However, governments are not the only people they can lobby. To lobby government is to create laws to encourage managers to change their attitudes to the importance of certain input/output functions. On one level, this makes sense. It is very important that pollution or safety are real contingencies for the organization. We will discuss this further when we look at public policy. However, we should raise the possibility of lobbying corporations directly. That is, perhaps the public interest groups should be targeting particularly likely organizations for restructuring. The hope is that these organizations, through institutions such as industry groups and interlocking directorates, will transfer the new ideology to others.

1 Interview, Charles C. Caldart, Staff Attorney, MassPIRG, July 11th 1989.
A gradual change strategy would involve attempting to persuade senior management that new approaches are in the interest of both the corporation and the public interest group. The problem is access. I speculate that any chief executive who is open enough to public interest groups to give them time and be persuaded by their arguments for a restructuring around certain secondary objectives does not need to be lobbied. Rather, such a process will already be under way if it is feasible. This assumes that an organization which is open to some outside stakeholders will be open to all. Therefore, it will already be aware of the possibility for improved management of contentious inputs or outputs. More likely, target executives will be too busy to see advocates, and too shielded by both their organization and their cognitive schema. Therefore, interest groups must target accessible people to do the persuading who can command the time and respect of management.

The most obvious people are the company's outside directors. They sit on corporate boards to ensure that the firm is run in the shareholders' rather than management's interest. They are almost invariably responsible for regulatory compliance. Therefore, since virtually all contentious secondary objectives are either regulated or on the political agenda for regulation (e.g. child care), they are an appropriate target. They could argue strongly that in the face of an uncertain regulatory future, it is prudent for the organization to gradually raise the importance of the objective. This argument could be bolstered with the fact that the federal government, through the joint and several liability provisions of the 'Superfund' legislation, has created a precedent for making organizations retrospectively liable for their behavior. That is, the outside directors could argue that these organizations should maximize their efforts now, because the government may well penalize them for tardiness later.

The key questions are first, whether or not outside directors are likely to be receptive and second, whether or not they are likely to be effective. I interviewed one
person with multiple directorships. She argued that the choice of directors varied by industry. Utilities, for instance, tend to have only directors from within the industry. Consumer products corporations, on the other hand, tend to try to make their boards very diverse so they can be sensitive to their markets. Therefore, we expect differential effectiveness in different industries. Furthermore, the directors come from many places. Of the two main groups, universities and other corporations, the directors with academic positions are more likely to be receptive to advances.

On the question of effectiveness, we must be very speculative. We undoubtedly expect variations between industries, on the basis of core processes and regulatory experiences, between corporations, on the basis of its structure and history, and between directors, internal and external, on the basis of their individual characteristics, interpersonal relationships, and the respect they carry on the board. However, the literature offers virtually no guide as to how large the effect, independent of all these, is likely to be. The only empirical guide is the success (or lack thereof) of secondary boycotts and devices such as the 'corporate campaign'. These involve boycotting or lobbying key suppliers in the name of the right to unionize or specific industrial demands. These have had mixed success. They were most successful when there was strong federal government support for the right to unionize. Given that these initiatives have been around issues central to work place management, and have aimed for defensive rather than proactive change, I am very hesitant to attempt to generalize to other secondary objectives.

Other groups however, could be approached. Insurers insure both corporations and individual directors. They have a strong interest in ensuring they both minimize the risk to which they expose themselves. Banks and other creditors have a similar interest.

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2 Interview, Jill Conway, outside director Colgate-Palmolive, IBM, and Nike, September 1989.
Finally, auditors must satisfy themselves that the company is not exposing the shareholders to unnecessary risk. It is not unreasonable to expand that definition to include risk to future regulation.³

Furthermore, public interest groups can act indirectly on the firms by applying pressure at the local level. This can be done through plant tours and extensive use of "right to know" provisions. This will put pressure on plant managers to increase their emphasis on waste reduction.

Rapid change requires a crisis. Some organizations generate their own, as Exxon did with the Valdez accident and its subsequent management. Other times, outside groups generate them, such as the INFORM/INFACT international boycott of Nestlé, and Greenpeace's attack on Polaroid's Cambridge waste. Therefore, interest groups can attempt to create crises or they can exploit firms' mistakes. It may well be politically dangerous to be seen as perpetually preying on companies' misfortunes. However, this approach may be feasible in certain political climates (e.g. Valdez, Bhopal) or when the offending company is very sensitive to public perceptions, such as in consumer products industries. The lesson of this thesis is that the interest groups can do much better than castigate the organizations for being 'fundamentally evil', 'negligent', or whatever. They would, potentially, do much better if they directly attack the quality of the organization's management. That is, instead of presenting the company as rational and evil, they might to better if they argue that management is simply incompetent. Furthermore, boycotts should obstruct the supply of key inputs such as entry level graduates.

³ It is unclear to me whether or not this is best achieved by legislation to change the formal responsibilities of auditors, a request from the board that this be included in auditing activities, or an offer from the auditors as a part of their services. Depending on which of these three approaches is most appropriate, the interest groups would want to lobby politicians, management, and auditors respectively.
Interest groups can induce crises through their second function, citizen’s suits. Interviews with one attorney indicate that these suits can be very good at precipitating communication between various groups in the organization. He noted that often, the first substantive discussions between ‘production’ and ‘waste management’ about the possible modification of core processes to reduce waste occurs at the negotiating table after the suit is filed. This could well be a temporary intervention. The company will resolve the issue and then probably return to past practices.

To initiate permanent change, the senior management must perceive that the environmental contingency is permanent and much greater than the previously imagined. Two devices are available to do this. One, which is being used increasingly by governments, is to make environmental offences criminal. As such, management risks jail. This has been relatively successful (e.g. Greider 1979). The public interest group equivalent is probably to ask the court to levy very high fines. In a recent citizen suit, MassPIRG compelled General Electric to pay $1 000 000 for repeated Clean Water violations at its Lynn MA jet engine facility. Of this, $750 000 was the cost of works to come into compliance, leaving $250 000 in fines, penalties and costs. While $250 000 may seem like a large fine, the site employs 15 000 people. I estimate that facility generates well in excess of $1 Billion (possibly greater than $2 Billion) in gross revenue annually. I doubt the company even noticed the fine. Public interest groups should seek the legal maximum fine against offenders like this. This will have two effects. First, senior management will take more notice of what is going on at the plant level. Second, the level of bad press and public ‘humiliation’ of plant and corporate management will increase with the size of the fine. This may encourage management to start taking the environment seriously.

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5 Caldart (Footnote 1)
UNIONS

In general, unions have an interest in ensuring the best possible management of secondary objectives. If we consider pollution, we can see that toxins which are not eliminated from industrial processes become work place safety hazards or part of the waste stream. That waste stream must be managed by workers. Often, it is employees from the plant who are subjected to drinking water polluted with the plant's effluent. For example, one General Electric facility was in gross violation of the Clean Water Act with several toxic discharges into the local river. Many employees lived in a town immediately downstream. However, it took several years and repeated toxic discharges before a couple of citizens developed the courage to act and have the firm brought into compliance (New York Times 198x). It is impossible to know how often this is repeated throughout the country. Energy conservation parallels the problem Dean Nankin faced at Harvard. He had the choice of saving energy or slashing programs. Various people in the trade union movement have, at various times, looked into energy conservation as a means for reducing industrial costs without shedding labor, and hence creating jobs through expanded markets. Unions have an interest in many other secondary objectives, however. For example, child care is contentious at the moment. Solutions available vary from the highly orthogonal (such as pay subsidies) to the highly aligned, (such as home work (Bailyn 1988)).

The down side of effective management of secondary objectives, as far as unions are concerned, is that all technological change provides opportunities to displace labor. In competitive industries, where excess labor can imply lack of competitiveness, loss of market share, especially to foreign firms, may well pose a greater threat. Labor losses to efficiency increases may be more than offset by gains (or non-loss) in market share. In non-competitive industries, however, real trade-offs may be involved.
The extent to which unions can have input into changes in organizational objectives depends on the extent to which labor is included in corporate strategic decision making. If, as Kochan Katz and McKersie (1988) suggest, such participation is increasing, there is real hope that this will be a mechanism for change. If, however, union participation continues to be relatively superficial, as suggested by Thomas (1989), these concerns are unlikely to be articulated early enough in the decision making process to be acted upon. Instead, we will see the industrial equivalent of physical plant departments commenting on the complete design drawings for buildings, rather than participating in the initial layout discussions.

INDUSTRIAL GROUPS

Industrial groups face a similar trade-off to unions. On one hand, the good firms can develop a competitive advantage by having inherently cleaner processes than their competitors. With strong enforcement, high waste disposal costs, and high fines, they do well if their opponents suffer. On the other hand they derive big advantages from being in a clean industry. The very safe nuclear power plants suffer from burdensome regulation and an inability to build new plants because of their less safe counterparts. Similarly, other organizations' freedom is constrained by the regulatory environment. The severity of the regulatory environment is determined, to a large part, by the extent to which organizations solve the social problem in response to the regulation. If the problem is not solved under one regime, then a stricter regime is likely to follow. This is determined by the performance of the mean, or possibly the worst firms. Therefore, the high-performance firms are subjected to regulations that are stricter than are needed for them to modify their behavior.

Hence, often, the high performing firms have an incentive to transfer some of their knowledge to the poorer performers. This improves their corporate image and
reduces the severity of the regulatory environment. The mechanisms available will depend on the circumstances and individuals involved. They undoubtedly span from explicit information transfer and sharing, either from corporations or industry groups, to informal persuasion of individuals through social interaction.

GOVERNMENT

Finally, we come to public policy. Before considering alternative approaches, we will critique existing approaches in the light of our model. We will consider two approaches to pollution policy; the various forms of command and control regulation which currently dominate the regulatory framework and the alternatives suggested by the economists. Then, we will discuss some approaches advocated in the energy conservation literature. We will finish the section, the chapter, and the thesis, by considering alternative public policy models.

A CRITIQUE OF EXISTING APPROACHES

COMMAND AND CONTROL

Under command and control regulation polluters are expected to comply to a standard set by the government. Four different approaches are generally advocated. The first involves specifying that a particular technology be installed. Since this completely stifles innovation, it is used rarely, and warrants no further discussion. The other three approaches involve determining a standard, either on the basis of 1) the health risk faced by people, animals, or plants subjected to the pollution, 2) available technology, or 3) economics, either in terms of benefits and costs or simply organizations' abilities to meet standards, or a combination thereof. After that, they are essentially the same. A standard is set and polluters are required to meet that standard.
This approach has two problems. The first, to do with administration, has been
dealt with in many places (e.g. Blinder 1987). The essential problem is that the system
of licenses currently in place is very expensive to administer. With low government
commitment to enforcement, as we saw in the early Reagan years, the whole system is
liable to collapse. The second is that polluters have no law-induced incentive to abate
beyond their licence provisions.

The key question for command and control is whether standard setting can yield
satisfactory abatement. I think not. We have seen very clearly that in most cases
organizations will select orthogonal solutions to their pollution problems if they are
viable. Conversely, if we consider the policy-making process, it is unlikely that a
regulatory agency will require anything stricter than what most organizations can do
relatively easily; orthogonal solutions. However, as we noted in the opening pages of
this thesis, the aligned solutions are the ones we seek. Further, since aligned solutions
require modification of the core technology, and this varies from industry to industry, if
not site to site, it would be very difficult to develop a legally defensible definition of
‘best available aligned technology’. Therefore, even regulations based on best available
technology will be based on ‘best available orthogonal technology’.

Technology forcing is an attempt to push organizations to aligned solutions. In
terms of our discussion here, a technology forcing regulation is one with no viable
orthogonal solutions within the organization's bounds. We have seen, however, that an
effective technology forcing regulation induces a crisis in the organization before it will
reframe and comply. If it fails to recognize the crisis or it reframes and fails to find a
viable solution, then it will be forced into non-compliance and, if the courts support the
regulators, out of business. Will the courts support the regulators? The evidence
suggests that the courts use a political calculus. They will support the agency if it has a
very strong mandate from the people, as in hazardous waste (RCRA 1989) or Chloro-
Fluorocarbons, or if the regulatee is politically weak. For example, while the petrol engine manufacturers were able to successfully block catalytic converter legislation for several years (International Harvester vs EPA 1973) the diesel engine manufacturers, with much less political power, could not obstruct particulate traps (NRDC vs U.S. etc. 1981). Such an approach also has equity problems. If the only people who can be effectively regulated this way are the politically weak, then we are likely to see regulatory differentials for big and small business. This would exacerbate differentials which already pervade the regulatory framework (Pashigian 1983).

So, given an organizational perspective, we can see clearly why the current regulatory system has been a failure.

MARKETS

Since Ronald Coase suggested that markets and hierarchies are virtually interchangeable forms of social regulation (Coase 1937), regulatory analysts has been tempted to jump from one to the other. Throughout political circles at the moment there are cries to go from command and control regulation to a market based model. My feeling from the debate is not so much that people believe in markets, but that they have given up on one model, and want to try the other alternative (as if there are only two). As I said in the introduction, many people have ethical reservations about the market approach (e.g. Sagoff 1988). However, irrespective of this, I see no reason why an unbridled market will work better.

The core of the economists' argument is that pollution is an economic problem, and that through the creation of a market, polluters will develop the most efficient means for mitigating their waste (Blinder 1987). However, we have seen in the energy case, where the technical problem is much simpler, this is just not the case. Organizations are not driven to solve these problems by economic incentives. Similarly,
a division of Dow's return on investment for waste reduction in 1988 was 267% (Nelson 1989). This suggests two things. First, creating a market is not going to change objective incentives very much. Second, even a company like Dow which clearly favors aligned solutions and is considered a stellar performer is under-investing grossly.

Quite simply, while pollution control and energy management have an economic component, they are not economic problems. Decisions are not generally made by rational substitution at the margin. They are organizational problems. Therefore, a policy predicated on the assumption that firms will substitute freely at the margin is bad policy.

There is one other major problem with the creation of pollution markets. By creating a market, the government abdicates responsibility for environmental management. Once a firm has bought a pollution permit, the government has no right to tell it to abate its pollution anyway. The firm has bought that right from the government. Those downstream of the dirty, but rich, company, simply have to suffer for as long as the permit is valid. The establishment of a market for pollution significantly reduces government control over individual polluters for little gain in pollution performance.

If we consider the way in which organizations would respond to a pollution market, the idea becomes less heartening still. There is no reason to believe that firms will not start to speculate on the future price of pollution permits. A futures market might well emerge. Attention to the problem is likely to be focussed in the financial offices of the firm, far from technical information, contextual information, and skills rather than in engineering or line management, where it needs to be for aligned solutions to emerge. If other firms are abating, prices will drop, and the incentive for a given firm in the sector to abate will drop also. In the face of price uncertainties, with a high possibility of price reductions in the future as other firms abate, firms are likely to take
a very short-term orientation to abatement.\footnote{If the other firms actually do abate, this is not a problem. It means that a few firms will exploit the actions of the many. The problem is if everyone assumes that everyone else is going to abate. At that point it becomes a large game of 'prisoner's dilemma'.} Again, incorporation into core production appears unlikely.

**Energy Policy Approaches**

Energy policy analysts attempting to explain the energy conservation market’s failure to clear refer to something they call the high implicit discount rate (e.g. Williams 1989). They note that consumers and firms appear to require a very high rate of return for energy conservation investments. (See Williams (1989) for discussion and citations.) As we have seen, at an institutional level, this high implicit discount rate occurs because energy conservation is essentially not an economic problem. A similar effect is observed for individuals. An experiment by the Bonneville Power administration found that while consumers were responsive to information and very responsive to explicit incentives, there was a very strong interaction between the two (see figure 7.2). This suggests that provision of an incentive overcomes some sort of cognitive barrier to acceptance of new information. That is, it induces individual reframing (Bartunek 1988).

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<th>Incentive level</th>
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<td>Promotion Level</td>
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Sales per 10 000 households. Smallest cell has 20 500 eligible households.

**Figure 7.2 The Impacts of Incentive and Promotional Efforts in the BPA Solar and Heat Pump Water Heater Programs. (Bonneville Power Administration; (1976) Solar and Heat Pump Water Heater Program, Second Interim Report) As Cited In Williams (1989)**
than seeing them as a hook to attract energy consumers' attention (Williams 1989). In contrast, we saw at Tufts, MIT and The University of Massachusetts at Amherst, that the subsidies were much more important for attracting managerial attention than for making programs viable. The same thing appears to happen with shared savings contracts. Two contractors I spoke with noted that the shared savings contract was often much more of a marketing tool than a device for providing a turn key service. They said that once people understood the projects, they would frequently self-finance and capture all the savings.

Given this, we can imagine a much less restrictive set of options for the creation of energy conservation programs. Subsidies are (theoretically) the most expensive way of attracting managers' attention. Shared savings programs can rarely go beyond an organization's infrastructure. The contractor has no contextual information at all. A move from the economic paradigm to an approach which considers incentives as one of many dimensions to be considered should enable cheaper and more effective policy design.

A FRAMEWORK FOR ALTERNATIVE POLLUTION POLICY

An organizational conception of pollution policy would stop viewing the problem unidimensionally. Rather than oscillating between markets and hierarchies, it would consider all dimensions of organizational decision making, and would, over time, attempt to persuade organizations to make pollution control a primary objective. Government can do this two ways. First, it can act directly on the organization. Second, it can act through the other agents; specialist managers, top managers, and external groups. Both times, it will aim to do one of two things; to push back organizational bounds to ensure that they encompass as many options as possible, and to persuade organizations to make a secondary objective primary. (See figure 7.3)
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<td>Outreach Programs Emphasizing Skills and Technical Information. Demonstration Projects</td>
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<td>Temporary Changes in All Bounds</td>
<td>Levy Fees at just below the Social Marginal Cost. Ensure Organizations have Sufficient Resources</td>
<td>Subsidies and Other Programs to Empower Managers. &quot;Tactics&quot; Transfer Programs</td>
<td>Seminars, Compulsory Workshops, Lunches. Aggressive Regulation. High Emphasis on New Facility Design</td>
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<td>Outreach Programs</td>
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<td>Gradual and Permanent Changes in Objectives</td>
<td>Levy Fees at just below the Social Marginal Cost. Ensure Organizations have Sufficient Resources</td>
<td></td>
<td>As Above plus Uncertainty and/or Increasing Severity in Regulation. Empower Potential Change Agents</td>
<td>Ensure Supply of Resources and Information through &quot;Right to Know&quot;, Citizens' Suits, etc.</td>
<td>Outreach Programs and (for Industry Groups) Regulations Based on Worst Organizations' Performance</td>
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<td>Rapid and Permanent Changes in Objectives</td>
<td>Levy Fees at just below the Social Marginal Cost. Ensure Organizations have Sufficient Resources</td>
<td></td>
<td>Criminal Liability Provisions. Regulation which is as Aggressive as Politically Possible</td>
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<td>Empowerment and Legitimation in Legislation. Increase in Size of Fines</td>
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**FIGURE 7.3 POLICY OPTIONS FOR GOVERNMENT; ACTING ON EXTERNAL ENVIRONMENT, SPECIALIST MANAGERS, SENIOR MANAGEMENT, AND OUTSIDE GROUPS**
POLICIES WHICH AIM TO PUSH BACK ORGANIZATIONAL BOUNDS

As we saw above, policies which aim to push back organizational bounds temporarily can operate in one of two ways. Either they can target individual bounds, or they can attempt to unfreeze the organization temporarily while it attempts to solve a novel problem.

The first condition for an effective policy is that the organization's external environment should reflect the public interest and not inhibit decision making. Therefore, polluters should pay just less than the marginal social cost for their pollution. This could be as a financial cost, or on an alternative metric, such as a threat of criminal prosecution if the organization does not meet standards. It is important that they face the right incentive to abate so that when they are moved to action, they move the right amount. However, this is not a right to pollute. It is an incentive to abate. It could easily be used in combination with an emissions standard. Given that waste reduction often pays handsomely, this is probably more important as a stimulant to action than as an incentive. A dollar spent is more salient than a dollar not saved (Tversky and Kahneman 1981). Second, organizations should not be constrained by the availability of resources, information or skills for them to modify their production techniques. As appropriate to the industry, outreach and assistance programs and demonstration projects which expose organizations to ideas and overcome external constraints should be integral to any policy.

Policies can operate through all three of the other groups of actors. First, it is possible to structure policies which make it much easier for specialist managers to overcome the internal bounds of organizations. For example, we saw that the principal reason energy subsidy programs worked in three of the case study universities was that

7 If they paid the full social marginal cost then further regulation would be theoretically unjustified.
they were very effective at attracting the attention of senior management and therefore overcoming political constraints to energy conservation. Consequently, a program directed at specialist managers could have a series of devices created to overcome these bounds. These could range from subsidy programs to information transfer programs to teach managers tricks for getting around institutional obstacles. However, they should not be prescriptive since contextual factors will vary between industries and sites.

We saw above that senior managers will institute temporary attacks on a problem if they see opportunities or if they perceive a crisis. Given that aligned solutions are often so lucrative, one policy approach involves making managers aware of the opportunities. This could be done through seminars, compulsory workshops on waste minimization or other aligned solutions as part of licensing, or compulsory lunches with outreach workers for companies participating in outreach programs. Such programs could emphasize the need for enhanced communication between specialists and line managers, and the possibility of moving responsibility into line positions (actually a gradual but permanent change strategy). Alternatively, crises can be created. This can be done by regulating as aggressively as possible given the political climate for the problem at hand and the constraints of the Administrative Procedures Act. This will induce reframing in the maximum number of organizations. Finally, as with energy conservation, the most important single determinant of the pollution coming from a plant is its initial design, not subsequent modifications. Enormous regulatory effort should go into new facility design.

Because the solution of one problem is unlikely to permanently solve a polluter's problems, many public interest groups are interested in using citizen suits to bring about long-term changes in organizational approaches to pollution control. Therefore, creation of a temporary crisis which does not change management can often be seen as a

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8 Interview, Charles C. Caldart, Staff Attorney, MassPIRG, July 11th 1989.
failure. If we accept this perspective, which governments interested in permanent solutions to pollution problems should, there are no real policy options here. Since this is not a conventional area for union activity, the most important policy approach is probably outreach to make unionists aware of the potential for solutions which they could use to lever their positions during discussions with firms. There is probably little government can do to facilitate discussions in industry groups, except possibly to increase the incentive for good performers to help poor ones. This could be achieved by making explicit the fact that future regulations will be determined, in part, by the worst organizations' performance.

POLICIES WHICH AIM TO CHANGE OBJECTIVES

We noted above that specialist managers cannot aim to change objectives. Further, the policy approaches for the organization's external environment (ensuring the organization faces the marginal social cost and is not resource, information, or skills constrained) do not differ for temporary and permanent change. Neither do prescriptions for unions or trade groups. Therefore, we will not discuss any of these further.

Policies directed at senior managers to induce gradual permanent change need to show either that there are benefits from a permanent shift in objectives or that there has been a permanent shift in the institutional environment which threatens the organization. Such a policy needs to promote a long-term perspective on the problem. That is, it should be seen as something fundamental to organizational survival in the long term, not as a short-term issue. Two devices are available to do this. The simplest is to make each successive policy more severe than the one it supercedes. That is, each piece of legislation should be seen as one of a series of laws, not just an isolated piece. However, there is another alternative. The government can create to possibility of increased severity without actually doing so by the careful use of uncertainty. At Dow,
I found that the liability provisions of the 'Superfund' act were effective at modifying organizational behavior much more because they created the possibility of retrospective liability for new pollution to air and water than because they created liabilities for old hazardous waste.

Another alternative would be to intervene directly in the structure of the organization. That is, recognizing that organizational boards are inherently political, attempt to empower people who support change. This could be done by mandating the creation of board environment and safety committees or changing the audit laws to include susceptibility to environmental contingency. The aim here would not be to create change. Rather, it would be to increase the probability of change.

Long term rapid change is achieved by discontinuous and rapid shifts in the environment. The aim would be to increase the contingency perceived by senior managers. We noted above that the creation of criminal liability for pollution violations appears to be doing that admirably. Aggressive regulation appears to be the other alternative.

"So I turned to the judge and I said, 'We may be gadflies your honor, but we're Congressionally authorized gadflies.'" (Caldart, Interview 11 July 1989) discussing response to a defence attorney who questioned the right of public interest groups to bring citizen suits.)

Any external group operating in the policy arena needs a political mandate and resources. The labor legislation of the 1940's gave unions that legitimacy. The Environmental legislation and supporting debate of the past twenty years has given environmental groups the power to perform citizen suits, access to information (through compulsory emissions statistics filing) and resources (through cost recovery provisions of the legislation). A policy aimed at permanent change through interest groups has to perpetually reaffirm their right to participate in the process and guarantee that their work is not obstructed by a lack of information, skills, resources, incentives, or power.
Furthermore, these groups must aim for radical change. They are unlikely to sue a firm more than once. Therefore, they must be seen, by the organization, as real threats. Since they cannot bring about criminal suits, they must be able to secure strong civil remedies. Therefore, the amount of damages they can secure should be increased. Possibly the fine provisions of the legislation should be changed so the fine equals a significant percentage, say 10%, of a facility's annual revenue (i.e. most of the profits).

CONCLUSION

This completes the policy options. None are new; all have been proposed before in one form or another. What is new is the framework for assessing them. Effective policy addresses nine elements of organizational decision making; technical information, contextual information, connected information, skills, capital, land, labor, power and incentives. Furthermore, if it addressing a long range problem, it aims to change the regulated organization's objectives so that its decision making will be as rational as possible given the forces bearing on it. If this can be achieved then organizations will make good decisions, hazards will be eliminated, and public objectives will be realized.

(The answer to the question on page (ix) is:

One, but it takes two years and ten months.)
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APPENDIX A. ENERGY TECHNOLOGIES

I. INTRODUCTION

Throughout this report and the appendices there is reference to different technologies and their changes over time. In this appendix, I briefly review their histories for readers who are unfamiliar with them.

II. LIGHTING

The incandescent light bulb, developed in the nineteenth century, operates by passing a current through a very thin wire (generally Tungsten). The current heats the wire until it glows white hot. This glowing lights the room. These lights are very inefficacious, producing only about 20 lumens of light for every Watt of power input. Most of the energy is lost as heat.

Consequently, the development of the fluorescent light tube was a major breakthrough. Their greater efficacy meant that they not only did produced more light for each unit of energy input, but they also gave off less heat. This reduced cooling loads considerably. The conventional fluorescent tube consists of two parts, the tube and the ballast. The tube contains a gas. If a current at high enough voltage is passed through it, electrons will be excited and become quantized. (That is they jump from one energy state to a higher one, or even escape from the atom completely. They then hit the side of the tube, which is painted with phosphorus, and excite the electrons there. These electrons are quantized and jump up a state. When they are returned to their initial state they emit light. Some of that light is in the visible range. The process of exciting
the gas initially is complex, though it is important to note that it takes a significantly higher voltage to initiate the process than to perpetuate it.

The other part of the light fixture is the ballast. This ensures there is sufficient voltage across the tube. However, savings can be made by reducing the voltage after the light has been initiated, and by increasing the frequency of the current. By increasing the frequency the illumination level increases. Finally, there are two ways of controlling the voltage. Either an inductive transformer can be used, or an all-electronic system can be used. So, there have been changes in ballast technology over time.

An optimizer ballast (cost $20.00) differs from a standard ballast (cost $5.00) and an electronic ballast (cost $65.00). A standard ballast is a step-up transformer which raises the voltage in the tube while the tube is on. The optimizer ballast only raises the voltage until the arc strikes, and then it returns it to a lower level. An electronic ballast raises the cycling frequency in the tube, to increase the amount of light in the visible range, and it has an electronic rather than an inductive transformer. This has a longer life than a conventional ballast.

In the early 1980's it was possible to make the electronics small enough and cheap enough so that the entire tube and ballast could be installed in a fitting about the same size as a conventional incandescent bulb. This created a tube with about ten times the lumens per watt of input and about ten times the life (10,000 hours) for only about twenty times the cost ($10.00 versus $0.50). This gives big savings in three areas; the lights produce much less heat, use much less electricity, and require changing much less often. (It costs about $2.00 to change a light bulb.) These are known as compact fluorescent, U, or PL light tubes.
III. CONTROLLERS

A building control system consists of four distinct components; a computer or computer system, controllers, sensors and actuators. The actuator is the device that actually opens and closes the valve, moves the damper, or whatever after being instructed to do so by the controller. The controller tells the actuator when to operate, similarly it may tell lights to turn on or motors to start. It does this on the basis of information that it receives from the sensors (temperatures or light levels compared to set points) or from the central computer. The extent to which that information is locally generated has varied over time and is discussed further below. The following is a brief history of the development of these control technologies. I make no claim of completeness; I have included only those facts that are relevant to the four case studies in this research.

There are three types of actuator in common use at the case study universities. The simplest is an electronic switch that turns equipment (especially lights) on and off when instructed by the controller. Electric actuators have small motors that mechanically open and close dampers and valves. That is, the motor is mechanically geared to the spindle that opens the valve (the valve stem) or damper. When the motor turns, so does the spindle. Pneumatic actuators, on the other hand, raise and lower the pressure of air in a tube to open and close a bellows which is attached to both the valve stem and an opposing spring. As the bellows moves out, the spring contracts and the valve stem moves.

Sensors include things like thermometers, barometers, humidity gauges, light meters, and so forth.

There are two types of controller in use; pneumatic and digital. "The principle behind pneumatic controllers is that the sensor sends a pneumatic signal whose pressure
is proportional to the value of the variable being measured. (e.g. temperature
difference) The controller contains circuitry that compares this air pressure from the
sensor to the desired value of air pressure, and outputs a control signal based on this
comparison. The pneumatic controller receives and acts upon data continuously.\footnote{1}

"A direct digital controller receives electronic signals from the sensors, converts
the electronic signals to numbers, and performs mathematical operations on these
numbers inside the computer. The output from the computer takes the form of a
number, and can be converted to a voltage or pneumatic signal to operate the actuator.
The direct digital controller must sample its data because the computer must have time
for other operations besides reading data. If the sampling interval for the digital
controller is chosen properly, no significant degradation in control performance will be
seen due to sampling.\footnote{2} Direct digital control was first used in 1976, and has become
increasingly popular ever since.

Pneumatic controllers are significantly harder to maintain than direct digital
controllers, and a lot less reliable. They are generally maintained by the heating,
ventilation, and air-conditioning (HVAC) maintenance staff. Very significantly, they
are set in the field, and even if connected to a central computer, it is often hard to
determine the set-point. Direct digital controllers on the other hand are much more
reliable. If they fail however, the tend to go into gross error, not to slip gradually out
of adjustment. Failures are obvious. Since, they require very different maintenance
skills to pneumatic systems, they are often maintained by a special group such as the fire
services people. They are rarely maintained by the heating, ventilation, and air-

\footnote{1} American Society of Heating, Refrigerating and Air Conditioning Engineers; 1987
HVAC Handbook; Heating, Ventilating, and Air Conditioning Systems and Applications, p51.1, 1987,
American Society of Heating, Refrigerating and Air Conditioning Engineers,
Atlanta, GA.

\footnote{2} ibid
conditioning mechanics. Set points and actual performance can be read from a central computer. In other words, pneumatic systems are less reliable, are set in the field, and are maintained and set by the same people who are maintaining the equipment being controlled. For direct digital control, the setting and maintenance are carried out by two groups, neither of which is maintaining the equipment being controlled. Systems are reliable, but fail grossly and rapidly.

Until the late 1950’s, building control systems consisted of controllers, actuators and sensors, plus a manual gauge to put in set points. (Like a thermostat dial) With the advent of the digital computer, it has been possible to control the system remotely. Two types of systems have evolved. One is a centralized monitoring (or supervisory) system; that is a device that either enables or disables local controllers on the basis of times, and sometimes temperatures. That is, all the system set-points are input in the building. Keeping track of the set points is an enormous management task by itself. So, to set back temperature at night, two thermostats are needed. At the appointed time, the computer switches one off and the other on. These systems can also log data for analysis. With these systems, all the controlling is done locally (in the building).

Traditionally local control was done with pneumatic controllers, though it is possible to connect these systems to local direct digital control systems, but only on a monitoring basis. Recently, some simple computational controlling has become available. For instance, master/slave programs have been developed where the computer will turn on several building systems if one goes on. This is very useful for applications like pipe-freezing protection in Winter. Similarly, some systems will alter the start-up time for heating equipment in response to the outside temperature.

There are two ways of connecting the computer to the controllers. One method is to run a pair of wires to each controller from the computer. However, it is possible to run a single pair from the computer to a device called a multiplexer. This acts as a
gateway from the computer to the controllers. Originally multiplexers were 'dumb'. That is, they could only perform functions if instructed by the computer. More recently, smart multiplexers have become available. These perform the mainframe functions locally and the computer is used as a repository of data and to change times.

With a direct digital control system, the controlling is done with a computer. So, instead of the computer being auxiliary to the system it is integral. The computer calculates a valve or damper position, and sends a signal, possibly via a transducer, to an actuator. These systems are much more powerful than the supervisory systems since it is possible to program the entire system, rather than just individual controllers. So, control can be highly integrated and carefully optimized. Algorithms can monitor system feedback very closely and optimize on that basis. The control systems have the added, and very significant, advantage of being able to monitor individual pieces of equipment. So, they can monitor both hours of operation which is useful for preventative maintenance, and actual operation, so they can see (for example) if a belt is slipping. This can be of great assistance to maintenance personnel (and management) because it enables them to ensure that mechanical repairs are successful (whether they like it or not). It is not possible to beat the system by either by-passing the controller or altering the set-point. Also, direct digital control systems are much more reliable than the pneumatic, which tend to slip out of calibration every month or so.

As with the monitoring systems, the early direct digital control systems had a pair of twisted wires going to every controller from the mainframe. Subsequently, unit controllers which operate at a building (or a floor) level have come available. In these more distributed systems, the mainframe collects data from the panels in the buildings, while the actual controlling is done by the panels themselves. As well as saving on wiring, since these unit controllers run the buildings, it is possible to install direct digital control systems on a building-by-building basis; without any need for a mainframe. The
mainframe is for centralized operation and monitoring, data collection, and optimization.
APPENDIX B. MIT

I. INTRODUCTION

A. INTRODUCTION TO THE CASES

The cases raise many issues beyond those presented in the main text. While the main document deals with data relating to energy efficiency in the four universities, the case material presents that data in much more detail within the context of other things going on in the university. So, for example, understanding how operations and maintenance is carried out is important if we want to see the organizational bounds in a much less abstract manner.

In all the cases, I have tried to keep the interview summaries to the main text and have used the footnotes to either provide limited analysis, expand upon points, or elaborate on terms.

B. COMPARISON WITH OTHER CASES

The MIT data was collected differently from the other cases. As an MIT student, doing MIT sponsored research, I could develop much better relationships with the interviewees. Consequently, interviews were more numerous and more specialized and therefore the data is more focussed. In addition, I could gather a lot more informal data on both building operations and users' attitudes. This offsets, partially, the fact that the MIT data was collected first.
C. THE CAMPUS

The 130 acre MIT Cambridge campus, on flat site adjacent the Charles River, has been growing since 1916. There are about 115 buildings with a total floor area of about 9 000 000 square feet serving a community of 10 000 students (5 000 undergraduate) and associated faculty (950) and staff (7 100).

The campus grew principally in the period 1960-1980. The total floor area almost doubled from 3 750 000 square feet in 1962 to the time of the first energy management system's implementation (In 1976).1 Not surprisingly, this was accompanied by hectic. At one point in the mid-sixties nine buildings (including 500 000 sq. ft. of laboratories) were completed in a period of two years. Buildings designed prior to the early-1970s (and built in the mid-1970s) were engineered with little consideration of energy consumption. Those energy conservation studies carried out during design showed that energy saving technologies were not cost effective. All buildings were designed or refurbished by leading architects, the selection of whom is discussed below.

The campus comprises buildings of all types, but principally residential (dormitories), office and laboratory, and parking garages. Within these are energy uses representative of most domestic, commercial, and industrial situations. The high energy Physics laboratories (North West section of the campus) are metered separately from the main campus and their research energy use is charged to sponsors as direct rather than overhead cost.

D. THE INSTITUTE STRUCTURE

MIT never stops.

1 Barrett, P.F., (July 1983); "How our energy management system has changed the way we run our physical plant." Annual meeting of physical plant administrators of universities and colleges. Louisville, Kentucky.
The Institute has five schools; Architecture, Engineering, Humanities and Social Sciences, Management, and Science. There are many support departments. Most relevant for this study are the Physical Plant Department, the Housing and Food Services Department, the Planning Department (responsible for campus planning), and the Office of Facilities Maintenance Systems (responsible for space allocation and space use planning). The Physical Plant Department is responsible for design, operation and maintenance of all structures and non-laboratory equipment on the campus, except the dormitories. These are designed and operated by the Housing Office, which has its own staff for minor repair work. The Physical Plant Department provides utilities, maintenance and operation of HVAC plant, and workers on request.

The Institute is dominated by its engineering school. There has been, traditionally, the strong emphasis on technical solutions to problems which engineering provides. All the senior administrators in the Physical Plant Department and many in the Institute are engineers. When the new director of physical plant was appointed in late, ‘Tech Talk’, the official Institute newspaper, noted that the Physical Plant Department staff, when asked, had requested that the new director be technically competent. While there are many ways of interpreting this, two obvious ones are that either 1) the Physical Plant Department staff see management of the 700 physical plant staff as predominantly a technical task, or 2) that ‘Tech Talk’, reflecting the reporter’s interpretation of the Institute culture, believes this is the most important thing for readers to believe. Both are ironic, given the major findings of this thesis.

The Physical Plant Department is traditionally separate from the faculty. Whereas, at the other case study universities, faculty have been brought into policy decision making in the Physical Plant Department, at MIT they are conspicuously absent.
II. HISTORY AND ORGANIZATION FOR ENERGY CONSERVATION

Energy conservation has been pursued, with varying intensity, since the early 1970's. Rough effectiveness measures are:

* Electricity consumption peaked at 16-17 KWH/sq ft/yr in 1971 and dropped 25% to 12.4 KWH/sq ft/yr by 1978. It has subsequently risen to about 14 KWH/sq ft/yr and until the start of the Cambridge-Electric initiative, was rising at an annual rate of 5.5%. Most of this rise is attributed to the proliferation of personal computers and laser printers.

* Steam consumption peaked at 175 lb/sq ft/yr. At the end of 1987 it was 100 lb/sq ft/yr, and falling.

However, please note that the intensity of space use, independent of energy conservation, has changed significantly in that time. New buildings have been added to the campus, many of them with very extensive laboratory, computer, or hospital facilities. In addition, people's consumption habits, particularly due to the introduction of computers, has changed.

A. THE ENCON PROGRAM

1. ORGANIZATION

Before the installation of the Facilities Control System in 1976, the MIT Physical Plant department comprised three large divisions: Utilities, Architecture Engineering and Construction, and Building Operations. Building Operations was responsible for cleaning and grounds as well as building envelopes and contents. At this time, the operations group was divided into three units, under a supervisor, each of which was responsible for a different area of the campus. Each building had its own mechanic who would be responsible for ensuring it remained operational and comfort standards were met. There were about sixty building operators.
Generally, this system was unsatisfactory. Adequate maintenance quality was difficult to ensure. This was attributed to several factors, but in particular, quick solutions rather than thorough ones were desirable. Therefore, praise and promotions were available for quick (and low quality) workers. Also, people worked in very localized teams, so it was difficult to provide centralized supervision of their work, or to obtain any management information. Finally, there was significant conflict both between the various shops, with people from some shops refusing to even walk into others,\(^2\) and between management and the work-force, with management on the second floor and labor on the first. Since the system was poorly maintained, comfort was difficult to achieve.\(^3\)

2. THE PROGRAM

In November 1973, one month after the start of the first oil crisis, the Physical Plant Department created an Energy Conservation Committee.\(^4\) This committee initiated ENCON, MIT's first energy conservation program. In January 1974, The Union Pacific Foundation gave MIT a grant to employ an environmental engineer for twelve months to initiate an energy conservation program. Mark Farber joined the staff and has devoted virtually all his time to the campus energy system ever since.

The ENCON program had several phases. Some emergency measures preceded systematic analyses:

* Temperatures were set back to 68° in occupied spaces, 50° in unoccupied spaces, and 65° in corridors. Night setting back began

\(^2\) Interview, Superintendent of Operations

\(^3\) Barrett, P.F.; ibid

\(^4\) The reader should note that, not surprisingly for this case, the committee did not involve anyone outside the Physical Plant Department, either in the other administrative departments (such as planning) or on the faculty. Similar committees at other sites had extensive faculty involvement.
(where previously heat and light had been maintained 24 hours daily) and after-hours ventilation in non-laboratory buildings stopped.

* Winter air-conditioning was stopped except in computer rooms and laboratories.

* Unnecessary lights were removed, general and task illumination levels were lowered, and there was extensive conversion of incandescent to fluorescent lighting.

* After-hours classes were moved to low-energy using buildings

* There was an extensive outreach program which included a fairly unsuccessful inter-dormitory competition.

The second phase involved a detailed analysis of building energy use characteristics. They found that the energy guzzlers were the buildings constructed after 1960, particularly the air-conditioned structures. So, they refined the operations of these buildings. In particular, they eliminated as much simultaneous heating and cooling as possible by operating systems so that they either just cooled, in Summer, or just heated, in Winter. Simultaneously, they maximized air recirculation, except where it was cheaper to use fresh air (if the outside temperature is between 53° and 78° Fahrenheit. Also, they installed a series of simple time-clocks to save operators from turning the systems on and off the whole time. As part of Phase II, the Physical Plant Department produced an impressive document explaining the ENCON initiative, describing the technology of heating and cooling, and appealing to users for

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6 Some (but not all) HVAC systems operate by chilling air so it is at least cold enough to provide heating to the area needing least heat, and then adding heat locally (reheating) so that each zone is at the right temperature. See ASHRAE (1985) for more information. At MIT, they simply stopped reheating, and controlled the temperature of the one air stream much more closely. As well as giving more variation in the temperature, this also increased the humidity significantly (in Summer). However, no one complained.
cooperation. Most notable about the document is its very strong emphasis on the technical problems of running an HVAC system.

B. DIRECT DIGITAL CONTROL

1. THE INITIAL DECISION

As the program continued, it became obvious that computerized facilities control offered savings. In 1975 they started looking at possibilities for control and in rented an IBM System 7 computer. It was little more than a 'glorified time-clock'. It was operated on a small scale, and showed that there was potential for better operations through computerization. It was called Facilities Control Systems One (FCS-1).8

The Physical Plant Department drew up a specification for a conventional pneumatic control system. Lacking skills, they seconded an IBM employee who had extensive experience in controls, especially for machine-tools. This engineer thought it would be relatively simple to develop a direct digital control HVAC control system and that the industry would probably start moving to direct digital control.9 So, they drew up a fairly standard specification but included a statement that were interested in direct

7 MIT Department of Physical Plant, ibid.

8 While all the other sites refer to these computers as energy management systems, MIT's is a facilities control system. The choice of the word facilities indicates their understanding that this technology pervades the plants' operation. The choice of the word control, rather than management, provides a revealing insight into the MIT mind-set. Furthermore, while the other sites nickname their computers 'The Delta' (Harvard) and 'The large system' and 'the small system' (The University of Massachusetts at Amherst), the MIT computer is referred to by an acronym.

9 These systems are differentiated in Appendix A. In essence, a direct digital control system uses algorithms to compare sensed data to set-points and directly operates motors which actuate valves and dampers. A supervisory system operates more or less as a time clock, enabling and disabling locally set, pneumatically actuated, controls.
digital control and a sketch controller design. All of the bids came in at about the same price. None of the tenderers offered direct digital control.

Once they won the contract, some of the technical people from United Technologies felt they could do the direct digital control, so they offered it at the same price, if MIT agreed to help write the algorithms. The Physical Plant Department committee was divided over whether to accept the bid. While it was theoretically very attractive, MIT would be the prototype installation. The then Director of Physical Plant (subsequently Senior Vice President) decided to pursue the direct digital control system. While the vendor underwrote a lot of the development cost, MIT staff were involved extensively in the writing of the algorithms and the teething problems associated with installation. He said in an interview:

"And then we had United Technologies that was interested in developing this system, and some of us thought that if they could run 707s and other complicated things, maybe they could run a simple air-conditioning system."

The system controlled 34 of the most energy-intensive buildings on the campus; some 4 000 000 square feet, including the dormitories (which were later controlled much less). A wire was run from each control point to the central mainframe.

The benefits of the system were felt almost instantaneously. As one interviewee said:

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10 There were seven at the meeting, six staff members and the then Director. The six staff were divided evenly so the director made the decision. None of the interviewees described the decision making as conflictual or acrimonious. However, it may be a coincidence, but, of the four who supported the implementation, one became Senior Vice President, one Director of Physical Plant and another Associate Director of Physical Plant. Of the three who opposed the decision, two subsequently left MIT.

11 Subsequent generations of the technology, which appeared almost immediately afterwards, had unit controllers in the individual buildings and communication lines running back to a central computer. That way, instead of having a pair of wires from every control point, there was only one pair for the building.
"We found that when we put the first system in, that most of our systems were being run on a pretty gross manner. A small example; if someone has a plugged strainer in their radiator, you can either clean the strainer or put hotter water in the system. The mechanic found it easier to put hot water. So you found that all systems were operating like that.

"We found several cases where pre-heat valves were combined. It was about 60° the day I looked at it, and bringing it through a pre-heat coil raises it to 110°. With a chilled water coil, it drops it back to 60°, and everybody's happy. But we spent a lot of money in between. Those things never showed up. But with the energy management system, where you are remoting all those points, and putting an alarm on all those points, you'll know about it right away."12

Redundant control points were installed to improve diagnostics. However, the original system had insufficient temperature sensors, so there was poor feedback. Redundant sensors limit very wasteful practises such as controlling temperature very precisely by simultaneously heat and cool. However, excessive diagnostic points would be prohibitively expensive. Similarly, the control system wasn't run to the end of the physical system. The last stage is generally left to local (often user, but not always) control. The controls are operated on the basis of algorithms developed over time, and dependent on such things as outside temperature and humidity. This provides an upper limit on the gross energy available in the building.

As we would expect there were difficulties bringing the system on-line. But, the faculty and senior administration were reasonably understanding, so there were no major difficulties.13 These were small when compared to the organizational change the computer precipitated.

12 Currently supervisor for engineering design
13 The observation comes from Barrett, P.F.; ibid. It is an interesting insight into the organizational dynamics of MIT that he didn't mention acceptance or understanding from either the students or staff.
2. Organization

a) Operation and Location

The installation of the facilities control system significantly affected the operation and organization of the plant. Initially, they tried to install it in a space adjacent the central utilities plant but were met with strident opposition. So, they moved it into the midst of the mechanical shops.

Barrett, in his paper says:

"At first, we didn't fully recognize the far-reaching management implications of the location decision for the FCS monitors. Because we had space available, we initially put them in a building adjacent to our central heating plant. When the question arose of who would do the monitoring around the clock, it seemed logical to consider training the heating plant watch engineers for this work. They were already maintaining a 24-hour rotating schedule. As we started to put this into effect, we immediately received a grievance from the plant engineers. ... They felt very uncomfortable getting involved with events outside the boundaries of the plant and wanted no part of the computer. ... We began to rethink our initial decision in relation to management control of this very critical operational tool. ..."

The Operations Center was moved from the central utilities plant and its functions were expanded significantly. It is located amongst the various shops in the Physical Plant administrative building. This greatly improved communication between the shops, as it created a central focus, and highlighted the need for increased communications between functional groups. Its establishment was also used to move some of the line managers onto the ground floor, decreasing the organization's hierarchical nature.

While it would be unreasonable to say that the Facilities Control System was the only reason for creation of the Operations Center, it was the principal cause. Vacha (1981) has noted that there were several other elements. Particularly he emphasized..."
Institute growth. However, he does devote the major part of his paper to the implications of the installation of the facilities control system, and in his conclusion says, "The operation of the Control Center is going to get even greater attention during the next few years. Computerization is a mandatory consideration. ..."\(^{14}\)

\(b)\) Restructuring

The facilities control system had two radical effects on the organization of the Physical Plant Department. First, it changed the organization’s channels of information flow. Second, it redefined many mechanics’ jobs. In particular, the one third of the mechanics who spent their time touring the buildings became redundant.

Rapidly, the operations section and the central utilities plant became more tightly coupled. The computerized system was fulfilling several quite distinct functions.

* **BUILDING OPERATIONS MONITORING AND CONTROL.** This allowed optimization of the operations of the individual components and frequent observation to ensure they were not failing (removing the need for walk-throughs) Feed-back was possible.\(^{15}\) The need for manual adjustment of valves etc. in response to changes in central plant output was eliminated.

* **OPTIMIZATION OF CENTRAL PLANT.** Careful control of temperature and pressure of steam and chilled water flowing into buildings and the timing of electrical devices allowed minimization and staging of energy consumption. This allowed more even and predictable operation of the central plant.

* **DATA ACQUISITION.** The centralized monitoring system constantly measured systems. This was, (and is) relatively easy to log into memory.

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\(^{14}\) Vacha, Thomas F.; (1981); "Establishment of an Integrated Physical Plant Control Center." *Annual meeting of physical plant administrators of universities and colleges.*

\(^{15}\) Informal interviews with users and a direct digital control vendor suggest that this can create complacency where the operators of control systems become less sensitive to problems with system elements which are not attached to the control system.
The other effect was the change in the staff profile. Prior to the Facilities Control System's installation, sixty mechanics maintained 6,000,000 square feet of space. With the system in place, only 40 are needed to maintain 9,000,000 square feet. Most of these savings result from elimination of the need for people to walk through the buildings regularly, and the ability to infer problems with the Facilities Control System, and therefore send mechanics to sites with all the tools they need to fix things.

Rapidly, the central monitoring center grew into an operations center. From this base, it took on scheduling responsibilities and the day-to-day running of Physical Plant operations. These functions do not fall exclusively in the province of the central plant. And, in fact, optimization of the operation of the central plant on a day-to-day basis needs considerable coordination between the central plant and the local operators. Hence, it is not surprising that the introduction of the computer system was soon followed by a re-structuring of the Physical Plant Department into the current four divisions. This restructuring had not been anticipated when the energy management system was purchased. However, once it was realized that changes needed to be made, the opportunity was exploited to bring about other needed organizational reforms.

These reforms required extensive, and often difficult, staff retraining to facilitate communications. The few managers who were unable to adjust to increased communications and lateral sharing of information were replaced with externally recruited managers. The mechanics were all reclassified and their numbers were reduced from 60 to 40 (by attrition). Evening and night shifts were added.

So, the Physical Plant department was re-organized into four divisions. They are:

One of the less obvious reasons for incorporating the central plant into the Operations Division was the potential for an externality arising. i.e. If the plant and buildings were optimized separately, the sum of the two optima would be less than the combined system optimum. This is true on both a day-to-day basis and in the longer term. For example, when replacing some equipment, the Operations Division may over-emphasize maintainability and under-emphasize energy savings in its choice.\textsuperscript{16}

The need for training was identified after it became apparent that the facilities control system demanded higher quality maintenance and therefore higher quality mechanics. It was formed initially to bring building watches up to the level necessary for effective operations.

* Support Services and Building Maintenance
* Architecture Engineering and Construction
* Utilities and Engineering

The physical plant director oversees Building Operations and the Support Services groups. However, the associate director is considered to have specific expertise in energy management, having been responsible for both the ENCON and BEAM programs and therefore takes responsibility there.

Within the Operations Division, it appears that decision making is not as formalized as the structure suggests. Each manager has both line and general responsibilities. Several interviewees commented on the strong matrix management structure that had been developed, at a managerial level, (manifested through collective decision making on a given level at weekly meetings).

The Support Services and Building Maintenance Division has no direct interest in energy conservation. (However, insulation could be used as a selling point for re-

\textsuperscript{16} This is still a problem, despite the apparent linkages. Components are purchased virtually always on the basis of operability, though they have moved to things like high efficiency motors recently. It appears that this has happened because high efficiency motors are probably no harder to operate than standard ones. Therefore, energy conservation which does not compromise operations. (c.f. the decision to remove heat recovery units at Tufts.)
roofing, just as the superintendent thought a fly-over could be useful for the
Cambridge-Electric initiative. (see later)) Since it is not accountable for energy costs, it
is unlikely to put heat reflecting film on the windows. Similarly, not surprisingly, it is
uninterested in retro-insulating buildings, claiming instead that the insulation gets in the
way of maintenance people. As a final example, one of the buildings (Building 13) has
a large foyer with swinging doors that face a tunnel between two large buildings. The
wind through the tunnel is very strong, and makes the foyer quite uncomfortable in
Winter. Although the building has been analyzed for retrofit three times, this issue has
never been raised. Neither revolving doors nor a planter of trees outside the entrance has
been proposed. The Associate Director commented that it was difficult to get this group
to do energy conservation work. By the time their projects come up to for approval it is
too late to look at different options.

c) The Operations Center

The Operations Center is the node of communications between the MIT
community and the divisions of Physical Plant. However, it doesn't control all the work
done by Physical Plant. Preventative maintenance and other routine functions are
controlled elsewhere. It receives and logs calls from users, Physical Plant staff, and the
telemetry system, and passes the work on to the relevant group. For problems needing
immediate attention, radios and pages are used extensively. Work orders are used for
less urgent problems. Sometimes problem assessment is carried out using radio
communication and a work order is generated for later solution.

Other responsibilities of the Operations Center include monitoring the fire alarm
system and calling the Fire Department (of the City of Cambridge) and the MIT
response team (selected people from the Physical Plant Department and the MIT
Environmental Medical Service) if necessary. Also, it is responsible for the effective
operation of the Facilities Control System in its energy conservation role. Mark Farber
became manager of the Operations Center to carry out this function in 1985. While he
is over qualified and experienced in one sense, the job doesn't require his experience, he
has managed to reduce energy consumption by about 10% over two years. This has been
brought about by progressive optimization of the computer's algorithms. Similarly, he is
responsible for the optimization of FCS-3, the current Facilities Control System. As of
August 1987, they were still completing installation and writing algorithms.

(1) Data Acquisition

The Operations Center, not surprisingly, is the focal point for the Physical Plant
Department's data acquisition. Data are acquired by the following means:

* FIXIT. This is the Operations Center's dial in service number.
  Users call in if they see a problem and the call is logged. The calls
  are recorded. For certain classes of problems, the calls are placed in
  a file corresponding to the relevant building. The shop supervisors
  can then check these files to ensure that there are no endemic
  problems. It is felt by some, however, that this is virtually
  unnecessary, since the various shop supervisors should pick up from
  their jobs any trends in building failures. However, interviews with
  progressively more senior people in the Physical Plant Department
  suggest increasing scepticism over the system's efficacy.

* CLEANERS. The cleaners carry a list of things that can be wrong in
  a room. They are expected to fill it out if they see something in
  error. The lists are then forwarded to the Operations Center which
  makes out work orders. It's unclear how well this works.

* TELEMETRY. As a result of the computerized Facilities Control System, large amounts of temperature, flow, and consumption data are monitored virtually continuously. (I don't know how much of this is trapped or whether or not it is analyzed.)

* PREVENTATIVE MAINTENANCE. As part of the preventative maintenance program, an inventory which lists the equipment, its
date of purchase, servicing frequency, spare parts specifications and
other pertinent information has been compiled. It doesn't list the
servicing history of the components.

* FROM USERS BUT NOT VIA FIXIT. There is a history of
  complaints coming to the Operations Center through the organization
  but not via the FIXIT number. These can be broken down into two
  specific groups.

  * Those that come to the supervisor of the Operations Center from
    either faculty members or staff (generically) or from

279
Administrative officers (specifically). This is the principal route by which Physical Plant expects to deal with problems that are not resolved the first time.

* Those that come via circuitous routes to the Operations Center. The most common of these is via direct complaints from senior faculty to the director of Physical Plant or the Senior Vice President for Operations. The frequency of these complaints is used by the Superintendent of Operations as a rough indicator of the thoroughness of his employees' work. He told me that their frequency has dropped off significantly, so he is satisfied with the way things are going.

* CONTROL DATA. Data are also collected on the jobs that are done, how long they take, where they are done, what parts are used, etc. "The only thing we don't know is the time of day the job is done." (Superintendent of Operations) (Paraphrase only).

d) Preventative Maintenance

MIT has a comprehensive preventative maintenance program. The two operating divisions, operations and support services, are responsible for their own preventative maintenance. In operations, a file, as described in the previous section, is kept on every piece of equipment. The files do not contain service histories for the equipment. Every piece of equipment, including windows, has a maintenance schedule and a set of preventative maintenance tasks. It is all checked at prescribed intervals ranging from daily to annually.

A mechanic who finds anything wrong with a piece of equipment, beyond preventative maintenance, notes it. A work order is made out for someone to address the specific problem. This is given to the supervisor of the relevant shop who then allocates priorities to jobs.

During preventative maintenance, the mechanic takes average measurements on machine performance, but only to ensure the machine is performing satisfactorily. Since there is no equipment optimization program, preventative maintenance is not used to check equipment sizing.
3. Control Operations and Subsequent Upgrades

a) Operations Policy

Everything down to the local level is controlled by the facilities control system. Locally, thermostats are used. These range from user-operable dual dial thermostats, used in offices and other small spaces, through to concealed models. That is, the thermostats are either visible and adjustable, or invisible and adjustable.\textsuperscript{17} For a while they experimented with caged thermostats in the classrooms and other public areas. However, since MIT students are perfectly capable of getting into anything with a lock, this provided excellent entertainment for many enterprising students.

These local thermostats will be effective only if the Operations Center allows sufficient heat or cooling into the zone for them to reach their set points. That is, the operator will control the temperature of the influent water to a building and the local controls will partition the heating and cooling to the space after that.

For large spaces, such as lecture theaters, the temperature and ventilation are controlled from the Operations Center. The setting of the timers for the supply of heat and cooling either for whole buildings or for particular spaces is determined by four factors: 1) The thermal characteristics of the relevant space and the energy system design, 2) the use and schedule for the space, 3) the indoor temperature, and 4) the outdoor temperature.

The Facilities Control System's algorithms allow all this to happen automatically. More direct user control is precluded by the nature of the building's energy system and the long time it takes for a room's temperature to change after heating or cooling begins (30 minutes to an hour, depending on the mass of the structure, its external exposure, etc.).

\textsuperscript{17} For example they might have a little lever on the air-vent. The user would probably never find these.
and the power of the heating system). So, for example, heating of buildings 1 to 10 (the original 1916 group) starts at 6:30 am. This allows half an hour for the steam lines to pressurize and then three quarters of an hour for the buildings to heat before people come in to work in the morning. Once the heat is available, it can be controlled locally (and in this case manually) by hand using either manual adjusters or thermostats.

In other buildings, for example building E40 (East Campus, mixed use), bulk heat and cooling is provided during normal working hours (eight to five). At other times, people with offices may supply heat or cooling with local devices that have timers on them. Those whose work space is in the core of the building miss out. The Physical Plant Department is moving more and more to this approach, as it enables it to optimize heat provision during the day, and to provide comfort without wastage out of hours. It has the ironic effect of providing heating and cooling out of hours for faculty and staff but not for students. The irony is that it is generally the students who work late. (In other buildings, if someone wants heat or cooling out of hours, an entire zone [generally a quarter of the building] has to be conditioned.)

b) Upgrades

In 1979 the system was expanded to include sixteen further buildings, many of them new (FCS-2). These had local (building) controllers with lines running back to the central computer. These local controllers would operate the building independently, and would feed data back to the main Operations Center which would monitor performance and receive alarms while new settings can be fed into the computer. Theoretically there was no need to run the controllers back to the mainframe for anything other than emergency calls and possibly to dump data. However, this approach allowed centralized management of the facility, as well as better operation. For instance, in particularly well understood buildings, it is possible to see almost instantly belt failures or lubrication failures on motors using the facilities management system. Similarly, it is possible to see
whether or not a mechanic has successfully fixed a problematic component (If that component is on the system).

In 1987, the system was upgraded again and the building controllers were replaced with localized processors on each floor. This upgrade was precipitated by a combination of a budget surplus caused by the oil price drop and a very attractive offer from United Technologies. Some problems have been encountered where systems are not based wholly on one floor, but have components on one floor controlling systems on another. (In other words, floor based systems almost need to be in buildings that are designed to be controlled on a floor-by-floor basis.) Now, 60-65 buildings, which consume some 80% of the energy on the campus, have local unit controllers doing the controlling but monitored by a central mainframe. Other buildings are operated under more primitive controls, (time clocks etc.), set by the controls group in the engineering division after consulting with the Operations Center manager.

Many dormitories now have only their main heat exchangers connected to the facilities control system, whereas they had more extensive control originally. The FCS Managers found that it was very difficult to please users. For instance, East Campus (one of the dormitories), had steam radiators with local controls. With the advent of the facilities control system, these were changed to cycled steam. However control was poor and systems were noisy, so it was removed. In other dormitories they found that they needed to place sensors in certain rooms to act as thermostats for much larger areas. The occupants, not appreciating the significance of this, would open their windows and

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18 The vendor had only three facilities of the same specification as FCS-1 in operation and was spending a lot of money training service personnel. Therefore, it was prepared to subsidize an upgrade.
increase the temperature in the rest of the building.\textsuperscript{19} Currently, localized thermostats
are being re-installed with limited success.\textsuperscript{20}

C. THE BEAM PROGRAM

The BEAM program, from 1976 and 1980, was initiated when the federal
government agreed that capital works for energy conservation could be charged to
overhead. For MIT, this meant that approximately 60\% of costs could be charged
directly to sponsors. MIT decided to fund the project by charging the costs directly to
overhead. That is, they did not take out any loans or issue bonds to fund it. The
Physical Plant Department felt that it did not have the skills in-house to do the design
work, so they had all the assessments done by consultants.\textsuperscript{21} The program involved
analyzing the energy consumption, and particularly the air flows, through the most
energy intensive buildings, and retrofitting them with more efficient systems. Six
buildings of ages up to twenty years and with chronic energy problems were retrofitted.
When the program was terminated, one additional building had been studied and the
drawings had been completed (building 66 (Chemical Engineering)), a second had been
studied but not drawn (Building 54 (Earth Atmospheric and Planetary Sciences)), and a
third (buildings 36 and 38 (Electrical Engineering and Computer Science)) was half way
through renovations.

The program was terminated for several reasons. Buildings 36 and 38 were
halted because of user objections. The principal problems related to air quality. People
complained about freshness. While the air had tested as satisfactory, some of the intakes

\textsuperscript{19} Some dormitories still use this system.

\textsuperscript{20} Discussions with manager of Operations Center.

\textsuperscript{21} It was presumably a marginal decision between putting on extra staff and hiring
consultants. There was enough work to occupy an engineer for several years. However, one person may not have been able to work quickly enough.
are near roads, bus stops and loading docks. Another is at roof level adjacent fume hood exhausts. Efforts were made to prevent polluted intakes by prohibiting parking, moving intakes, etc, but the users weren't satisfied. In addition, there was an air distribution problem in the space. Users insisted that the air volumes be increased, and that fans be run 24 hours per day. This resulted in a humidity decrease.\textsuperscript{22} Also, the building temperature became difficult to control, leading to more complaints.\textsuperscript{23} People then insisted that the air volumes be increased further. A couple of years later (~1985), a consultant was employed and the air volumes are now being reduced. Electric humidifiers have been installed. (This is the first time that artificial humidification is being used on campus.) Significantly, it would be cheaper to extend the steam lines to the buildings and use them to supply steam instead, so these will be retrofitted in the near future.

The other buildings were stopped for a few reasons. In 1980, the U.S. was in the grips of a recession, so research funding was very tight. Since the program was being funded directly from overhead, rather than through loans, it caused the rate to rise in the first year, though it would drop in second and subsequent. At that time, the faculty was pressuring the administration to drop the overhead rate. So, this program was suddenly very unattractive. The problem would have been solved easily by either issuing bonds or going to third-party financing. However, this never happened for a variety of reasons.\textsuperscript{24}

\textsuperscript{22} As air gets colder it can retain less moisture. Cold air, when heated, is very dry. If you recycle a lot of the air, it can pick up some moisture from respiring people and plants. However, if you are exhausting all the air, as they were here, it doesn't have that opportunity.

\textsuperscript{23} As more new air added to a space more variation in the space temperature is possible.

\textsuperscript{24} Apparently, the person responsible for organizing the financing wasn't terribly interested in energy conservation.
Simultaneously, the Physical Plant Department was under pressure from the administration to cut costs and staff. The senior administration had lost confidence in the Physical Plant Department's ability to implement the program smoothly. The Plant had under-estimated the managerial effort required to accommodate all user concerns. It soon became apparent that the engineer involved could not handle the management task alone and since the director had just come into the job, there was a shortage of senior management time to assist him. So, they decided that the engineer involved would be more effective concentrating on other parts of the plant's operations.

Since the abandonment decision was made on inter-personal rather than economic grounds, it is reasonable to conclude that the program could have been extended significantly beyond the few buildings that were treated. Therefore, there were presumably significant system savings to be gained in other buildings around the campus. Also, the original buildings treated under the program could possibly benefit from re-analysis in the light of new technologies. These conclusions were borne out clearly in the Cambridge-Electric Initiative

D. THE CAMBRIDGE-ELECTRIC INITIATIVE

In response to a Massachusetts Department of Public Utilities requirement, the Cambridge Electric Light Company initiated an electricity retrofit rebate program. If consumers could satisfy certain criteria, specifically:

* That works be completed by August 31st 1988, (later extended to August 31st 1989)

* That works be carried out under a shared savings or guaranteed savings contract, 25

25 Under a shared savings contract, the consumer splits savings with the contractor in a pre-defined ratio and the contractor finances the works. Under a guaranteed savings contract, the contractor guarantees to save the consumer a certain amount of money and the customer pays for the works.
That savings be measurable, then Cambridge-Electric would give them a cash rebate based on the energy savings, the economic life of the installed capital, and the utility's avoided cost.

MIT decided to participate in the program and, lacking the necessary spare staff and administrative skills in the Physical Plant Department, hired a retired assistant dean for facilities in the Faculty of Arts and Sciences at Harvard to manage it.

He realized rapidly that the job was too big for one contractor, so he solicited proposals from 15 and selected five. He then partitioned the campus on the basis its metering system. He made it clear to the contractors that he was only interested in sharing electric savings with them, rather than savings in oil, gas, or water, or sharing the rebates. So, the contracts were made on that basis. He knew that in doing this, he was exploiting the firms' desires to work at MIT. Normally they would be able to insist in sharing non-electricity savings or the utility's rebate.

The contractors were given historical data, consumption data, and information on prior works.

On the basis of their assessments, considering the value of new capital, electricity savings, rebates and savings in steam and chilled water, the program manager anticipated that the savings accruing to MIT would exceed $14,000,000 (capitalized value over seven years). This excluded the contractors' share, a section of the campus which needed to be re-analyzed, final estimates (the contractors had not quite finished their estimates for the savings at the time of the interview (Sept. 18th 1987)), savings in maintenance, or savings from substituting fuels, but it assumed that all their proposed works would be completed. This corresponded to more than 2,000,000 KWH/yr of energy.

While (before release of these figures) the Senior Vice President was very suspicious that the project would yield anything other than minor savings, the Director of Physical Plant saw benefits in rebates, energy savings and capital renewal, (in that order).

26 Comprising a capitalized value of $7,000,000 in direct energy saving, $2,500,000 in new capital equipment and $4,000,000 in cash rebate over ten years.
1. WORKS

The firms all identified savings through the following:

* Lighting, fan and motor replacements with optimized sizing of motors
* Fume hood motor speed controls and open hood alarms
* Installation of motion sensors
* Placement of heat reflecting film on glass

A likely consequences of large scale capital renewal is a reduced need for maintenance staff. Presumably new motors and light fixtures require less servicing.

It is worth considering quickly these projects.

* Because no non-electric projects are included, few systems savings can be designed into the works. (Note, however that some are being achieved. For instance, fume hood replacements reduce fume hood motor, air handling equipment, and air heating and cooling costs. Notwithstanding, these works will have been optimized for electricity savings only, and not for overall savings)

* While this partially relieves the Physical Plant Department's capital replacement problem, it doesn't replace old capital used to move steam.

* This new capital has a limited economic life, and therefore the failure to implement a system that will replace it at an appropriate time is likely to lead to similar problems in the future.

2. FUME-HOODS

Depending on who you ask, there are somewhere between 600 and 1600 fume-hoods on campus.\textsuperscript{27} However, at the time of the writing (data as of April 1988), it appeared that only about 150 would be retrofitted under the Cambridge-Electric

\textsuperscript{27} The project director thought there were 1600. An interviewee from the Environmental Medical Service thought there were 1000. The Physical Plant Department's manager for utilities (one of the Physical Plant Department staff involved in the negotiations) thought there were 560. The Associate director of physical plant thought there were 600.
initiative. As the footnote suggests, information on this conflicts strongly. However, it appears that the vast majority of the hoods are not going to be retrofitted. Given that each retrofit hood probably saves the Institute about $1,000 annually in energy, this is significant. The enormous loss of savings has arisen, in part at least, from a conflict between the Physical Plant Department and the Environmental Medical Service. The following is a fairly long and detailed account of the problem, as it emerged. It is included because it shows how intra-organizational conflict can frustrate decision making.

Traditionally, MIT has had a policy of running its fumehoods 24 hours daily. The rationale is quite simple. Laboratories with fume- hoods use them as the sole source of ventilation. They are spaces that contain chemicals which may spill accidentally, or may have the tops left off their bottles, or whatever. Similarly, laboratory accidents can occur very rapidly and elicit panic. Therefore, given an uncertain hazard in the laboratory, it is prudent to ventilate them continuously with the hood fans running at full speed. This is an approach that is technologically very simple, and therefore likely to be reliable.

The Physical Plant Department would like to run the hoods so that when the sash (the plexiglass cover which forms the front of the hood) is lowered, the ventilation rate drops. This can be done two ways; one is to put a switch in the sash and to use a two-speed motor. When the hood reaches the very bottom of its travel, the motor drops its speed. When it is raised, the speed picks up. This is the older approach, and has been used in some of the buildings on campus. More recently it has been possible to install a small microcomputer controller with reasonably sophisticated sensing in the hood, and a variable speed drive on the motor. The controller MIT prefers is manufactured by Phoenix. These controllers have advantages over the two-speed drives. First, it is possible to vary the motor speed (and hence ventilation rate) so that the face velocity...
(that is the speed of the air as it enters the hood) is constant. This maximizes the savings. Second, it is possible to keep very close track on the mechanical equipment and its operation, so that if anything is not working properly they alarm and run the hood at full speed.

There were several types of hoods that the two offices were able to agree should be removed from the program. First, the contractors were not interested in hoods that are used for radioactive chemicals. Second, there was general agreement that if a hood is one of several operated by the same fan, it was probably not worth retrofitting.\textsuperscript{28} MIT has a general policy of only having one hood per exhaust (they are particularly worried about exhaust gases mixing and reacting) so there are very few hoods like this. Third, some of the very old hoods (dating from 1916 when MIT moved to Cambridge) had known problems and the Environmental Medical Service prohibited retrofitting them. So, in buildings 1 through 14, there are about 120 hoods. These conditions reduced the number eligible for retrofit to 74.

For the rest of the hoods, the Environmental Medical Service placed two conditions on the Physical Plant Department. The first was that the face velocity of the hood should never drop below 100 feet per second. That is, the air entering the hood should be travelling at at least 100 feet per second whether it is up or down. This is supposed to ensure that any toxins in the hood cannot escape back into the laboratory. The second condition was that there should be a minimum of 15 air changes per hour in the laboratory. That is, on average, the air in the laboratory should be refreshed every 28

\textsuperscript{28} This is a control problem. Essentially, they only want the fan speed to drop significantly if the sashes are down on all of the hoods. Otherwise, it is possible to accidentally stop adequately ventilating the remaining hoods. While one could develop a system where the fan speed drops marginally as each hood is lowered and significantly if they are all lowered, it is much more complicated than the one hood case, and therefore more susceptible to problems.
three minutes. The argument here was that the laboratories have no other ventilation, (they are deliberately separated from the building HVAC return system so that laboratory air is not recycled into offices) and given that there is a chance of unknown spills or open bottles, it is important to maintain a high ventilation rate.

At this point it is worth digressing to consider formal responsibility for the hoods. The Environmental Medical Service is responsible for ensuring that the hoods operate adequately. To do this, they smoke test them between one and four times annually (depending on the hazard). The hoods are then certified as safe. If the hood fails the test, or problems are noted at other times, the Physical Plant Department is called in to fix the equipment. However, the equipment is not the responsibility of the Physical Plant Department, and it is not on the Physical Plant Department's preventative maintenance program. Responsibility for keeping the hoods clean and free from obstruction lies with the department.

In early 1988, as this dispute arose, the Physical Plant Department tried to bring a newly renovated laboratory into service. It had three hoods, all with the Phoenix controllers. Starting up the laboratory had been very difficult. First, there were problems with the design, especially with the make-up air system. Second, the construction supervisor had not been vigilant with the installation, so the installation was poor, and the set-points on the controllers weren't adjusted properly. Finally, as they started up the systems one of the controllers broke. The net result was that it took a lot longer to bring the laboratory into service than it normally would because the controllers

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29 In fact, the refreshment rate in the quiescent corners away from the hood, and especially those separated from the hood by ventilation sources such as doors or air inlets will be ventilated at a much lower rate.

30 Make-up air is unconditioned air brought into the room from the outside and fed into the face of the hood. This saves on air-conditioning costs. It is interesting, and probably significant, that the Environmental Medical Service has never objected to the use of make-up air in the laboratories since make-up air also reduces the laboratory ventilation rate.
kept going into alarm. This was extremely frustrating and time-consuming for the laboratory supervisor and the Environmental Medical Service staff. The irony of this was, however, that many (but not all) of these problems were problems not with the controller, but problems the controller had identified. Normally these would not have been found until the hood was recertified.

Back to the story: The Physical Plant Department employed a consultant to smoke test the hoods to determine the face velocities and to calculate the ventilation rates. He was also required to create a computerized database of the hoods he surveyed indicating things such as age, motor type, fan type, and so forth. The Physical Plant Department felt that this would be a useful management tool for them and particularly the Environmental Medical Service in the future. The tests revealed two things. First, many of the hoods were in poor condition and failed both tests. However, those that failed the face velocity test (about a third) generally failed for one of two reasons. About half of these had something in the hood, like bottles of chemicals, that was obstructing the air flow. The other half had stray air, especially from doors, pushing the air around and out of the hood. Both of these problems were soluble. The obstructions could be removed, and the 'open door' problem would be alleviated by lowering the sash. Second, while most of the hoods had adequate face velocities, only 5% had ventilation rates in excess of fifteen changes per hour. One hood ventilated at 0.9 changes per hour. The consultant also found one hood that was completely broken and, more significantly, found a few where the belt on the hood was broken, so that the

31 This was partially to ensure that there were no disputes with the contractors over workmanship after they had done the modifications.

32 This indicated a problem that the Physical Plant Department had never considered before in their building design, namely that the actual configuration of the laboratory could affect its inherent safety.

33 This was not a worry however as it was being used to store coffee making equipment.
hood motor was operating, but the fan was not turning, and the laboratory users didn't know about it.

Given this, the Physical Plant Department asked the Environmental Medical Service to waive the ventilation requirement. The Environmental Medical Service refused and expressed concern about the reliability of the controllers and their safety in an accident. So, the Physical Plant Department did two things. They wrote to other schools that had installed the Phoenix controllers34 and they wrote to the federal government to see if there was a ventilation standard. All of the schools said that they had had no trouble with the hoods. One, which had 200 controllers, had kept no reliability records, because it had had no trouble with them. Others reported similarly. They all had face velocity standards, but none had ventilation standards nearly so rigorous in their laboratories. The federal government wrote that it had no standard, but that it was about to promulgate one. In that standard it would recommend between four and twelve air changes. Armed with this information, the Physical Plant Department went back to the Environmental Medical Service and asked it if it would accept the federal standard. The Environmental Medical Service said they didn't like it, but that they would have to. So, the Physical Plant Department adopted it. By this stage, the number of eligible hoods of the 120 in buildings 1 through 14 was down to 63, or 60 with the broken hoods.

The Environmental Medical Service was still concerned about ventilation, so it decided to survey the laboratories. It asked researchers five questions; did they use carcinogens, flammables in large quantities, hazardous chemicals on the work bench, odorous compounds or heat generating equipment.35 If they answered yes to any four of

34 University of Michigan, Perdue, Johns Hopkins, Dartmouth, Harvard, and Cornell.

35 One or two Physical Plant Department interviewees felt this survey was politically motivated rather than by safety. They pointed out that common laboratory solvents fell into two or three of the categories.
these, the hood was eliminated. In buildings 1 through 14, this brought the eligible number down to 48. The situation was similar in other buildings. For example, in the Chemistry building there were concerns about the exhaust fans.\textsuperscript{36}

The essential problem which has emerged is one of conflicting intra-organizational objectives. On one hand, the Environmental Medical Service sees a trade-off between known savings and unknown safety. That is, they know they are endangering no-one in particular, but they also feel they are reducing the safety level in the laboratories by reducing ventilation rates. They concede no operational advantages from the new controllers, and instead feel that they will make the laboratory operation less reliable. The Physical Plant Department, on the other hand, sees it differently. They feel that they are offering to trade safety with the Environmental Medical Service. In return for the reduced ventilation rates, they can offer greater fume-hood reliability and better maintenance. In addition, they can apply some of their savings (from the rebate program) to improve facilities in other areas (such as replacing the mushroom fans with conventional ones).

Both the Environmental Medical Service and the Physical Plant Department said in the interviews that if they had handled the whole affair much better, there would have been much better results. The Physical Plant Department believes it will probably end up retrofitting about half the hoods it should. It was also surprised by the systematic complexity of the hoods, and will put much more care into their construction and commissioning in the future. It sees the whole experience as a fortunate education as it moves into design of a new Biology building.

\textsuperscript{36} They are 'mushroom' fans which require service people to work in the space where the exhaust goes. If service people are working and one of the fans is turned on somehow it could be very dangerous.
3. Users

The last aspect of the Cambridge-Electric Initiative which deserves attention is the way in which users have been managed, and how effective that has been. What this appears to be showing is how difficult it is to reach out to users. It also shows that the contractors avoid changing the quality of the work environment.

The casual user on campus has had limited need for outreach. There was a small article in MIT's official organ, 'Tech Talk', in July 1987. This said that MIT was undertaking the initiative, and outlined the procedure. Since this happened in the middle of Summer, there is every likelihood that no one took much notice.

In December 1987, the Physical Plant Department attempted to address the monthly meeting of administrative officers. However, energy conservation appears to have not been on everyone's mind. Only 30 of the 160 administrative officers came. Worried by the poor attendance, in March 1988, the Physical Plant Department wrote a short letter to all the administrative officers and invited them to a series of meetings (different meetings for different areas of the campus) to discuss the program. At the same time it published another article in 'Tech Talk' to say that the program was happening. Still, attendance at the meetings was not as good as hoped. Finally, it wrote to all of the space occupants and warned them that people were going to start coming into the space. This letter outlined what people could expect to happen.

One thing that is interesting is that the letter didn't go to the space occupants at the very start of the project. Obviously, the contractors, and MIT, were not interested in altering the quality of the work environment in any way. They aren't interested in de-lamping, for instance; just in replacing existing lamps with more efficient ones. Clearly, the sort of user cooperation this would entail is too difficult for the Physical Plant Department to obtain.
III. CURRENT OPERATIONS

In this section of the appendix we look at the current operations of the Physical Plant Department. The discussion will consider the Operations Division. Discussion of Support Services and Building Maintenance, where relevant, is embedded in the section above. Then, we will look at the way MIT goes about constructing and renovating buildings. The section concludes with a discussion of the operations budgeting process.

A. OPERATIONS

1. OPERATIONS POLICY

MIT has a general policy of heating to at least 68 degrees and cooling to at least 78 degrees, in a given space during normal working hours. However, some spaces, laboratories especially, have more specialist requirements. Because of the large number of laboratories, the design of the zoning of the heat control system, and the large amount of individual control that is granted, there are very few places on campus where this standard is enforced. In these, the Physical Plant Department has found from experience that it is better to be lax with the standard than to risk alienating users. The marginal benefit of a few degrees temperature change does not appear to justify the cost. (However, people may voluntarily adjust their own systems to comply.)

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The laboratories' operations policy appears non-negotiable. The Physical Plant Department appears not prepared to try to alter the standard, or even discuss it with researchers. As at the other sites, it's assumed that everyone is or will be a Nobel laureate, and therefore cannot be brought to discuss energy usage. Similarly, Physical Plant is highly unlikely to approach them if modifications will bring about significant disruptions. The faculty have no incentive to reduce energy use of their own accord (especially if this involves works). Consequently, energy is wasted in two ways:

First, the Physical Plant Department lacks contextual information. For example, Faculty may happily work with less illumination, but no one has ever asked them, and so it never happens. Similarly, many savings remain unidentified until communications begin. For example, if a building has insufficient supply air,
On the campus, Physical Plant tries to be invisible. For instance, significant portions of the repairs and preventative maintenance around the campus are done at night. Similarly, there is no program to reach out to users to ask them to minimize energy, nor has there been since the mid-seventies; though there are occasional article in the official MIT newspaper (Tech Talk). With the exception of a few seminars given for students and faculty during the Independent Activities Period, Physical Plant has no outreach program to communicate with the users. One staff member thought that a suggestion box could be useful.

Similarly, there is no on-going program to assess the energy consumption requirements of the laboratories, or to assess ways in which their energy could be used better. A recent article about the Physical Plant in 'The Tech' (The MIT student newspaper) emphasized this low profile. As a final example of this policy, the Physical Plant Department leaves no indication if a mechanic has visited a space.

Infiltration increases, so the labs become draughty, and therefore people turn up the heat. Increasing the air supply pressure solves the problem.

Second, energy is wasted because faculty have no incentive to conserve. For example, faculty may demand steam supplied distilled water in Summer, which would lead to a need for lots of steam and cooling to compensate. However, portable systems may be more appropriate.

38 The Tech, September 1987.

39 It is interesting to note that being invisible and avoiding dealing with the faculty are compatible activities. If you insist on having a low profile as an organization, you are not in a good position to ask people to curtail their energy usage.

40 Therefore, if the problem is not fixed, the user may think that the complaint has been ignored. This creates a subtle pressure for the user to generate alternative solutions to problems not solved the first time. The less the user knows about how to go about getting things fixed, the greater the pressure to generate solutions. For instance, if the room of someone relatively new is overheating in Winter and they have complained once or twice already, they have to find out that the administrative officer (or using the alternative route the Director of Physical Plant) is the person to contact, then they have to decide that the problem warrants taking up the time of an administrative officer. At some point it is easier to just open the window. This is one illustration of the need for user education, since the better educated users are, the less likely they are to need to look for alternative solutions to the most energy efficient.
2. WORK ORDERS

Work orders are the principal means for assigning work and distributing information about problems within the Physical Plant Department. Therefore, an understanding of the work order system is pivotal to our understanding of how the Physical Plant Department deals with problems in general, and energy problems in particular.

a) Sources of Work Orders

Work orders come from the four sources outlined under data management, and internally to Physical Plant:

* From people calling in problems by telephone on the prescribed number (FIXIT). (70,000 calls per year)
* From alarms from the telemetry system
* From people calling in problems, but not in the prescribed manner
* From the cleaners
* From preventative maintenance discoveries and other internal sources

Only calls from the first two sources (FIXIT and telemetry) necessarily come through the Operations Center. Calls in the third group are supposed to be exclusively from the Administrative Officer of the relevant facility to the supervisor of the Operations Center. In reality, there are other routes, from relevant faculty to the Director of Physical Plant or the Superintendent of Operations, for instance.

b) Work Order Processing

Work orders are used for non-urgent problems. They are dispatched to the supervisor of the relevant shop who combines them with work orders from other parts of the plant, particularly preventative maintenance, and allocates the work. A copy of the original Operations Center work order is filed under the building number.
On completing the job, generally at night, the mechanic indicates the work done and this is filed. If the job problem isn't solved the user is expected to contact his or her administrative officer who knows to contact the supervisor of the Operations Center.\(^{41}\) The supervisor will then make out a work order suggesting that the mechanic look beyond the immediate symptoms.

There is no systematic analysis of historical work orders other than a rough hand analysis carried out by the manager of the Operations Center. Since the Operations Center files the work orders under building numbers they can be processed by hand by the relevant supervisors. However, more than one interviewee thought that this was redundant because the supervisor would note mentally the large number of calls for a particular building, and therefore would look for systems problems anyway.

On the basis of my interviews it is very hard to tell whether this is true or whether the lack of information is reinforcing a myth that systems problems are being addressed. Discussions with the preventative maintenance staff indicate that only a very small proportion of the equipment needs work on it in excess of that required for preventative maintenance. Therefore, it would seem that most problems are being picked up. The new database offers the possibility for answering this question.

\textit{c) Data Processing}

There are two distinct types of data processing. The first is how the data is used for day-to-day and immediate problems. The second is how it is used for strategic analysis for the determination of energy conservation policies.

\(^{41}\) Once again, there is an assumption that the person with the problem is powerful enough to ask the administrative officer to take time to help resolve a problem.
Data is used on a day-to-day basis to determine what urgent minor and preventative maintenance should be done when, how, and by whom. It appears to be satisfactory with the following exceptions:

* Technicians can’t know if the job has been done before, by whom, or when, what was tried, and what investigations were carried out.

* The success rate of the non-preventative maintenance cannot be measured. Since the data is collected, and there is no follow-up, even if repeat calls were monitored, there would be no way of knowing who had had their system fixed, and who had given up.\(^{42}\)

It is generally acknowledged that the non day-to-day uses of data are pretty poor. However, it is felt that the new work order database system will create an environment in which these functions could be better managed. Notwithstanding, many of the interviewees felt that they were catching a lot of the recurrent work orders throughout the existing system.

\(d\) The New Database

The Physical Plant Department is currently (April 1988) installing a new work order management information system. It has been designed over the last four years and will be used for the following:

* To store information on the nature of calls into the Operations Center and provide historical data on their nature and the result. Retrieval will be available by building, room, or a search by word.

* To generate work orders.

* To provide historical accounting of the operations center’s behavior and that for the calls logged.

* To give the operators interactive information about calls still current, building system shut downs, etc, to avoid the need for redundant call logging.

\(^{42}\) There is an obvious cost trade off between the cost of collecting and managing this data and the benefit derived from keeping it. If the mechanics had to file a report for every job they completed, and they had to go to the computer to check every job before they went to it, it could significantly increase their job size without necessarily improving the quality of service for the vast majority of jobs.
To give managers the opportunity to search past work for specific problems; for instance, to account for glass breakage around the campus over time.

The new database will give managers the opportunity to manage data more completely. However, given the responses of some of the interviewees, I'm sceptical that they would see a need to use this ability.

The new database will not be based on the ‘INSITE’ spatial database program developed by the MIT Office of Facilities Management Services. Two reasons were given for this. The Director felt it was much more important to get a strong accounting link to the management information system, while the Superintendent of Operations couldn't see any real need for a link. (Or so I infer from his comments).

3. TECHNOLOGY SELECTION

A large proportion of energy conservation which occurs on a campus happens because of equipment retrofits. At MIT, the Physical Plant Department has historically concerned itself only with the university's infrastructure. While more recently it is concerned with the way equipment is selected and used, as yet it has not attempted to look at that. In this section we look at the way the Operations and Support Services and Building Maintenance Divisions makes choices about their technology.

In the Operations Division, the projects are selected as follows:

* The Superintendent of Operations brings all the relevant staff into a meeting, and they go through the campus, building by building, identifying projects on the basis of interpersonal interaction and recollection of the recent past. (This is where the $8 000 000 comes from)

* These are ordered roughly by priority, with more care toward the top of the list, and the list is submitted to the Director who allocates a budget.

* Projects are implemented going down the list until they are all satisfied, unless emergency failures necessitate a change.
No economic analysis is carried out because priorities are not purely economic. The order of priorities is generally:

1. Projects to protect the health and safety of staff and users,
2. Projects to replace machinery that is causing damage that is becoming increasingly expensive to replace,
3. Projects to alleviate constant costs,
4. Projects to improve aesthetics.\(^{43}\)

For some of the energy conservation projects, a simple payback period is used however. To be financed, a project generally has to pay back within 3-5 years.\(^{44}\) This figure is significantly different to that given to me by the Senior Vice President for Operations who gave a (non-simple) payback of ten years as the criterion for internal funding.\(^{45}\)

The vast majority of projects come from the second and third groups. These are amenable to economic analysis, but it is not surprising that none is performed since current funding allows only about 4% of identified projects to be completed. (There are $8\,000\,000 of identified projects in the Operations Division and an annual capital budget of about $375\,000) Several of the interviewees saw economic analysis as being impossible to carry out since one of the dominant parameters, maintenance hours, is hard to estimate and price.

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\(^{43}\) Interview, Superintendent for Support Services and Building Maintenance. The general spirit of this was conveyed in many other interviews, however.

\(^{44}\) Interviews with Associate Director and Operations Center Manager.

\(^{45}\) This suggests that economic opportunities are not the principal impediment to energy conservation. It appears likely that staffing levels is a major factor.

\(^{46}\) An alternative explanation is that they feel uncomfortable doing such an analysis, rather than the analysis itself being impossible. However, with such a severe budget constraint, it is likely that any project towards the top of the list would have a payback of less than ten years. The corollary of this is that a lot of cost effective projects are being missed. Therefore, the capital program is being constrained by either available capital, available staff, or some unidentified internal organizational constraint.
Concurrent with this is another impediment to energy conservation. All the shop supervisors are trying to maintain equipment that is approaching the end of its economic life. Given the low rate of capital turnover, the maintenance task is growing annually. However, staffing is not necessarily being kept up to match. Therefore, there is undoubtedly strong competition between the various shops to ensure they get sufficient capital projects to occupy fully their staff. However, energy conservation interests are not explicitly represented at the decision meetings. Therefore, there will be a tendency to select against energy conservation projects until each shop is sure that it is doing the maximum work it can to minimize its recurrent work in the future.

Third, the projects are selected on a building by building basis. While this is understandable on one level, namely that it is conceptually easier to think in terms of individual buildings, there is no chance for system improvements under this system, only improvements on individual buildings. Similarly, there is no chance for small projects that have a broad scope, such as lighting retrofits.

Finally, this sort of selection method is likely to turn up easily identified and similar projects in each of the buildings. Projects that lie beyond those that the managers have been accustomed to implementing will be ignored.

a) Components

Many of these buildings still have their original components; fans, pumps, blowers, etc, even though they are either very old (for older buildings) or very inefficient (for newer buildings). These can be replaced with more efficient designs on failure. With the exception of the BEAM program, there has been no systematic analysis of either the individual components or of the way these components fit into the broader energy system.
When a component fails it is replaced. Otherwise, it is maintained until it fails or until failure appears to be imminent. Replacement is always with equipment of the same rating as the equipment that is being replaced. For instance, if a motor has a rated capacity of \( x \) but is only loaded to \( 2x/3 \), no attempt is made to replace the motor with a better sized one.\(^{47}\) This is not surprising, since no specific measurement appears to be made of the power consumption of motors, except on those large enough to be monitored on the Facilities Control System.

For mechanical equipment, the supervisor reads appropriate literature to ensure that he is aware of products on the market. Once he is satisfied of the appropriate replacement, he purchases on first cost. The rationale is that the market will ensure the products are as efficient as possible and that innovations will be incorporated into products (consider for example the infusion of rotary screws into compressors).

However, for mechanical equipment, the principal concern is that it be reliable, rather than efficient, except when comfort is its main function. The supervisor believes reliability and efficiency are virtually independent, and that cost and system efficiencies are better served by maximizing reliability.

Electrical equipment is replaced on the basis of the device’s nameplate specification. However, certain standard changes are made. For example, DC motors are replaced with AC, pumps get variable speed drives, compact fluorescent lamps are used for flood lighting applications, and so forth. The same list of standard replacements came from several people. This appears to indicate that some sort of list, real or imaginary, exists. Several key elements aren’t on this ‘list’, as is shown by the current Cambridge-Electric initiative. For example, high efficiency ballasts and motors

\(^{47}\) The mechanical efficiency of motors increases significantly as they approach their rated capacity. Therefore, significant savings could presumably be made by optimizing motors on replacement.
were mentioned by none of the interviewees. The question remains as to whether this agreed upon list *precludes* other kinds of replacements or whether the list is a depiction of what people generally see as standard.

Under this sort of a system, standard replacements are likely to be made on the basis of first rather than lifecycle cost. i.e., once a component meets the requirements set out on the nameplate of the product it replaces and those on the 'list' it will be selected on price. Therefore, the supervisor is likely to select against, say, higher cost, higher efficiency motors. If lifecycle costing were used however, component reliability and energy consumption would enter into the selection explicitly. However, the future reliability of new components is very difficult to assess.

Also, if the electrical supervisor (or the mechanical supervisor for that matter) sees an opportunity for a systemic improvement, the job is turned over to the engineering department. However, this appears to be rare. Otherwise, direct replacements are made without analysis.\(^{48}\)

To facilitate this hand over of projects and healthy communications in general, weekly meetings are held between the engineering department and the mechanical and electrical supervisors. At these, the week's new projects are discussed, as are on-going concerns and projects. Engineering can then review projects it chooses.

It is interesting that neither of the shop managers interviewed saw any shortage of capital for maintenance. They felt that if they were reasonable, they could get what they asked for. If the work load was too great then they were quite at liberty to farm the work out to contractors.

\(^{48}\) There could be high institutional pressure on the supervisor to only send engineering projects with virtually certain and large savings. The organizational embarrassment of asking someone to look at an unviable project would be significant in all organizations.
b) Systems

With the exception of the staff member involved in the chilled water system rationalization, no one in the Physical Plant Department is responsible for ensuring the whole energy consumption system is looked at systematically. Notwithstanding, large systemic savings have been made in the past. For instance, one staff member explained how replacing a building’s steam heated domestic hot water with gas for the Summer paid for the hot water systems in a matter of months because of the reduction in line losses.⁴⁹

4. CENTRAL PLANT AND DISTRIBUTION

a) Central System

The original central facility was a coal-fired cogeneration plant constructed in 1916. The waste steam was exhausted in Summer and used for heating in the Winter. It provided all the campus’s electricity requirements until the late-1930’s. Up until this time, buildings were almost exclusively steam heated. In the post-war years, it became practice to use hot water heated through exchanged steam instead. Buildings constructed between about 1960 and the oil embargo tend to have poorly conceived energy systems because they were built at a time when energy was cheap and supervisory resources were over-utilized because of the rapid expansion of the institute.

(1) Current System

Currently, the central plant, comprising steam generating boilers and chillers, is on Vassar Street, with a satellite chiller for the East Campus on Amherst Street. The chilled water system has a 10 000 ton per hour capacity and is capable of satisfying a maximum demand of 6 000 tons.

⁴⁹ Interview, Manager for Utilities.
The steam system has a 400 000 lb/hr capacity (comprising 1 * 100 000 lb/hr, 2 * 80 000 lb/hr and 2 * 70 000 lb/hr boilers). It has met a peak demand of 225 - 250 000 lb/hr. The steam generating plant is fairly old, and has a deferred maintenance requirement of about $1 500 00050. Two of the boilers need to be retired, and some of the boiler feed pumps need rebuilding. The decision to fix these will be made after final decision is made on cogeneration, as this will affect both the need for these facilities and their performance specifications. However, the plant manager does not think that these costs are being factored into the cogeneration construction decision.

In addition to the deferred maintenance problem arising from the protracted decision to go ahead with the cogeneration project, there is concern in the central plant that extensive re-training of staff to run the new equipment will be needed, and that they will have to run the plant while the new equipment is being build in the middle of it.

A significant proportion of the maintenance effort at the central plant involves "fire fighting" since the plant cannot be shut down, and preventative maintenance is difficult.

(2) Cogeneration

While cogeneration offers the potential for very large savings in energy for the institute, I will not dwell on it too much in this work since 1) It is not an energy management device in the conventional sense. By cogenerating, you alter the base line for energy consumption, rather than managing effectively within the local constraints, 2) it is so big, it will overshadow everything else, and 3) it appears to be highly institution dependent. For instance, if one institution could get a gas contract five years ago, and

50 Interview, manager of the central utilities plant.
another can't now, this is a minor reflection on their respective management, even though the relative impact is major.

MIT's plant will be of between 12 and 22 MW of installed capacity, (as opposed to the MIT average load of 14 MW). All power generated will be sold to Cambridge-Electric at their avoided cost. This is currently unknown, but will probably be lower than Boston Edison's old avoided cost of $0.065 per kWH. MIT will continue to purchase power under its existing contract. This was a deliberate policy decision by MIT to avoid changing the electric rate structure of the Cambridge area.

Cambridge-Electric put out a request for proposals for cogeneration plants in March and MIT still had not submitted its in October 1987, after about a year's negotiation. However, proposals are often rejected.

The MIT senior administration has put five conditions on the design, construction, and operation of the plant.

1. MIT should stay friendly, or become friendlier with the utility, the local community, and the MIT community as a result of the venture. (Noise is not considered a problem.)

2. The project must be able to secure a firm supply of gas for ten years.\(^{51}\)

3. The project must pay back completely in ten years.

4. The contracts must be consistent. A disparity developed where MIT could only get a twenty year electricity sale contract and a ten year gas supply contract. (This isn't acceptable)

5. They should use proven technology. This is a supply venture and not a research one. (For instance, they aren't interested in running the turbines using an El Masri cycle.)\(^{52}\)

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\(^{51}\) Gas is very short in the North East, as there is insufficient pipeline capacity. So, this has been a significant problem. There has been no difficulty in finding gas supplies. It's simply a problem of getting it to Cambridge. There are three options, of which the most likely is a guaranteed supply for 335 days, with MIT using #2 fuel oil for the other thirty.

\(^{52}\) Professor El Masri is on the MIT faculty.
b) Distribution System

The distribution system is used to take the utilities from their point of entry onto the campus (for gas and electricity) or generation (for chilled water and steam) to the point of entry into the building of final consumption. More than one interviewee described it as the "orphan" of the Physical Plant system, with no one really having an interest in it.

The system of most interest for this study is that for steam distribution, since it is older and larger. It is also responsible for about 100% of the heating requirement for the campus.\(^{53}\) It was sized originally for a smaller campus (indicating that pipes will now be too small) but with anticipation of growth and buildings using much more energy than they do today (creating a demand for larger mains). Therefore, many mains are poorly and inconsistently sized and virtually none of the metering works.

There are similar problems with the chilled water network. So, in late 1987 C.T. Main carried out a network analysis to try to overcome some of these problems, and see whether or not pumping loads could be reduced. If so, it will be easier to control all the buildings on a given main and simultaneously reduce primary pumping requirements.

In addition, a major works program for the near future is the replacement of a steam main that is leaking. It is fairly old and sits below a road in fairly acidic groundwater. It will be moved to a higher location adjacent the road. Two cost estimates I've heard for this are $700 000 and $1 500 000.\(^{54}\)

\(^{53}\) Interview, Manager of Operations Center, August 13 1987.

\(^{54}\) Conversation with Manager of Utilities.
5. TRAINING

With the implementation of the first Facility Management System, the need to train the watch mechanics for more sophisticated tasks initiated the training program. One aspect of the program is a weekly meeting for the 24 or so supervisors and managers in the Operations Division. The structure of this meeting varies from an informal get together with coffee and doughnuts to a lecture by the superintendent to videos. Some of the sessions are lectures, all by the superintendent, while some are more participatory.

B. NEW CONSTRUCTION

The Physical Plant Department is responsible for the design and construction of all works on campus. Within reason, they get what they ask for. However, budget constraints always intervene in construction, so there are inevitable trade offs between systems and facilities in a building. Notwithstanding, Physical Plant has the duty to ensure that the 'right design' emerges. One interviewee saw this as being difficult to achieve because of inherent conflicts between users, Physical Plant, the architect and the budget.55

1. FINANCING

The Physical Plant Department determines the budget for the building on the basis of experience and other data. This budget is determined exclusively on the basis of first cost pricing. As one interviewee explained, they don't understand lifecycle costing nearly well enough to use it successfully.56 Several other interviewees also indicated that it was so hard to raise money for buildings that physical plant tends to be

55 Director of Physical Plant

56 Associate Director of Physical Plant
compromised during the design. To overcome these problems, the administration has
guaranteed to fund the differential for design modifications which will pay back in
savings in less than ten years.

2. ARCHITECT SELECTION AND PROJECT CONTROL

Until just before this study, and in sharp contrast with all the other campuses
studied, the architect was not selected by the construction committee that oversees the
project. At MIT the architect was selected by a member of the senior administration.\textsuperscript{57}
Recently, MIT moved to selection by committee.

The project is managed by a senior administrator in either the Physical Plant
Department or the Planning Office, say the Director or Associate Director of Physical
Plant. This person sits on a committee which comprises relevant people, particularly
representatives of Physical Plant and the tenant department/s and administrative bodies.
It is worth noting that the departments that are getting new buildings are generally
growing rapidly and have bright futures. Therefore they are very influential. Hence, it
is not surprising that one senior Physical Plant administrator described them as having
'mixed luck' influencing design.\textsuperscript{58} The Physical Plant Department's general strategy is to
try to have a lot of input into the design in the very early stages, because they feel that
it is then that the important operational parameters are determined.

\textsuperscript{57} I see this as creating several problems. First, many problems can be anticipated
very early in the design process. If a committee selects the architect, they can look
for the problems they anticipate in the architect's prior work. Second, they can also
make these concerns explicit to the architect before selection. This means the
architect does the conceptual design with these concerns in mind, rather than trying
to fit them into a previously framed design. Third, if the architect is selected by
one group and managed by another, it is never quite clear whose agenda should be
satisfied. We saw in chapter five that the senior administration, the Physical Plant
Department, and the faculty can have quite different priorities.

\textsuperscript{58} Associate Director of Physical Plant
Although the brief requires architects to consider alternative envelope designs and building systems, and MIT is glad to pay for the extra work, it is often very difficult to get this done. In fact, they tend to follow the same design sequence that they have for previous buildings. (This would tend to suggest that selecting the right architect is as important as getting the right HVAC sub-consultant.) The engineers are often sub-contractors to the architects, so Physical Plant cannot get access to them. Presumably, there will also be conflicts if the engineers start attracting capital resources for which the architect has other intentions.\textsuperscript{59} This problem is illustrated by the construction of buildings E23 and E25 (College of Health Science and Technology and the Medical Center.) For these, physical plant wanted peripheral heaters to be installed for occupants out of normal office hours. The architect refused.

In addition to these complications, the Physical Plant Department has difficulty exploiting its own knowledge of building systems in a balanced way. While senior management saw this as knowledge that is under-represented in decision making,\textsuperscript{60} middle and lower management thought they had little time or skills to offer this process.\textsuperscript{61} One senior plant official noted that new systems are often inappropriately designed by the plant's engineering department, because engineering have poor

\textsuperscript{59} The reader should note that because virtually all MIT buildings have complex operational requirements; for energy intensive biological, chemical, physics, or electronic equipment, this issue is probably much more critical at MIT than elsewhere.

\textsuperscript{60} Director of Physical Plant

\textsuperscript{61} For example, the superintendent of operations thought that the appropriate place for his input is through the specification. Where he did have further input, he saw himself as 'one voice in a litany', that may or may not be heard depending on circumstances. His supervisee, the manager of the electrical shop saw himself as fighting with the architects, only to be ignored, while the mechanical manager saw it as a function of the time he had available, and since that was limited, and since he has confidence in the engineering department to be sensitive to operational issues, he chooses to not get involved.
conceptions of appropriateness and feasibility of design. This would seem to reinforce this viewpoint.

3. Specification

To overcome the problems described above, Physical Plant deliberately specifies that certain design features should be incorporated into its buildings. Hence, it mandates that the buildings should have operable sash windows and direct digital control systems. For these to be carried out, they have to be mandated by the Senior Vice President for Operations. However, architects still try to override them if they are inconvenient. For instance, in the design of one recent building there were extensive arguments with the architect who insisted that conventional pneumatic controls would be satisfactory rather than more expensive digital ones. (This was despite the fact that the whole campus was being controlled digitally.) In general however, design requirements are not beyond the relevant Massachusetts design codes.

4. Major Refurbishments

The refurbishment of buildings proceeds in much the same way, except the proportion of internal MIT resources attributed to the task is higher. Of particular note is the way in which the same pressures are being brought to bear. For instance, in the renovation of the Stratton Student Center, there were extensive discussions between the architects and Physical Plant because the architects want to use incandescent lighting.62 Also of note is the way in which the fact that the whole building isn’t being renovated prevents system redesign. In the Student Center for instance, renovations are occurring on only three of the five floors. Therefore, the heating and cooling system cannot be revamped.

62 This was at a time when incandescent lights were being replaced with fluorescents throughout the rest of the campus.
5. Hand over of buildings

Interviewees in the Operations Division and the academics I interviewed emphasized the importance of effective hand-over of buildings following the completion of works. The people in Physical Plant who mentioned this also noted that this isn’t done terribly effectively at MIT.

C. Operations budgeting and deferred maintenance

1. Budgeting

For about the last fifteen years, the budget for Physical Plant for capital maintenance was $330,000. Recently, this has increased to $1,500,000. Most of this increase was brought about when the Physical Plant Department showed it could exceed its budget allocation for a given year. Otherwise, for the previous five or six years, it had a constant nominal budget. The senior management of Physical Plant see this as unrealistic because of inflation and because structures built during the 1960’s boom all have plant that is approaching the end of its economic life.

2. Deferred Maintenance

The current deferred maintenance program for the Physical Plant Department’s Operations Division is $8,000,000, (Total for the Physical Plant Department is about $25,000,000) including $1,500,000 for mechanical equipment. The annual capital budget is about $375,000. The superintendent claims that this is the maximum that his staff could handle. Note that this means that about 4% of the identified works are carried out each year. The superintendent also noted the severity of the staff shortage

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63 Senior Vice President for Operations talking about the Physical Plant Department’s claimed needs.
brought about by a hiring freeze that following a long period of attrition. He felt that this was the biggest constraint on his division's ability to do extra work.

The Provost, in 1987, asked one of his staff to spend part of her time looking at the deferred maintenance problem on campus. As this comes under the responsibilities of the Senior Vice President for Operations, I presume that the appointment is under the Provost simply because he had the relevant person available.

This officer was under the impression that the job had been created principally as an acknowledgement to the Physical Plant Department that there was a deferred maintenance problem. One of the tangible responsibilities with the job was determining project priorities and securing finance, since money that MIT raises through overhead for depreciation of capital stock (2% of the value of the buildings used for the research) is not allocated to the Physical Plant Department, but rather goes to central revenue. In addition, there are several other severe cost pressures on the Institute:

* The volume of sponsored research is declining

* The NSF is withdrawing salary support for faculty outside the Summer

* Large institutional projects, like Project Athena, have large capital needs.

The officer believed the job had come about because physical plant had started, for the first time, to overspend its budget, and was therefore capable of dealing with a larger sum than it was currently being allocated. In the past, it hadn't had sufficient resources to even look at the problem.

The Senior Vice President for Operations saw the situation differently. In his view, this officer's job was to take physical plant's submission for funds and turn it from a list of projects to a proposal, with more "history, future, and analysis." The
analysis would show expected reductions in operating costs and planned capital replacements into the future beyond the current deferred maintenance.

a) Financing

On one hand, the Physical Plant Department is very heavily financially constrained. Its budget is a significant proportion of the operating budget at MIT. This is fixed, and so the capital works program and monies for an energy manager are not easily appropriated.

On the other hand, the Senior Vice President for Operations made it clear to me that there were precedents for MIT (or possibly the Corporation) in energy management and other cost saving ventures at MIT, to lend money to the Physical Plant Department if it was satisfied that projects could pay for themselves within ten years. Therefore, given that most energy conservation programs work with pay-backs of 3-5 years, it appears that it would not be difficult to attract capital for sensibly conceived energy management works.

While the Plant Director was well aware of these opportunities, and said that some hundreds of thousands of dollars of works had been financed this way, he felt that it needed institutionalization. That is, there appeared to be institutional barriers in place that prevented the Physical Plant Department from putting up projects to be funded and getting them approved. It seemed that there was a lot of effort associated with putting up projects one at a time. Presumably he was not talking about the problems of writing a proposal, but rather those of maneuvering through the funding process. He hoped

\[64\] Similarly, such projects would need to be big to be justifiable. Senior people don’t have time to bother with small projects.

Alternatively, he could have meant that they don’t have the staff to put up projects individually. That is, an additional staff member is needed to put up these proposals, and without some sort of institutional recognition of this need, the staff position won’t be created.
that the Cambridge-Electric initiative would provide a stimulus, and a cash source, to institutionalize such a program. He noted that the Senior Vice President thought he was aware of all the problems in Physical Plant, and that therefore it was impossible to dramatize any submissions, as could competing interests.

Given that the BEAM program was frustrated, in part, by the short term effect of the energy conservation works on overhead, I spoke with an employee of the Fiscal Office. He indicated that there would be no difficulty whatsoever allocating part of retrofitting costs to overhead in proportion to the percentage of energy consumed in the building for research. On average this is 60%, but in some buildings it is higher. For large projects, it may be necessary to incorporate the works over a period of time (up to five years). This was the only obstacle he saw.

He pointed out that if the financing were arranged properly, the overhead rate should drop almost immediately; because the pay-back for the works should be greater than the interest rate on the money used to finance them. Therefore, with the exceptional possibility of a slight rise in the overhead in the first year (because you start to pay for works before you reap the benefits), there should be no administrative or faculty objections to energy conservation projects.

He went on to point out that under such an arrangement MIT would have to fund about 40% of the works. Again, he didn’t think this would create a problem, since (with the possible exception of the first year once again), there would always be net savings in a given year. Money could be raised internally or on the outside market.65

MIT is not eligible for energy management subsidies under the Department of Energy’s programs. Its percentage of federally sponsored research is so high that it

65 Harvard has made extensive use of Higher Education Financing Authority (HEFA) bonds to finance its works. MIT used them to finance FCS-1
Peter Cebon (1990)

would cost more to accept the subsidy (and not allocate the cost to overhead) than it
would to allocate it directly. MIT is one of the few institutions in this situation.
IV. HOUSING

As at Tufts and The University of Massachusetts at Amherst the Housing Office, part of the Department of Housing and Food Services, is financially independent from the rest of the university. It raises money through rents and this is supposed to pay for the upkeep and operations of the buildings. The Physical Plant Department is responsible for all facilities in the building, but will only attend at the request of the housing office.

Each dormitory has a house manager who is responsible for the day-to-day operation of the building, including such things as safety and security. In addition, each dormitory has at least one resident faculty member and the undergraduate dormitories have graduate tutors as well.

The quality of energy management in the dormitories is highly dependent on the quality of the house manager and his or her concern for energy management issues. Interviews were held with the managers of two dormitories for this study. The data presented here presents not only the differences in the objective reality at the dormitories, but also the differences in the perceptions and priorities of the house managers.

A. BURTON-CONNOR

This dormitory comprises two towers. The first tower was started in 1927 and completed in 1948. (Presumably there was a break in between). The second tower was completed in 1970.

Heating is by hot water radiators with local regulators and is supplied from October 15th through May 1st, as required by Commonwealth law. It is provided by Physical Plant on a timed basis. Generally the daily cycle involves turning the heat on
first thing in the morning, turning it off at 10 am, and turning it back on from mid-
afternoon until late evening. Towards exam time the hours are extended. The system
works adequately unless there is a hot spell towards the end of October, at which time
the dormitory overheats. A phone call to Physical Plant is generally sufficient to
eliminate this problem.

The system has to have air bubbles bled in October by the dormitory handyman.
Students are generally cooperative as this proceeds, even though it often takes two or
three attempts. However, the radiators are fairly old and often need major repairs.
Similarly, the boilers are quite old and, I infer, need refurbishment or replacement. The
system and architectural design of the dormitory is such that it is difficult to heat the
tops of the two towers properly simultaneously. If one is heated adequately, the other
overheats. Also, there are local hot spots. Students tend to open windows in these
rooms. This is seen as unfortunate but probably unavoidable. The corridors are not
heated, so students sometimes complain of being cold going to the bathrooms. This is
generally discussed and problems are resolved. If students’ rooms are cold, they let the
manager know quickly, since electric heaters are banned (for fire reasons). If they are
hot, they know that they are expected to let the manager know, or Physical Plant on
weekends. On weekends, however, they often tend to just open the window, since they
seem to want to go through the manager at the start of the next week. If it is very cold,
the manager asks Physical Plant to adjust the heat. This tends to happen slowly.
(Probably a supply constraint in very cold weather)

Students’ Lighting is by standing lamps in each room. Students can add lamps as
desired. The dormitory will provide electricity for this, but not light bulbs. For the
standard lamps, ‘miser’ light bulbs are supplied. The dormitory conducted quantitative
tests on these and concluded that they were cost effective. The suite lights, those lights
common to a set of rooms, generally serving bathrooms, lounges, and kitchens, were
changed recently for high efficiency fixtures. Simultaneously this opportunity was used to remove old or broken glass fixtures. It would probably not be possible to put movement sensors on the standing lamps. The manager has not considered putting movement sensors or time switches on the suite lights.

When asked about the possibility of using compact fluorescent lights in the rooms, the manager was unaware of their existence. If they looked attractive, they would be implemented on a trial basis. Probably one floor would be tried first, and careful measurements of light life would be taken. When told of their price, some concern was expressed. However, the manager concluded that it would be reasonably easy to set up a protocol to ensure that there was not too much theft. Probably, the students would have to return old bulbs when they took out new ones.

There are signs that ask students to turn off lights. The night watchman turns off all non-emergency common area lighting at midnight. In addition, on vacations and long weekends, the handyman goes around the outside of the building looking for open windows, and the manager enters all rooms to check that lights, alarm clocks and electric blankets have been turned off. In brown outs, days of high energy consumption, the manager asks all students to turn off stereos, etc. This is generally done.

The manager was unaware of the Cambridge-Electric energy management initiative. However, I was told by the Institute’s liaison on this project, that this is more the fault of the energy contractor than of the dormitory manager.

The housing office, to insure against possible escalations in the price of energy, overcharges students for energy and then rebates the excess at the end of the year. The rebate is uniform for all students in the housing system. So, a dormitory benefits only partially from its own energy conservation efforts. (Given the large number of dormitories, perhaps incidentally is a much better word.) However, the manager of this
dormitory uses the size of the rebate as an inducement for the students to save energy and tolerate lower heating standards than they would normally prefer. In the second dormitory, however, the manager considers the rebate to be something between the housing office and the students, and therefore doesn't try to use it as a lever in any way whatsoever.

B. NEW HOUSE

The second dormitory was designed and constructed in the late 1970's/early 1980's, with a high emphasis on energy efficient design. It houses 352 students in 268 rooms as singles, doubles and triples, and has accommodation for eight tutors.

Included are 20 passive solar rooms with large overhanging windows, black floors, and blue and grey walls. The intent was that the student would open the blinds in the morning and this would allow light in. This would heat the floor and walls during the day. At night the blinds would be closed and the concrete would irradiate the heat back into the room. The manager was very sceptical of these being used this way, claiming that the students are too lazy.

Also, there is extensive use of sky-lighting on the top floor. However, since these leaked the manager doesn't like them either.

Heating is by hot water in risers. Each room has a radiator with lower and upper vents. Air is sucked in through the lower vent and pushed out the upper, taking advantage of natural convection. Overheating tends to occur in the upper floors if a room on a lower floor has a draft and large amounts of hot air rise through the vents. In rooms that are overheated, the students tape up the upper vent. This is considered a barely satisfactory solution to the problem.
The dormitory has no forced ventilation, except through the bathrooms and the dining room/kitchen system which is closed, so it doesn't affect the rest of the dormitory. The only air inlet is through the doors, which is minimal, and down through the chimney of the open fireplace in the dormitory living room. The chimney was modified in the Summer of 1987 in an attempt to minimize the down draught that was making it inoperative. The dormitory gets quite dry and stuffy in Winter; some students humidify the air artificially.

There are few problems with open windows in Winter because the students cannot close them without the assistance of the house manager. The windows are too heavy for their hinges, so if they are closed without the assistance of suction devices to lift them, the cranks get torn out of the closers. One of the manager's primary tasks in the Fall and Spring is helping students close their windows.

The corridors are heated to a comfortable temperature.

Lighting is by standing lamps in each room. The original lamps had fluorescent 22W lights with swinging arms. Not only did students hate the light, but it was relatively easy to override the stops on the lamps. If they were screwed down hard enough, the insulation on the wires would be severed and the wires would short to the stand. Therefore, these were all replaced with new incandescent fixtures. In these, 'miser' bulbs are used. The manager thinks that these are not cost effective, since they have a short life, but has not carried out experiments to verify this (c.f. Burton-Connor). Some students bring in their own lamps with bulbs since the rooms have inadequate desk lighting. The students must supply their own bulbs.66

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66 This is undoubtedly very wasteful. Students undoubtedly buy the cheapest and most inefficient bulbs possible. With the advent of compact fluorescent bulbs, it would be much cheaper to give students bulbs at the start of the year on the proviso that they return them at the end.
Peter Cebon (1990)

The manager was not interested in considering the use of compact fluorescent lights, and concluded that since movement sensors used power to operate, they couldn't be used to save energy. The manager intends to change exit lights to fluorescent tubes, apparently at the behest of the Housing Office.

According to the manager, the principal energy wasters (and fire hazards) in the dormitory are old refrigerators. These are followed by stereos. It is common for students to put stereos, refrigerators and other appliances on the one circuit, and therefore trip the circuit breaker. Similarly, if refrigerators and smoke detectors are on the same circuit, the refrigerators will trip the smoke detectors.

In the manager's opinion, there are two things which students are not interested in; safety and energy conservation. In both cases, you should leave the students alone and just 'do it'. The manager concluded that the key to energy conservation was simplicity, but didn't elaborate.

The manager was vaguely aware of the Cambridge-Electric rebate program, but wasn't terribly interested in it, presumably since he thinks there are few savings to be made other than in the energy consumption of the students' equipment.
V. COMMUNICATIONS

A. COMMUNICATIONS WITHIN THE PLANT

Communications in physical plant operate on two fairly distinct levels.

* Communications needed for the day to day management of problems.
* Communications for long run and strategic decision making and resource allocation.

There is evidence that this first sort of communications have improved considerably with the introduction of the Facilities Control System, and that, by inference, it was pretty terrible before hand. As Barrett says in his paper,

"In some instances, fortunately very few, existing supervisors were not able to adapt to the changed ways of operating our facilities. The couldn't adjust to the need to freely share information laterally and delegate responsibility."67

Unfortunately, there is strong evidence that communications of the second kind are poor. This communication takes two forms.

* Communication of information to others, normally people lower on the hierarchy, of decisions that may affect them.
* Lateral communication to others that can use your information to improve their effectiveness.

Two middle managers told me that they had been informed of decisions that directly affected their work well after that decision had been taken. They felt that early knowledge would have been extremely useful and saved them a lot of time. In addition, they had found out about things almost by accident from third parties.

For the second type of communications, the evidence is less direct. The superintendent for operations explained that one of the principal reasons for bringing

67 Barrett, P.F. ibid
people together for weekly training meetings was to get them together in the same room at once. In addition, the engineering group meets weekly with people from the Mechanical and Electrical shops to review decisions made by the different groups in the previous week and in the week to come. Finally, the Operations Division has two quality circles that try to solve problems of service delivery and morale. The Superintendent claimed that before these meetings were instituted, staff wouldn't even walk into each other's shop. Therefore, we can conclude safely that these communications were bad when he instituted the weekly meetings. Off-the-record comments by several interviewees indicated that communications were still poor.

More importantly, with the exception of the meetings described above, no one sees themselves as being responsible for ensuring effective communications within Physical Plant.

B. USERS

If all goes smoothly, all interaction between users and Physical Plant should be through the Operations Center. However, if the system breaks down, an intermediary needs to be involved, either the house manager in the dormitories or the relevant administrative officer on the main campus. Informal interviews with users suggest that this secondary interface is not well understood. It should be noted that while the Operations Center is responsible for generating the job and has to deal with the public, it has no responsibility for seeing the work gets done. From interviews, this appears to be a source of friction.

While the lines of communication between users and Physical Plant are fairly simple, Physical Plant tries very hard to accommodate users' needs. For instance, there is a problem with inadequate circuit capacity in some of the dormitories; the students overload the system and so the circuits are perpetually breaking. (See for example the
discussion of this problem for New House.) However, the Physical Plant Department has resisted trying to manage user demand (e.g. by restricting refrigerator size.)

1. The Interface between Users and Technology

In the main body thesis I suggested that an energy management organization will often attempt to use technologies to automatically substitute for users' decisions. As the reader can imagine, an enormous amount of labor can be saved if the room schedules for all but the very largest of spaces are controlled by motion sensors or timers rather than having to input them into the computer. MIT has attempted, with limited success to install such devices.

Time switches were experimented with at one point, but they were noisy, and their going off often caused interruptions; (including at one time, the disruption of a doctoral defense that wasn't going well to start with). Time switches in the dormitories didn't work very well either. Movement sensors are installed in a few buildings, and work reasonably well. As part of the Cambridge-Electric initiative, motion sensors, which have dropped significantly in price, are being installed extensively. As stated above, individual rooms have thermostats, some of which are user adjustable. No instructions are given to users on either how the thermostats work or what temperature to set them at. (From personal experience, it took me about a week to work out how to use a thermostat with two adjustment dials. The only clue to their operation was that one was red and the other was blue.)

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68 A secondary advantage is that an educational institution is likely to have a lot of unscheduled space use. For instance, groups of students may look for an empty room for a discussion. While laboratories may be occupied well into the night, that doesn't mean they won't be empty for most of the morning.

As set out in the main thesis, if you provide manual control for these areas, there is no guarantee that systems will be turned off once people finish using the space. The problem with automatic systems is that the heat really needs to go on half an hour before people enter the room.

327
2. MIT's Teaching and Research and Energy Management

Given that MIT is a highly technical institution, and that energy management has a very large analytical component, it is worth concluding this appendix by looking at the ways in which the Physical Plant Department has historically attempted to incorporate the work of students and faculty into its decision making, and the extent to which it has tried to involve the faculty in the operation of the Institute. There are several faculty at MIT who are interested in various aspects of energy consumption technology and facilities management.

As part of this study, interviews were carried out with two faculty members from the Laboratory of Architecture and Planning. They are both interested in the overall management of facilities, so one of them has looked at aspects of MIT's construction program and the design of individual buildings. They see themselves as students of MIT and therefore do not pass any of their findings back to Physical Plant. As one put it, MIT is much 'too political' for that. He said that it was difficult to know what to do when you found things that people didn't want to know about. However, another faculty member, who has been at MIT significantly longer, thought that change was relatively easy to bring about. He said, however, that one had to be reasonably skillful in doing so.

In addition, one faculty member has worked on a high efficiency cogeneration operating cycle. Physical Plant is adamant that that will not be used unless it is proven by the time they do their final installation, except possibly on a small research cogenerator housed alongside the plant's.

Although the original Facilities Control System was the first direct digital control facility of its type in the country, no faculty input was sought in its design. The
Director noted that no one on the faculty was specialist in that area at the time, so faculty assistance was not sought in the final decision.

The Physical Plant director was not interested in involving the architecture faculty in on-campus design. He pointed out that the faculty tend to have different skills to those of interest to Physical Plant. He broke architectural design into three parts; exteriors, design, and systems. MIT faculty apparently specialize in the middle of the three, and systems people have tended to be denied tenure.
APPENDIX C. HARVARD

As with the other appendices, the main text consists of either quotations or summaries and synthesis of the interviews. The footnotes generally comment on the main text or attribute the quotes

I. OVERVIEW AND UNIVERSITY-WIDE ISSUES

A. OVERVIEW

1. THE CAMPUS

Harvard University has three principal campuses, one in Cambridge and two in Boston. The Cambridge campus contains all the schools except Medicine, Dentistry and Public Health which are located in the Longwood Medical Area and Business which is directly over the Charles River from the main university, in Allston.

Virtually all of the work for this study has dealt with the schools on the Cambridge campus, particularly the schools of Arts and Sciences and Education. These were selected because they are the largest and one of the smallest schools respectively. The campus was established in 1635 with the university. However, very few of the 350 odd buildings pre-date the mid-nineteenth century, and many have been built or refurbished since the second world war. Of these 350, about half, 175, are owned by the Faculty of Arts and Sciences. The campus, excluding the business school, accommodated 14 800 students, 975 faculty, and 6400 staff in 1987.\footnote{Fact Book, Office of Budgets, 1988-89}
2. **Physical Plant**

Steam for the campus is supplied by Commonwealth Energy from a steam plant off campus. It is delivered at 100 lb pressure through a series of underground tunnels owned and maintained by Harvard Facilities Maintenance Department which has master meters both at the plant and in the tunnel where the steam leaves the plant.

Potable water and natural gas are delivered to the individual buildings by the relevant utilities. (Harvard has a delivery system of sorts for water, but that is not very large.) Chilled water is manufactured by the Facilities Maintenance Department at a plant on the corner of Oxford and Kirkland Streets (under the Science Center). It is then distributed to 43 buildings.

Potable water, chilled water, electricity and gas are metered at entry into buildings. Steam is metered by measuring the condensate returns to the system. The utilities bill the Facilities Maintenance Department which then bills the schools. The users are generally charged at the utility rate, but, for electricity line losses are factored in. Overhead recovery is discussed later.

The distribution system is maintained from resources recovered from a separate expense class in the building operating budgets. In most cases it is related to the number of units of that particular utility consumed by the building.

The buildings are ‘owned’ by the schools on university land.² The schools are responsible for their financing and maintenance. Routine maintenance, except structural work which is performed by a preferred contractor, is carried out by the Facilities Maintenance Department. Non-routine maintenance is done by contractors or by the Facilities Maintenance Department. For all schools except the Faculty of Arts and

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² Technically, everything is owned by the President and Fellows of Harvard College.
Sciences, the Facilities Maintenance Department generally oversees these external contracts.

Facilities are controlled on campus with an extensive computer system. It a hybrid of one system which has evolved over about 25 years and controls about 95% of the campus, and a new one. The new system comprises direct digital controllers in individual buildings. These are owned by the schools and operated by either the schools, the Facilities Maintenance Department or external contractors.

B. OVERALL ORGANIZATION AND FINANCING

1. SCHOOLS AND THE FACILITIES MAINTENANCE DEPARTMENT

The organization at Harvard is considerably more complicated than at any of the other case universities. The various schools, Arts and Sciences, Business, Dentistry, Design, Divinity, Education, Government, Law, Medicine, Public Health and Radcliffe College are financially independent. Each levies its own fees and has its own endowment, which is administered by the Harvard Corporation. They purchase services from each other - for example the Faculty of Arts and Sciences provides athletics facilities - and from departments such as the Facilities Maintenance Department. In addition, they are levied an overhead by the administration to pay for the limited central functions the university provides. While the schools are financially independent, major expenditures and annual budgets are overseen by the central administration and the Corporation. Capital expenditures over $50 000 must be approved by the Vice President for Administration and those over $300 000 by the Corporation.

The study focussed on two of the schools, the Faculty of Arts and Sciences and a Small Professional School (One of Design, Public Health, Education, and Divinity). Arts and Sciences is the largest of the schools and constitutes the majority of Harvard. The
small professional school is one of the two smallest schools and was included to see the extent to which the Harvard structure prejudices against smaller and financially weaker actors.

The Facilities Maintenance Department reports directly to the Vice President for Administration, through the Director of Facilities Management. The Associate Director for Maintenance for the Cambridge campus, Thomas Risbey, has two people working for him in charge of distinct areas of the campus (Susan Hill and one other). They supervise teams of tradespeople responsible for various buildings around the campus. That is, the staff are divided into geographical rather than skill-based teams. In addition, he supervises the operation of the computer control center and the billing of utilities to the schools.

The Faculty of Arts and Sciences is headed by a dean who is assisted by an Associate Dean for Administration. During the large energy conservation program of the early 1980's (under Dean David Nankan) the Associate Dean was Dr Peter Dixon. The faculty work independently within the Faculty. This was emphasized frequently in interviews and when trying to design the research.³ This independence is probably extended to other Faculties.⁴ Under the Associate Dean for Administration there is an Associate Dean for Physical Resources and a Physical Resources (Facilities) Office which includes the Director for Physical Operations and the Director for Capital Projects. The Director for Physical Operations (Stephan Engel) was recently promoted from a more junior position, where he did the technical work for the energy conservation program.

³ The issue surrounded the polling of faculty to determine their opinions on energy issues. It was made clear to me that only the President polls the faculty. Similarly, I would not be able to get permission to go through the Harvard phone book to find out who they were.

⁴ A general feeling I had from the Facilities Maintenance Department staff was that faculty are not to be bothered about facilities issues. They are to be left alone completely. This is less so within the schools themselves, but only marginally.
In charge of most buildings is a superintendent who is responsible for the daily operation and maintenance of the building. Superintendents oversee between one and five buildings, depending on building size and whether they have other responsibilities. In addition, each major building has an energy monitor. Superintendents responsible for one building only are sometimes the energy monitor also. More often, it is an administrative officer. The energy monitor is responsible for monitoring energy usage in the building, managing the energy budget, developing local conservation initiatives, making local judgements about whether to there are sufficient people to justify heating a building, and so forth.

Facilities management in the Small Professional School is very simple. It is overseen by the Director of Fiscal and Administrative Services whose assistant prepares schedules for the buildings. A part time superintendent is on campus three mornings a week.

2. Relationships between the Schools and the Facilities Maintenance Department

The schools purchase services from the Facilities Maintenance Department and from outside contractors. On the Cambridge campus, the University compels all of them except Radcliffe to purchase steam, chilled water (unless a building has its own chiller), gas and electricity from Facilities Maintenance. In Cambridge, they all purchase much maintenance and most operations from the Facilities Maintenance Department also. The Faculty of Arts and Sciences, purchases 75% of the Cambridge utilities and 60% of those for the university in total. The Boston schools, Business, Dentistry, Medicine, and Public Health, purchase different amounts of service from the Facilities Maintenance Department. For instance, the School of Public Health has its system run, and to a large extent maintained, by an external contractor. The Business School is essentially separate other than purchasing fire services and automation from the Facilities Maintenance Department. For administrative purposes, its accounts are run through the Facilities
Maintenance Department. Other departments still, like the Harvard Real Estate Department, which operates off-campus housing, purchases little from Facilities Maintenance.

There is an unspoken agreement that the schools will buy mechanical services from the Facilities Maintenance Department. If the Divinity School chose to go to an external contractor, it would probably create few difficulties. If however the Medical School, which employs 15 mechanical tradespeople, chose to do so, the issue would need to be resolved definitively. Under the current union agreement, the university must keep its staff fully occupied before letting contracts. The Cambridge campus could not absorb 15 extra people.

Other services may be bought at will. These include specialist, 'knowledge' services like recommendations of consultants and management of projects. Historically there have been services that the Facilities Maintenance Department could not supply competitively, such as painting and structural services. That function was sold to a private contractor, with an agreement for continuing patronage. Some of the schools have their grounds maintained by the Facilities Maintenance Department while others have contract gardeners. Often, the Facilities Maintenance Department will be asked to bid against external contractors.\(^5\) This is very competitive. While the Facilities Maintenance Department is expensive, (it is unionized, has high overheads and a lot of this work is done on overtime), it also knows the facilities well, is highly accountable, will be there to fix errors, and is on campus to start work on short notice.\(^6\) The Facilities Maintenance Department staff see this as worthwhile, since it keeps them on their toes. Consequently, large jobs, such as re-wiring buildings, tend to be farmed out,

\(^5\) The bids are often prepared by the teams' supervisors.

\(^6\) Interestingly, the staff of the Facilities Maintenance Department did not generate this list of virtues of them doing the work when asked. Instead, they only talked about cost competitiveness.
while the Facilities Maintenance Department generally does the smaller more routine ones.

To cover its overhead services, the Facilities Maintenance Department levies extra charges on the schools on the basis of utility usage, (which pays for maintenance of the steam and chilled water distribution systems and the utility reserve), floor area (which pays for fire services and dispatchers), and the number of computer control points (which pays for the operation of the computer). In addition, to cover its overhead costs, there is a 30% mark up on direct labor and a 7.5% mark up on contracts. The utility reserve (about $500 000 annually) allows it to make unallocated purchases. If it wanted to make a large purchase, such as a new central computer, this would have to be funded separately or taken, with schools' approval, from the utility reserve. It would be bought on the recommendation of an inter-school committee set up to investigate a particular problem, or by a seemingly direct mandate from the President that the schools should cooperate (as is the case with the new digital telephone system.) However, even in this case, it is likely that there would be extensive prior negotiation.

To prevent conflict within the Facilities Maintenance Department, the faculties have jointly agreed with the union to provide the Facilities Maintenance Department with sufficient work to maintain manning levels. This doesn't mean, however, that the schools cannot move to external contractors through attrition of the Facilities Maintenance Department staff. Following the Buildings and Grounds Department restructuring, and other than in the structural trades, such as painting, there has not been conflict over this. The problems in structures arose because the work load varies so much during the year. There is work for 40 painters in Summer, and only five in Winter. Consequently, Facilities Maintenance Department was significantly more expensive than the outside non-union competition. However, in the mechanical trades,
work is less variable and wage differentials and the industry structure give very little advantage to external contractors.

This operating strategy has very high administrative costs. There has to be extensive metering, timekeeping, and accounting, irrespective of its managerial use, just to keep the system operating.

The Facilities Maintenance Department is constrained to operate within the budget set down by the individual schools, even if this is unrealistic. So, its policy of energy conservation is constrained heavily by its budget. Principally, the supervisors and the managers in the Facilities Maintenance Department determine the extent to which energy conservation is pursued; any project which pays back in more than a year requires sacrifices in another part of the budget or budget increases must be solicited.

3. 3. THE ROLE OF THE CENTRAL ADMINISTRATION

If the individual schools and departments pursue their interests, there is no guarantee that the final result maximally benefits Harvard. Therefore, the central administration must ensure that individual schools consider Harvard's long term interests when they make decisions, and that the schools do not make efficiency gains at each other's expense.

The central administration perceives that some of the schools have lifecycling problems in their decision making. A dean will make different decisions in the first year of office to the last because both his/her time horizon and enthusiasm will diminish. To counter this, the administration is moving from two to five and ten year plans. Similarly, it feels the schools may occasionally need or be tempted to defer
maintenance to facilitate other programs. To overcome this, it required the schools to conduct maintenance audits in 1985, and may do so again in a few years.7

The central administration, and the senior management of the Facilities Maintenance Department as part of the central administration, must arbitrate when the actions of one school adversely affect the position of another.8 The Facilities Maintenance Department generally tries to avoid getting involved in conflicts between the schools. As a rule, schools may to do as they wish so long as there will be a net benefit in the long run.9 Hence, the administration forbade the Business School from withdrawing from the Commonwealth Steam supply to build their own (cheaper) plant since all their savings would be thrown onto the other schools as increased costs. On the other hand, the Faculty of Arts and Sciences was not stop from using less steam in the Summer, rapidly increasing costs for the other schools. (Costs increased from $10-15/mmBTU to $35/mmBTU over three years.) While in the short run there were tensions between the schools, and massive cost increases for the smaller schools, there was an immediate cost reduction for the university as a whole and, after adjustment, a long run reduction for all parties. Similar things happened when the Faculty of Arts and Sciences installed a cogeneration plant at the athletics complex.

7 The audits were carried out under the ægis of the Planning Department, a department of the central administration that was in Buildings and Grounds until the early 70's. It is responsible for long-range planning issues like deferred maintenance. It presented the idea of the audits to the Corporation after concluding with the Facilities Maintenance Department that the audits were needed, and deciding that it was preferable for the Planning Department to recommend them. The recommendations ($200 000 000 of maintenance in ten years [compared to $500 000 000 at The University of Massachusetts at Amherst]) were given to the Corporation which then presented them with the schools. This occurred at a time when the stock market was buoyant, so the Corporation was able to offset some of the cost of the deferred maintenance by spending some endowment.

8 The key actor in this, for some time, was simultaneously director of the Facilities Maintenance Department and Associate Vice President for Operations.

9 It appears that there is no explicit consideration of what happens when a rich school gains a lot and a poor school loses a little.
Most short-run cost increases could be eliminated if the schools negotiated their works in advance, instead of thrusting them on each other. When a senior administrator was asked whether or not a negotiated approach to prevent short-run dislocation may be appropriate, he replied that "it takes so long to get cooperation that the solution is to get none." The other advantage of allowing one school to run roughshod over the others is that it creates an excuse for the university President to enter the process. He apparently often asked schools why they weren't doing as well at energy conservation as the Faculty of Arts and Sciences.

The only other time the Facilities Maintenance Department does intervene in the schools' activities is when it has either a custodial obligation, or concern for the safety of the maintenance staff. For example, one of the schools installed a series of hot water services in a manner the Facilities Maintenance Department thought was unsafe. It intervened without hesitation.

Compared to other universities, the central administration at Harvard is relatively powerlessness. At least two interviewees commented that if the President had taken a strong stand and stated that energy conservation was a Harvard priority then energy use reduction would have come about much more rapidly and much more broadly. However, the same two interviewees, and many more, stated that no Harvard president could in fact take such a stand. The schools are too independent.

4. Financing

The large energy conservation project carried out by the Faculty of Arts and Sciences was financed using about $6-$7 000 000 in tax-free Higher Education Financing Authority Bonds (HEFA bonds) that Harvard issued. Harvard's total issue of

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10 Former director of the Facilities Maintenance Department.
11 Former director of Facilities Maintenance and Susan Hill.
HEFA bonds is about $600 000 000. They have been used to finance structures including new buildings and the MATEP power station in the Longwood Medical Area. Since the government has capped bond issues at $50 000 000 per institution, these can be used no longer.

If the university is determining whether or not to back a project, it has a choice of discount rates that it can use, depending on the source and use of the money, and who's paying the bill. Generally, they either use a standard industrial hurdle rate, an industrial discount rate, or an internally generated discount rate. They do this to ensure they'll catch savings\(^{12}\). Since 85% of capital expenditure is on 5% of the projects, more care is taken over discount rates on the large projects. However, once the university has decided to back a project, it stands by it. Cash flow problems are never permitted to stand in the way of economically rational investment decisions.\(^{13}\)

The schools allocate the energy (and operations) budgets for the individual buildings based on recommendations from the Facilities Maintenance Department. However, they can allocate and recover costs any way they desire and the Facilities Maintenance Department must try to keep within the budget set irrespective of the appropriateness of the budget decision. Occasionally the individual schools will allocate smaller budgets than Facilities Maintenance Department recommends. This can create significant difficulties.

\(^{12}\) It was not clear from the interview whether or not there was a clear line between the times the different discount rates are used, or whether the person appraising the project has some discretion.

\(^{13}\) This comment was made by a Vice President. As with MIT, people at the operational level do not fully understand that this is university policy.
C. IDEOLOGY

Harvard’s ideology is important to energy management. The whole of the Harvard approach, and particularly the organization structure, the way in which the faculty are treated and the approach to money, are based much more in ideological commitment than in rational choices about the optimal organization structure for a university.\(^{14}\)

The Harvard organization structure is about as decentralized as possible without breaking up the schools into separate colleges. For instance, one interviewee noted that it would be impossible to put together a central (inter-school) committee to look at energy policy within the university. The schools, however, are highly centralized. The deans hold an enormous amount of power and influence over their faculty and staff. It is very difficult for faculty to do anything without the support of the dean.

However, people varied very strongly when asked about the decentralized structure. One saw it as a gimmick; something Harvard does so it can be different.\(^{15}\) Others see advantages, particularly in the quality of education programs, but think the four larger schools (Faculty of Arts and Sciences, Business, Medicine, and Law) are so powerful they overshadow the smaller five (Public Health, Dental, Design, Divinity and Education). This creates inequity and extremely high administrative costs, since all administrative functions have to be duplicated.\(^{16}\) One other interviewee said that he saw

\(^{14}\) Vice President for Administration, David Nankin, Susan Hill. C.f. the argument presented in chapter three that this structure, emerges, in part, because of Harvard’s highly differentiated teaching products which enable the schools to be quite separate. This differentiation creates the possibility of such a choice. It would not be as easily brought about at MIT, for instance, where uniformity across the schools is emphasized.

\(^{15}\) A middle level staff member.

\(^{16}\) This comment was made by former Dean of Arts and Sciences, David Nankin. He didn’t in any way substantiate his statement that the Harvard structure provides better education. Presumably he meant that the different schools, with their
the inequities created by the independence and differential wealth of the schools was a good thing since it reflected the schools' missions.\textsuperscript{17} Finally, right through the Facilities Maintenance Department, and especially at lower levels, people stated strongly that competition between schools and departments is good. It keeps people on their toes.

At Harvard people have a strong appreciation for money. Every faculty member who had had anything to do with the Faculty of Arts and Sciences energy conservation effort could tell me the relationship between annual savings and endowment.\textsuperscript{18} Similarly, many people emphasized that money saved in energy and facilities management could be spent elsewhere.\textsuperscript{19} To counter suggestions that there is some waste, two interviewees pointed out that a university has multiple goals, one of them being economic efficiency. However, these can conflict with other, legitimate, objectives such as quality of life on campus.\textsuperscript{20}

One interviewee noted the relationship between Harvard’s energy usage and national ideology.\textsuperscript{21} He thought their success in energy management was predicated on different ideologies, would generate different types of courses on a given subject, and hence variation would be promoted. I wonder about the strength of such an argument since it implies low tolerance of academic diversity within the schools.

\textsuperscript{17} The argument used was that it is appropriate for the Divinity School to be poor and the Business School to be rich. While I sympathize, this argument cannot be extended to the other poor schools, Education, Design, and Public Health. This suggests that a school's virtue is measured and future determined by its ability to graduate donating alumni, rather than well educated ones.

\textsuperscript{18} $1.00$ saved in operating cost is equivalent to $25.00$ in endowment. This could have more to do with the frequency with which the number was touted during the campaign than a deeper appreciation.

\textsuperscript{19} While this reflection is accurate at an ideological level, it doesn't hold in practice. One interviewee noted that money at Harvard was treated 'like monopoly money'. My own observation was that this is certainly true in all schools except the Faculty of Arts and Sciences. That is, people aren't actively trying to minimize costs. It may also be true there.

\textsuperscript{20} David Nankin and a senior administrator

\textsuperscript{21} David Nankin
Peter Cebon (1990)

the wastefulness that preceded it, and therefore it was not surprising they did so well. That former waste was based in national ideology and hence the values of students, staff and faculty, rather than Harvard's wealth.
II. THE FACULTY OF ARTS AND SCIENCES

A. HISTORICAL DEVELOPMENT AND THE ENERGY CONSERVATION PROGRAM

1. Pre-history

The high quality of energy management in the Faculty of Arts and Sciences is best understood in terms of its history. The restructuring of the Facilities Maintenance Department, and the energy usage reduction by the Faculty of Arts and Sciences are generally agreed to have been brought about by a series of events precipitated by circumstances and three key individuals.

David Nankin became Dean of Arts and Sciences at the end of the Summer of 1973 when the Faculty of Arts and Sciences was in debt to the Harvard corporation to the tune of $3 000 000. Its annual budget at the time was $45 000 000. Nankin entered office with a promise to the corporation to balance the books, and was under strong pressure to do so. One month later, the OPEC oil embargo began.

Over the next few years he developed a strong interest in energy conservation as a way to save money without jeopardizing programs. Consequently, he led a haphazard conservation program. The school concentrated on savings that appeared to be obvious without either analysis or consideration of interpersonal conflicts. So, they installed storm windows and caulked gaps in the walls. There was vast friction with the senior administration over which type of storm windows should be installed, but eventually one was selected. However, the university President had to meet with the Dean of Arts and Sciences to make the decision.\(^{22}\) In addition, they considered changing the University schedule, and contemplated moving resident tutors out of the dormitories over the

\(^{22}\) Apparently the decision was clouded by a conflict of interest.
Peter Cebon (1990)

Christmas - New Year break so that the heat could be turned off. Instead they just set it back a lot. As well as making many junior faculty and graduate students irate, this resulted in large numbers of broken water pipes. The end result was that not terribly much energy was saved. The heat was still badly controlled. Windows would be open in Winter. However, the Dean had managed to anger the students, staff and faculty, and was the butt of many jokes on campus.

In about 1979, Applied Science Professor Robert Poole discussed his own energy conservation work with the Dean. Since the Division of Applied Sciences at Harvard is separately endowed, it has an incentive for conservation independent of the rest of the Faculty. Over the previous few years Poole, an engineer by training, with the assistance of an administrative officer in the School, Peter Dixon (also an engineer), had managed to reduce substantially energy consumption in the Division of Applied Sciences. Poole persuaded Nankin that significant savings could be made. Since there was stagflation, inflation running at 18% and energy bills were eating into both the available funds for operations of the Faculty of Arts and Sciences and research budgets, Nankin was extremely interested.

A committee was formed. It comprised the Dean of Arts and Sciences, Robert Poole, (Co-chairs) some administrators, and some faculty members including the chairpersons of all the departments that are high energy consumers (Physics, Chemistry, Biological sciences, etc.). The committee invited Dixon to come back to Harvard over the Summer to act as a consultant. He had taken a position in Tennessee. Dixon conducted audits with the assistance of students and an engineer, and concluded that savings of about 50% could be made with less than 5 years simple payback. The Dean set this as an objective and a five-year, 50% reduction program began.

Either in addition to, or possibly as part of the same committee, a group was created consisting of representatives of both the Faculty of Arts and Sciences facilities
office and the Buildings and Grounds Department (which later became the Facilities Maintenance Department). As one interviewee said, this was done "so that it would become a group effort. Often in the past, not particularly in the energy area, but in the area of renovations and new construction and the like, faculties would go off more or less on their own, and do a project without consultation or assistance form Buildings and Grounds. (The administrative head of the program) saw (that) ... without the cooperation and support of the people who ran the buildings 24 hours per day, ... the program would go nowhere."

2. TECHNICAL ASPECTS

An energy group was set up in the Faculty of Arts and Sciences Facilities Office (which had itself been set up earlier to oversee work by the Buildings and Grounds department) and someone was appointed to carry out the work. He appointed a group of project managers to oversee the projects.

a) Building envelopes

Initial works focused on the building envelopes:

- They insulated roofs wherever they were replacing them or they could get in batts or blow in fibre glass.
- They installed storm windows and thermal windows wherever practical (and where they weren't installed early in the energy crisis).
- They applied weather stripping wherever they could.

b) Load control and scheduling

Once they were satisfied with the envelopes' integrity, they assessed the control systems for the buildings' machinery. Essentially, they tied equipment operation to building schedules. Time schedules are given to the operators at the start of each week.

28 Thomas Risbey
and input into the computer. Heating goes on about 1/2 hour before the first use and off a little before the end of the last use for the day. Lecture theaters generally come in three sizes:

* Large theaters, i.e. those with 200 - 500 seats are controlled exclusively with the facilities management system. They are used heavily so they are brought on in the morning and run all day until the evening, except on days when there are large blocks of time free (generally Fridays). On those days, the heat is tailored to use.

* Middle size theaters, seating 75 -150 people, often (6 - 10 of them) have a vent switch. That is, heat is provided throughout the day with minimal ventilation. When someone throws the switch, ventilation is provided at full occupancy level for two hours. This reduces the dependency on computer control and increases user control over the environment.

* Small classrooms rarely have their own zones or air handlers, so local control is often impossible to provide. Many have perimeter radiators. Occasionally they have a fan-coil unit with a timer and thermostat.

For areas that contain only offices, the heat goes off at 9:00 at night.

Laboratories are conditioned twenty-four hours daily.

Once load timing had been established, they looked at the loads themselves.

c) Equipment modifications

First, all fan and pump sizes were checked. Most were over-size, and were replaced or re-sized. Typically, a 20 Horse Power motor would be replaced with one of five. At Harvard, most buildings have both duty and standby equipment. The standby equipment is used when the duty equipment breaks down or needs service. Only the duty unit was replaced. Variable speed drives were generally avoided since they were expensive and the school had no plans for direct digital control. To change the impeller on a fan might cost $2000, but to put on a variable speed drive costs $35 000. It's much easier to get the payback on the $2 000 investment. The interviewee continued that
direct digital control systems were very new at that stage\textsuperscript{24} and that this didn't tie in well with the control system that they were using at the time.\textsuperscript{25} He also expressed, as did many other interviewees, a philosophy for keeping things simple. He indicated that this was much more of an operating philosophy than a policy.\textsuperscript{26}

Ventilation quantities were carefully developed for offices, class rooms and lecture theaters. These were based on actual air use, rather than on historical precedent. (Ventilation standards for public places assume an audience full of malodorous smokers.)

Similarly, considerable effort went into determining the appropriate ventilation pressure. A lot of the buildings, especially laboratories, were under-pressurized. Air would leak from the high pressure surrounding environment to the low pressure building. In some laboratories the pressure was so low that air would be sucked into the space through the hood exhaust even if the fume hood was going.\textsuperscript{27} Users, feeling the

\textsuperscript{24} MIT had in fact had DDC for six years.

\textsuperscript{25} A few things should be noted about their analysis. First, there was no attempt to optimize either the investment decisions or the way that things were approached. Not only did they say, "If it pays of in five years, do it", but they also seemed to say, "If there is a cheap (or possibly low disruption) five year project and an expensive (or maybe complicated) one, do the cheap one so long as we will achieve the overall objective of a 50% drop in energy consumption over five years." In other words, so long as that goal could be reached, there was no value in more efficient solutions.

Second, there appears to be a lack of foresight. It appears that variable speed drives were not appropriate because they couldn't link in well with the pneumatic control system then in use. The fact that DDC was an obvious reality (and eventuality) at that time seems to have been ignored completely. That makes it very difficult to go to variable speed drives later. Their installation is more marginal, and, it would appear, there is a need to raise a certain amount of momentum to get people to look at a building again after it has been audited and attacked.

\textsuperscript{26} My interview with Robert Poole would indicate that he was the source of that philosophy. The fact that it was a philosophy and not a policy would indicate its basis was somewhere in politics rather than in rational decision making.

\textsuperscript{27} Interview with Robert Poole
draught, would increase the temperature to a much higher level than they would prefer, to compensate. This led to significant user discomfort in addition to increased heat load.

So, for an individual building, the works program could be described as follows:

* Give buildings an early morning flush of fresh air (especially in the Summer)
* Improve controls on dampers
* Use night setbacks where possible
* Use fluorescent lighting where possible
* Use time-clocks where possible. That is, put a two hour timer on lights and ventilation etc.. This proved impractical for lecture halls where people would come into lit halls and the lights would go off (for example). People developed big hate complexes for timers, which also broke.

Fume-hoods were modified to operate at two speeds at a cost of $1500 - $2000 each. At the low speed, there was sufficient flow to maintain a vacuum with the sash down. Raising the sash turned on the main fan. This was not possible where fume-hoods had multiple hoods on the one fan. Therefore, they had to be controlled so that they only shut off when all the hoods were closed. It is possible to save energy by adding unconditioned outside air at the entrance of the hood (instead of bringing it through the conditioned space) saving on both air conditioning and air handling costs.

When asked whether or not they considered this, one interviewee said that they didn’t cost it, since they could get the sort of savings they wanted without going to that length, and to do so would have been very disruptive. New buildings, however, generally have an auxiliary outside air supply. This reduces heating and cooling loads.

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28 While this was the cost given to me by the project director, Robert Poole gave me a much higher price of $3000 per hood.

29 While he probably is right, adding outside air would have required extensive structural work, the fact that they didn’t cost it indicates either that the (social) disruption costs would have been prohibitively high anyway or that they were attempting to achieve their goal of 50% reduction, not optimal energy use.
d) Turning off the heat

One of the biggest savings came from the decision to stop using steam in Summer. As well as there being large losses as the steam comes up from the Commonwealth Steam plant in Cambridgeport, steam tends to heat the buildings in which it is used, and so they need extra cooling.

This decision had major implications inside both the Faculty of Arts and Sciences and the other schools. In the Faculty of Arts and Sciences, the no heat policy affected on many aspects of operations policy.

* Laboratories had to find new sources of distilled water. Over a couple of years tests were done in the laboratories with filtered water, reverse osmosis and electric distillers. While the senior administration felt there was no need for these tests, that the alternatives would work just as well as distilled water, they realized that the faculty needed to satisfy themselves. Works were delayed the necessary couple of years while the experiments were carried out.

* The cooling systems of the buildings had to be controlled much more closely since there was no possibility of terminal reheat.\(^{30}\)

* The policy of no heat in Summer means that there can be no heat in Summer, even if they want it. While the contract with the utility is theoretically open-ended, Harvard has decided to start providing heat on October 15th, and that is virtually immutable. This causes consternation during premature cold spells in the Fall.

* The no-steam philosophy can work only if different rooms generate similar amounts of heat.\(^{31}\) Excessive differentials in heat generation will create differentials in temperature. Therefore, many windows received an insulating film. This was fortunate since in one building (The William James building) some of the windows promptly cracked and the film holds them together.\(^{32}\)

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\(^{30}\) Heating the chilled air just before it enters the room.

\(^{31}\) Or if they have a variable air volume heating and cooling system.

\(^{32}\) The windows that cracked are all on the south side of the building and are all partially shaded in the afternoon. The Faculty of Arts and Sciences believes the cracking occurred because the temperature differential across the window had now increased.
There were humidity problems. In special areas, air was over-cooled and electrically reheated. However, in general, humidity control was banned.

In addition to the savings in steam, the drop in air conditioning load because the heat had been removed from the buildings more than countered the increase in electricity needed for additional humidification and distillation equipment. Hence, electricity loads declined also.

Outside the faculty, the negative effects were intense. As the Faculty of Arts and Sciences used less steam, larger and larger portions of the overhead were transferred to the other schools. Consequently, their overhead rates, and particularly those of the Law school, rose dramatically. This made the Faculty of Arts and Sciences very unpopular. Similarly, and as part of its restructuring, the Facilities Maintenance Department devoted significant effort to upgrading the steam distribution system. This followed pressure from the Faculty of Arts and Sciences, since a significant portion of its steam use was to leaks in the distribution system.

e) Major renovations

There were a few major renovations. For instance, the undergraduate teaching labs (chemistry, physics and biology) in the Science Center (circa 1965) were ventilated by one 100 HP fan and exhaust. If one of the rooms was occupied, all three had to be conditioned. This was changed to make the three independent and run from the facilities management system.

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33 Cold air can carry less moisture than hot air. Therefore to de-humidify in Summer you cool the air to force out the moisture and then reheat it.
Similarly, one library which had a dual duct system, and was changed to variable air volume.\textsuperscript{34} This did not present a humidity problem. The rate of ventilation of libraries is so low that new air could be introduced quite cold and heated by solar gain, providing de-humidification.

Also, since steam was cut off in the Summer, five of the buildings with absorption chillers were converted to central chilled water.

3. ANALYSIS AND FINANCING

Throughout the entire auditing procedure, projects had to be evaluated. It was decided, presumably by the committee, to use a five year simple payback (Which corresponds to an internal rate of return of about 18% or a real rate of return of about 12%). The analysis was not terribly rigorous, there were no "fancy calculations about interest rates and the like." Essentially, most of the projects paid off in less than two years, so rigor wasn't needed. To indicate how poor management had been in the past, one interviewee commented that, "I lived in the Harvard dormitories in the late 60's. I'm not a tremendous fresh air freak, but my window was open all Winter."\textsuperscript{35}

\textsuperscript{34} Dual duct systems have two air supply ducts, one hot and one cold. The air is mixed at the outlet to provide the right temperature. They are extremely expensive since there is both unnecessary heating and cooling. For example, to provide 68° air on a 68° day, one stream has to be heated by the same amount as the other is cooled. They are then mixed.

Variable air volume systems are much more efficient. They supply air at a fixed temperature, and the volume is varied to give the correct temperature to the conditioned space.

\textsuperscript{35} Thomas Risbey (both quotes).
4. PEOPLE MANAGEMENT AND ORGANIZATIONAL ASPECTS

Three distinct groups of individuals within the Faculty of Arts and Sciences had to be managed through the energy initiative; faculty, energy monitors and superintendents, and users.

To enlist generic support for what Professor Nankin describes as "a symbol of the new emphasis on cost consciousness", and to show he was serious, he emphasized the energy savings program in all fund-raising literature. Similarly, whenever he walked into a building and saw obvious wastage he would make a very big issue of it, not because the wastage was serious, but to show he was interested. Finally, he exploited the dramatic changes surrounding the removal of Summer steam to show his strong commitment.

Energy monitors and superintendents received constant support from the school. There were small cash bonuses, dinners, prizes, and so forth. One of the superintendents I interviewed indicated that he was impressed by receiving commendatory letters from the dean (but felt that his subsequent work wasn't appreciated).

The faculty had little direct incentive to cooperate with the program. It disrupted their work and took their time. While it wasn't the case, they probably thought it would lower their comfort. To enlist the support of the faculty, several mechanisms were used. The dean wrote letters to all the faculty and staff stating that the policy of the Dean of the School was to save energy. There is some debate about whether or not he actually shared the savings with the faculty. While some of the people I spoke to think he did, Professor Nankin denies it.36 Similarly, there is a

36 It is conceivable however that deals were made by people working for him. However, I doubt it, since these people couldn't trade in the likely bargaining goods of buildings, staff positions, and space.
common belief throughout the school that the dean would twist the arm of the faculty to
enlist cooperation. I was told that he ransomed buildings, faculty positions and
programs. However, he states this is untrue. He did note however that the dean of a
school is extremely powerful, and no major initiative can go ahead without his support.
Any academics with ambitious plans would have ensured that they had a good energy
conservation record before asking for anything, simply because they knew the dean
thought that was important.

It is important to consider the interpersonal events that started the program and
kept it in progress. One thing that was obviously crucial, and was emphasized
throughout the interviews, was the trinity of Poole, Nankin and Dixon.

An initiative like this could not occur without the strong support of the dean.
The next section emphasizes this by discussing how it could not occur under the current
dean. As well as being a supporter, Nankin saw his role, and that of Poole in particular,
as one of leadership. That is one of providing symbols and highlighting important
things. So, he saw the removal of distilled water from chemistry not only in terms of
the savings ($50 000 - $60 000 per year), but as a symbol of cost consciousness.
Similarly, the dinners and prize givings were partially to show they thought this was
important.

Professor Poole was important for two reasons; he is technically competent and
he is a senior member of the faculty. The technical competence allowed him to
understand the best ways to approach the problems. The importance of this can be seen
if we compare the second (and successful) energy initiative with Nankin's early attempts.
The faculty membership gives him several advantages. First, he was in a position to talk
to members of the faculty without having to worry about his relative status. This
enabled him to speak to them directly while fully understanding their position. Second,
at least one interviewee felt that Poole's academic training allowed him to seek creative
solutions to the problems. That is, he had "a vision to the problem". He also had a lot of credibility to start with, since he had done the pilot work in his own division.

Dixon was important because he was on the staff that would actually be doing the work. He was also keen and competent.

One final aspect of the program that should be emphasized is the very successful publicity that accompanied it. Most interviewees could tell me that they saved 50% in five years and that $1 000 000 in annual savings was equivalent to $25 000 000 in endowment.

5. After the Initiative

The subsequent dean, another economist, was appointed in 1985. He restructured the Faculty to reflect his different agenda for the school. Indicating that energy conservation was not on his agenda, he appointed an Associate Dean who is not terribly interested in it. He has divorced himself from most faculty administration. All interviewees who were asked noted that a conservation campaign similar to that of the early 80's could not be mounted under this setup. It is not surprising that they have also said that the program could not be sustained. Money is not available. The current leadership is much more interested in the growing need for structural maintenance and particularly, deferred maintenance.

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37 Alternatively, Professor Poole was able to propose solutions that other people has seen but didn't feel they were in a political position to pursue.
B. CURRENT STRUCTURE AND PROGRAMS

1. STRUCTURE

the Nankin deanship left two energy-related legacies in the Faculty of Arts and Sciences. The energy program in the facilities office is institutionalized, and because it still serves a useful function cannot be removed. Also, The new dean has ensured it has a large enough budget to do some works, so it is progressively upgrading the buildings' control systems.

a) Accounting

The faculty's annual facilities budget is approximately $30 000 000, or $0.90 per square foot 9 500 000 square feet of occupied space. This excludes capital items over $50 000 but includes some maintenance items above $50 000.

Capital requests are processed through the Office of Physical Resources, and reviewed by the Operations Department, the Capital Construction Department and the Planning Department, as appropriate. These combine to give a capital budget request to the Dean. Many of the capital requests come from new faculty appointments (discussed later).

Buildings are allocated individual budgets, consisting of capital and recurrent amounts. Many of the retrofits are of sufficiently low cost to not justify a 'capital' label, but have a payback of more than a year. (Small motors are an example, as would a preventative maintenance program.) This is not problematic; budgets are fairly flexible. They can be increased to pay for retrofits and the cost is picked up by the facilities office. However, once the budget has been increased, it is administered locally as much as possible.
Included in the budget can be capital sums. So, if a building's operators, normally an academic department, wanted to install direct digital control in a particular building, and the project required addition to the budget, it would be proposed to the dean. He would choose whether to approve it, would determine how to raise the funds, and would assure it was approved by the Vice President for Administration or the corporation, as appropriate. Once approved, the money is spent by the relevant person, generally the superintendent or the director of the laboratory. However, the costs are recovered from the school as a whole using an allocation formula.

There are two sources of economic inefficiency here. The occupants of the buildings themselves have very weak incentives to save energy, since they will only reap a small portion of the collective benefit. This is exacerbated by the fact that the superintendent must deal with people who don't like the 68° temperature requirement, but without something with which to bargain, other than imperceptibly lower overheads. The second is that only half the accounting (expenditure) is building based, while the other half (cost recovery) is not. Surprisingly, this does not result in a strong competition for capital where energy conservation offers side benefits.

To overcome these inefficiencies, Stephan Engel has initiated a "shared savings" program with the buildings. They can save money in any area of custodial, maintenance, and energy consumption and the facilities office will give it back to them for use in the building. They cannot take structural shortcuts (like not re-roofing) and they cannot apply savings to other programs, such as staffing or academic research.  

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38 As we noted in chapter five, this program creates a near-perfect market. People are free to make marginal decisions. They have an incentive to do so. Savings can be measured (c.f. preventative maintenance where they are hard to measure). They are not restricted in resources, skills, or access to contextual or technical information. However, savings can only be made in areas where the user can see them, namely in light fittings, temperatures, etc. They are not in the areas which are invisible to the user or beyond the user's understanding, such as air delivery systems and the like.
b) Coordination, control, organization and training

Physical Operations sets buildings’ budgets. It is controlled by either the laboratory director, for laboratory buildings, or the building superintendent for others. These people approve all purchases of Facilities Maintenance Department services. To exemplify this, Stephan Engel discussed a hypothetical decision to retrofit fume-hoods in a laboratory. In such a situation, the facilities office would approach the laboratory director with a suggestion. The laboratory director would take it up with the faculty and would make a decision. In no circumstances would the facilities office approach the relevant faculty directly.

Every building has an energy monitor. They are typically administrative officers in office and laboratory buildings or house managers in the dormitories. It is usually the superintendent for those buildings which have one. The smaller buildings, those without their own superintendent, tend to rely on the facilities office for assistance with day-to-day decisions. So, the facilities office wants to appoint a superintendent for each building. While ideally the energy monitors should behave as consistent cost minimizers, they have very different styles. (See the case studies at the end of this section.) To facilitate uniformity, the School has developed a comprehensive series of buildings’ operations procedures. These are very specific in well defined cases, such as the procedure for ensuring that the building schedule goes onto the computer. In others, they are less so. For the less specific procedures to work, the energy monitors must understand the building energy system. Hence, the monitors learn extensively about their building’s operations. Armed with these, monitors are encouraged to develop systems that match the building’s activities.39

39 This is an interesting example of the need to bring technical and contextual information together.
There is a big need for information transfer between the energy monitors and between the monitors and the facilities office. Monitors also need a stream of product information. Early in the energy conservation project, facilities office staff, who were intimately involved in systems changes and were often dealing with technology, would refer interesting discoveries to the monitors. Also, they saw the individual monitors often enough to act as conduits of innovation from one monitor to the other. Now, there are no formal modes of information transfer other than a biennial meeting where the energy monitors discuss their successes and problems. The strongest informal links are via the Facilities Maintenance Department and the Harvard purchasing office. The Facilities Maintenance Department purchases materials for its staff only. The Harvard purchasing office will fill the university's purchase orders. It will buy things like office supplies, laboratory supplies, and furniture. While people can still buy externally, most acquisitions go through one or both of these. This could allow independent (and casual) review as well as information transfer. Not surprisingly, the purchasing office does not do this, it simply negotiates prices for the equipment people want.

A related problem is the strong possibility that energy monitors will do things that are either inefficient, or can be done better. (For instance, one building has been retrofitted throughout with one model of compact fluorescent light. Presumably some variation would lead to either better lighting or more savings.) It is considered better not to intervene than to bureaucratize the process. Therefore, such inefficiencies are watched for but not acted upon unless extreme.

2. Components

Outside the large audits and retrofits by energy monitors, all component replacement in the Faculty of Arts and Sciences is carried out at failure with equivalent equipment. That is, things are not replaced before failure and better options are not pursued, unless the energy monitors generate replacement projects, which they do in
accordance with their knowledge and enthusiasm. Consequently, simple technologies such as compact fluorescent fixtures are relatively well diffused throughout the school. \(^{40}\)

We saw in chapter two that the energy manager can move responsibility to or from the user with motion sensors, light sensors, and time switches or by scheduling services. Consequently, these control technologies offer opportunities for flexibility at low cost. Motion sensors, if they work, are particularly effective for this. Consequently, it is interesting that at the Faculty of Arts and Sciences abandoned them because they couldn't get them to work well.

3. Systems

Building energy consumption is checked daily (by the Facilities Maintenance Department) and monthly (by the school). If consumption deviates from the expected value, the reason is determined. The daily check ensures that gross changes in energy usage are spotted quickly, that someone goes into and inspects the plant room of each building daily, and that the operators are close partners in the program. Monthly checks detect subtler changes.

Despite the current low emphasis on energy conservation, there is always some to do. New projects arise because they didn't do some of the identified projects during the initiative, and new technology is always presenting new opportunities.

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\(^{40}\) For the initial installation, the facilities office selected the fifteen buildings which it thought had superintendents, buildings, and users which were most likely to accept the new technology. That is, there were places where the lights would not look ugly, be too heavy, or be stolen, and the superintendents would make the efforts to install them. Diffusion into the remaining buildings appears to have been relatively slow.
4. CAPITAL CONSTRUCTION

There were no new buildings in the Small Professional School in the last five years, and hence little data collected is completely divorced from the Faculty of Arts and Sciences. Therefore, both generic and Faculty of Arts and Sciences capital construction are discussed simultaneously. Distinctions should be clear when they occur. Generally, I am referring to the Faculty of Arts and Sciences unless stated otherwise.

a) Works Types

There are three types of capital works, 1) adaptive reuse and new buildings, 2) work related to specific spaces for specific people, and 3) projects on building systems.

Adaptive reuse and new buildings are large scale projects such as major refurbishments. These are the most interesting for this study. Harvard has built four and two half academic buildings in the last decade. They are examined on a case-by-case basis. In the last five years, about 80% of capital expenditure has been on space renewal of some sort.

Point related work is generally in the sciences. New faculty need space in which to work. While in some cases this simply means buying a desk and a chair, in others it can require extensive, and often very rapid, modifications of space, such as construction of specialist laboratories. There are problems budgeting for these works because appointment dates are unknown in advance. Hence, the Faculty of Arts and Sciences hopes to move to a speculative budgeting system in 1988, where capital will be budgeted using historical averages.

Building systems works are also very hard to predict. They spin off from the maintenance program at unexpected times. They have the additional problem that budgets are determined in mid-winter for works that have to be ready for contract
bidding in mid-Spring for construction in the Summer. Again, a historically averaged budgeting system may be implemented soon.

b) The Construction Process

All major construction is overseen by a committee comprising people with different interests. It generally includes the donor and representatives of the beneficiary department, the planning office, the dean's office and the facilities office. This committee controls the project including determining the program and the architect. The most powerful people on the committee, the departmental representatives, are interested in maximizing the benefit for their discipline. The donor's interests are closely aligned, though they are also likely to relate to the building itself.

The project manager is employed by either the school or the university, primarily to get the building built on time and under budget, not to make sure that the building can be managed easily. Site decisions are made as the project manager sees best. Therefore, the Facilities Maintenance Department is rarely involved in field decisions.

c) Architect Selection

There is considerable disagreement about the influence of the donor in the selection of the architect for major works. The construction director assured me that the donor has little influence, while other people who aren't as intimately involved thought that the donor is very influential. He claimed that architects are selected competitively on the basis of their previous work and occasionally generic proposals for the structure. Harvard does not sponsor design competitions.

In the 1970's Harvard tended to select architects who would create impressive looking buildings. However, since these have often been operational failures, Harvard has moved to much more functional designers. For the Sackler Museum, Harvard
wanted an attractive exterior, so they appointed James Stirling to do the work. However, while the principal architect did all the space allocation and elevations, a more practical local architect designed the services. The facilities office claims that this worked quite well.  

The former Busch-Reisinger museum is currently being renovated to become the new home of the Center for Western European Studies. In this case, the architect was selected after a search and interviews by three groups, 1) The Central Planning Office, 2) Faculty of Arts and Sciences staff, and 3) building occupants. It was made clear at interview and before that the architect's work would be subject to intensive review by Harvard. Interviewees were short-listed and previous job sites were visited before a selection was made.

The Faculty of Arts and Sciences does not think that the Harvard Design School is pre- eminent. Also, Design school graduates do not receive their architectural training in the Faculty of Arts and Sciences. Therefore the Faculty feels no obligation to hire Harvard Alumni. (Similarly the senior management of Harvard are not all Harvard Business School graduates.)

d) Design Review

Several groups participate in design review. They include the energy management group in the Faculty of Arts and Sciences and the Facilities Maintenance Department. The operations group in the Faculty of Arts and Sciences takes a reactive, rather than pro-active, role. That is, it looks at drawings after each revision. Several reasons were given for this:

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41 Other interviewees disagree with the construction director about how smoothly it went. Apparently there were significant problems with the air-handling system and with the flooring.
* Extensive participation in the process takes up too much time for someone who isn’t principally concerned with it. So, extensive involvement of the operations people in design review will prevent them from performing their other duties adequately;

* There is too much variation between projects to enable the setting of standards. Therefore, every project has to be treated individually.\(^{42}\)

* Once upon a time, the people who were involved with operations also supervised construction. However, they devoted too much time to the (more exciting) construction, and insufficient to the (more routine) operations. Also, they found that good operators are not necessarily good builders, and therefore, they divorced the two functions;\(^{43}\)

* It is easier to react to drawings than to argue in the abstract.

This contrasts sharply with the views of the former dean, Professor Nankan, who believes that the energy and operations people should be in the review process from the very start.

The interviewees said that Harvard pressures architects to design energy efficient and easily maintained buildings, using the status of designing a Harvard building as a lever. It also places a high emphasis on other objectives such as safety and special scientific functions. Architects are aware from the start that there will be thorough review. However, controlling architects is still seen as a major, and difficult, task. In contrast, an interview with a local architect who has worked with all of the schools studied, indicated that Harvard is the most difficult to work for. While all of the schools saw themselves as having to spend their time controlling the excesses of architects, this architect saw her role as being one of mediating between the interests in the school. At Harvard, these are more differentiated than at other schools.

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\(^{42}\) Paradoxically, this is exactly the reason why you would want to include the operations people, not exclude them.

\(^{43}\) This may be true, but it doesn’t make it inappropriate to include them in the design process.
Architects generally design in excess of the brief and the budget. So, the building comes out more expensive than wanted, and less functional. The facilities office believes this skewed emphasis arises because users don’t give architectural awards. To influence the, often unwilling, architect into making changes, the operations department relies heavily on the Massachusetts energy code. In addition, it uses a book of construction guidelines and performance specifications prepared by the (now defunct) Construction Management Department. It leaves a lot for decision on a case-by-case basis.

It appears that architects, and their sub-consultants, are not very good at designing energy systems. Energy and operations aspects are not represented on the construction committee or in the brief, other than through a formal, and reasonably strong energy code and a weaker set of construction guidelines. Furthermore, the operators, the Facilities Maintenance Department, are virtually excluded from all but the final design review. Within that framework, however, operational aspects are given good consideration if they manage to be raised. For example, the redesign of the Bush-Reisinger museum was originally done with a once-through air system. That is, none of the air was to be recirculated. This had been predicated on the difficult structural layout of the existing building and a donor who was insistent on an elegant building. The system has been redesigned to give some recirculated air. But, as one interviewee said, "Before the energy initiative, there would have been no design review, now there is." He then went on to point out that one of the reasons for poor energy input in design was the current low price of energy. "If costs were twice as high, concern would be different."44

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44 The school’s attitude is naive for two reasons. First, if the basic building systems design has a life of 100 years then low energy costs cannot be relied upon. Second, energy conscious design of basic systems can often be equated with functionally conscious design. So, this attitude may well increase other operating costs. It is amazing how much the school did not learn from the energy crunch.
e) Design Standards

Harvard's central administration makes it very clear that buildings are designed
to stand for several hundred years. Therefore they are prepared to pay extra for systems
that work, so cost is not highly constraining. Budget extensions must bring an
acceptable return on investment, however. While it is well understood in the Faculty of
Arts and Sciences, this message hasn't filtered down to the Facilities Maintenance
Department. However, with energy, interviewees suggested, it is very hard to predict
actual building consumption, let alone the energy cost,\textsuperscript{45} so Harvard builds to State and
Federal Energy codes, and does not go much beyond them. They meet them with a few
exceptions, principally laboratories and museums. Beyond that, they don't "spend as
much time on energy as we probably should."\textsuperscript{46} Generally, they try to make the
building function well, subject to time constraints, especially the amount of time the
architect has to deal with these issues. Similarly, they are very hesitant about building a
structure than is more complicated than is necessary, since they don't feel that they
Facilities Maintenance Department, though improving, is reliable enough.

Energy consumption of a building is very much a function of the perceptions of
the donors and occupants who determine the design. For instance, if people (and
especially donors) feel that Tungsten lighting, extravagant air conditioning and high
ventilation are appropriate, this tends to get designed into the structure.\textsuperscript{47} This is
problematic as these parties often have incorrect perceptions of what is best for the

\textsuperscript{45} In fact it isn't that hard to predict consumption. You just have to be prepared to
pay to have it done. Many building systems are guessed rather than designed. A
much greater problem is extremely conservative design assumptions leading to
oversize equipment. As we saw above and at the other sites, motors quartered in
size during retrofits (although this is partially due to reductions in the loads they
have to carry).

\textsuperscript{46} Director of Construction.

\textsuperscript{47} This is obviously a source of potential conflict.
building. As a concrete example, when the Sackler museum was being designed, the museum wanted very high quality temperature, humidity and dust control. Once they saw what that would cost, they changed their expectations. One of the construction office's functions is to control these expectations. This is one of the principal reasons the operations people review building plans.

A key question in determining design standards is costing, particularly the question of whether to cost on the basis of first or lifecycle costs. There are three significant reasons to use first costs. First, energy is only a small portion of the operating cost of a structure. (Cleaning is very significant). Second, some expensive equipment is more complicated, and therefore costs more to operate. Third, so the interviewee argued, good energy design can take up highly valuable space. Against that is the generalization that higher quality initial designs have longer life cycles with less maintenance and lower maintenance costs. The key design issue appears to be care and understanding in the engineering of the building, rather than any cost calculations.

Generally, energy innovations that make the building more complicated, and increase the cost of maintenance, are avoided. For instance, before direct digital control, enthalpy controls were popular on HVAC systems. At Harvard, they generally didn't work. As a rule, Harvard prefers systems they know they can make work to newer systems that they don't. It is only if they don't have a good solution to a problem that they will look around for new ones.

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48 For example, many people have an aversion of fluorescent lighting on the basis of their experiences with the technology twenty years ago.

49 As can be seen at Canaday Hall, where a low cost structure is very expensive to maintain.

50 A school's flexibility depends on the amount it can trust its maintenance capabilities. A school with a reliably competent maintenance department would be much more flexible than one that must think seriously about maintainability with every acquisition it makes.
Many interviewees who were intimately involved in the construction process felt that costs played a minor role in Harvard's overall construction decisions. For example, Harvard regularly uses slate roofs because they are cheaper in the long run, despite their very high initial cost. However, Harvard feels it is already paying a premium of about 25% on the initial cost of its buildings compared to other institutions. (They don't really know why.) Budgets are rarely increased once a project begins. Also, the same interviewee thought the process works in the opposite direction. It is much easier to remove parts of a project from behind the scenes than it is to pursue more money. This would suggest a reduction in standards as a project proceeds. People are aware that there is no free capital lying around and that it is extremely difficult and time consuming to pursue extra funds. (It also makes managers look incompetent if they need their budgets extended.) Given this, it is interesting to consider the history of Canaday Hall, a freshman dormitory built in 1973. While the director of construction believes this was built at low cost as an experiment in low cost-high maintenance construction, other interviewees disagree, saying that a capital shortage precluded high quality construction. This is discussed as one of the case studies.

Irrespective of cost, there were some serious mistakes made that have increased the cost of maintenance. In the 1960's there was a high reliance on "wonder materials" such as synthetic sealants. These performed poorly. Similarly, fabric flashings haven't been terribly successful.

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51 This is different to bounded rationality. They know there are alternative solutions available. However, the alternative solutions create uncertainty that they would prefer not to deal with.

52 Director of Construction, Vice President for Administration, Stephan Engel and Thomas Risbey.

53 Former Director of Facilities Maintenance. This would suggest that there are very strong institutional constraints to budget increases, but once someone decides to overcome those constraints, capital is readily available. So, known 'lifecycle' decisions, such as slate roofs, are included in the initial design. The constraints operate on ideas that come later.
Peter Cebon (1990)

Only very recently has construction project review by the Facilities Maintenance Department become the norm. In the 'bad old days' Buildings and Grounds review would have been extremely rare. If the Facilities Maintenance Department can identify work with a reasonably short payback in either new or older buildings, then the faculty would fund it. It would use either, 1) the maintenance reserve, 2) a treasurer's advance, or 3) an external loan or bond issue.

While the Facilities Maintenance Department is being asked to look at construction now, there is no one on staff who is responsible for guaranteeing maintainability of new works. They hope that this responsibility will be taken up by their new engineer (See later section).

Although the Facilities Maintenance Department participates in design review, parts of the building at the periphery of renovations don't get renewed. For examples, although a space is being renovated, the pipes which bring hot water for heating to that space will not be. Interviewees hypothesized it is either extremely expensive to engineer an existing structure, or it isn't seen as being important, or there is insufficient money in the budget and it doesn't seem worthwhile to get it increased. Unfortunately, once these buildings come back on-line, and these things start to break, there are major dislocations. Users think their new space should work and therefore the Facilities Maintenance Department is incompetent. The Facilities Maintenance Department staff get angry because things should have been replaced.

5. Users

In this section, I am differentiating the way people responded to explicit requests for equipment changes during the Faculty of Arts and Sciences energy effort discussed above, (e.g. faculty who were asked to go from distilled water to filtered water), from
the way users have been asked to alter their behavior before, during and after the program.

Prior to the 1970's, Harvard's attitude to its users was clear. The students were the most important people on campus, and therefore they were to be comfortable. It didn't matter how much energy it took. With the energy crisis, operating standards were developed, and user management became more significant. The users can be divided into two separate groups. Students in the dormitories and everyone else.

For students in the dormitories, a lot of effort goes into ensuring energy is not wasted. From what I understand, the buildings are fairly old and difficult to operate, so vigilance is needed. When they enter Harvard, students are given a pamphlet that explains all relevant energy issues. The Facilities Maintenance Department believes students know that for 24 hours per day they can phone the central facilities maintenance number and get a response to their problem. Outside standard hours (7:00 to 3:00) these are dealt with by the evening and night shifts of operating engineers, who are essentially HVAC mechanics, but will respond to electrical and plumbing problems as well.

In particular, they try to stop wastage through ignorance. So, if someone calls in, and particularly if a student calls from a dormitory with a cold complaint, nothing gets altered. Instead, an operator goes to the room and measures the temperature. Then he'll check that the fireplace damper is closed and the storm windows are down and correctly faced (i.e. with the top one on top). He'll then explain that there is a setback after midnight of 64°. This is particularly useful with students from warmer climates who are unfamiliar with storm windows and fireplace dampers. If the room is cold and the cause cannot be found, the heat is put on for half an hour. This contrasts strongly with a decade ago when the building heat would have been raised all night.
Peter Cebon (1990)

To inspire the students to be energy conscious, energy saving competitions were run between the dormitories during the energy campaign. These were not terribly successful because of metering difficulties, especially in houses that had dining facilities incorporated. However, the competitions did raise people's awareness of the problems.

In other buildings, the energy monitor mediates between users and unscheduled uses. For instance, they decide whether or not there are enough people working to justify keeping the heat on at night. Similarly, they act as a consistent liaison between the building users and the Facilities Maintenance Department. Their training enables them to give reasonably intelligent analysis of the problems they encounter. The energy monitors are given energy use and maintenance expenses information by the faculty so that they will feel that they are part of the process, and will see the product of their efforts. Other than the pats on the back that go with this sort of work, there have been few incentives for good work by the energy monitors.

Harvard, like the other sites, has more trouble managing the distributed utilities, especially electricity, which is used on the basis of individual decisions, than it does managing the centralized ones.

6. Standards

The Faculty of Arts and Sciences generally subscribes to the Federal energy code requirements of heating to 68° and cooling to 78°. However, rather than mandate these, it generally lets users determine their own temperature settings, and assume they won't be profligate. Therefore, non-dormitory users have unrestricted choice of temperatures. Similarly, lighting standards negotiated. The school severely restricted other aspects of behavior however. For example, while laboratory buildings are conditioned 24 hours per day, 365 days per year, office buildings are conditioned until 7:30 pm only and not at all on Sundays. In other words, people are given a clear message to go home at 9:00 at
night, and not to come in on Sundays. Similarly, there is no heat available between May and Mid-October, except in kitchens, athletic facilities, and dormitories, where it is needed for hot water.

7. MAINTENANCE

The Faculty of Arts and Sciences is re-evaluating preventative maintenance. The current program is generated annually, and involves a lot of work which has no budget, and therefore doesn’t get completed. It also involves very vague work orders (like "service all the fume-hoods in the building") and work orders for equipment that has been decommissioned or has been replaced with similar equipment with different requirements. Probably, some equipment is left out of the system.

There is an interesting dichotomy of views expressed on the preventative maintenance program. Some interviewees saw it as an expensive use of precious resources, yielding little for the investment. Others, thought preventative maintenance was vastly inadequate, and that its funding should be increased. When this latter view was expressed to one a strong proponent of the former, an employee of the Faculty of Arts and Sciences, he didn’t appear surprised. However, this response was inconsistent with his earlier comments. He had not heard this contrary view expressed before, even though one of the energy monitors expressed it strongly to me.

The first stage of the review was underway in October 1987. Then, full preventative maintenance lists were being generated for the individual buildings. They hope labor being employed in "fire fighting" will be moved into preventative

54 Particularly the relevant facilities office interviewee.

55 A Facilities Maintenance Department interviewee and one of the building superintendents.
maintenance, giving greater system reliability and control with little extra cost.\textsuperscript{56} One interviewee in the Facilities Maintenance Department thought costs would drop over time, as was suggested by the literature. He conceded however that the studies referred to industry, where equipment down-time has an economic cost.

8. Case Studies

In a study such as this, it is difficult to differentiate the general from the particular. Hence, I have kept the insights and interviews from two of the buildings, the Science Center and the William James Behavioral Science Building, separate. In addition, I have added notes on Canaday Hall, a particularly interesting dormitory.

\textit{a) The Science Center}

The Science Center was opened in the early-1970's to provide teaching space (theaters and laboratories) for undergraduate science and office space for several science departments. Its floor area of 170 000 sq. ft includes 30 classrooms, five lecture halls and three teaching laboratories. It has 18 major air handlers, including three systems comprising bulk supply pumps, fan coil units, perimeter reheat units and return air fans for the Cabot library. There are 20 000 light fixtures, including 2 000 in the Cabot library (which also has fifty motors for its air conditioning). The energy monitor splits his time between being building superintendent and running, and teaching in, a machine shop in which students can develop skills.

His job as energy monitor has several parts:

* He monitors steam, electricity, chilled water, gas and potable water consumption. The last two of these are minor.

* He creates weekly schedules for the eighteen air handling units in the building. By careful programming he has managed to reduce the

\textsuperscript{56} Although none of the interviewees said so, it may also improve morale. People will no longer feel they are trying to patch systems up the whole time.
heating requirements by ten hours per week. The library is heated from 9:00 am to 12:00 midnight, while offices are heated until 10:00 pm only. However, if people want heat later in the evening he provides it. The zones are sufficiently small for the cost to be relatively low. Individual classrooms have unit heaters, so they can be heated (but not ventilated) when the central system is off.

* He monitors problems in the system, especially air in the hot water lines at the start of the heating season.

* He ensures equipment comes on and goes off according to its schedule. Often he will drop in on Saturday night to check that things are working properly. He generally finds about three errors per week.

* He identifies problems with the mechanical equipment. The equipment was about fifteen years old during the energy initiative, and so there had been many problems.

* He removed the incandescent spot lights from the lecture halls and installed compact fluorescent lights throughout the building. This was unsuccessful in the corridors however, since there was theft (about six have been stolen).

* He searches out other savings. He halved the power requirements of all the exit lights in the lecture theaters (by conversion of 50W globes to 25W)

* He turns off one of the major elevators on weekends

* He converted the cafeteria from incandescent to compact-fluorescent lights, reducing lighting needs from 5000W to 450W. Similar reductions have been made elsewhere. Now, he is not worried if people leave lights on since loads have been reduced so much.

* On Friday afternoons he turns off lights in classrooms, lecture rooms and offices.

* He meets with salesmen

* If he sees anything extraordinary with equipment he reports it to the Facilities Maintenance Department.

* Annually he checks the switches on all the mechanical equipment. Otherwise, when it gets cold, a couple of pipes freeze because of broken switches. When the switches work, the heat comes on when the outside temperature drops below 35°.

* Since there is a charge for equipment on the Delta (Energy Management System), he has pulled the air handler in his machine shop off the system.\(^{57}\)

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\(^{57}\) The annual charge is in fact only $50.00, plus maintenance.
The Facilities Maintenance Department only does works he requests.

He ensures there are reminder signs on light switches.

He has put in timers, at a cost of about $15.00 each, for areas too small to justify control from the facilities management system.

Similarly, in the chemistry labs, timers are used to control the small microcomputers in the fume-hoods. Going to more sophisticated control would require the assistance of consultants. Therefore, he prefers timers. 58

He gets some of his ideas from Stephan Engel and some from sales people. He gets none from the Facilities Maintenance Department. He says he could use more advice but that he doesn’t need it badly.

He made several comments about the energy management program. He was extremely proud of the fact that the Dean had written to him and thanked him for his work. He also remembered, extremely clearly, the dinner that was held to thank the energy monitors, and the fact that he had been given a cash bonus.

b) The William James Behavioral Science Building

This building has an energy monitor from the other end of the spectrum. He is the assistant director of the Center for Behavioral Sciences and the William James Building’s administrative officer. He is responsible for all facilities in the building from keys, storage and parking to energy. Consequently, his job spans five levels of the university hierarchy. While this creates very rapid responses to problems, a lot of the superintendent’s time is spent on issues that some would consider more junior.

The building was designed in the 1960’s to be conditioned at 70°, 24 hours per day. It is sixteen stories high, had single glazing, an absorption chiller in the basement,

58 I wonder if the safety office was consulted about putting timers on fume-hoods. If not, there is a serious flaw in Harvard’s management philosophy. It would appear that here, making people independent could lead to dangerous practices.
humidity control, induction heating and cooling, and lighting of about 900W
(floworescent) per office. It has asbestos lined false ceilings.

In the mid-1970's the Faculty of Arts and Sciences administration said that it was
only prepared to heat the building from 6:00 am to 10:30 pm. After the faculty uprising
had been quelled, the Faculty gave $20 000 of the annual savings back to the school.
After about three years, costs rose and the Faculty stopped sharing the savings. There
were none.

In 1981 a systematic redesign of the building's systems began with a lighting
redesign to lower power lamps with parabolic reflectors, etc. However, the asbestos in
the ceiling prevented modifications. Therefore, they delamped. Since the building was
grossly over lit, people welcomed the opportunity to lower the lighting level. About 70%
of office lighting was removed by negotiation and experimentation with users.
Similarly, half of the hallway incandescent lighting was eliminated. (Subsequent
replacement of the remaining hallway lights with compact fluorescent lamps was
abandoned because they are ugly.)

The absorption chiller was replaced with chilled water from the central plant in
1983. However, continuous chilled water makes the building too cold. Hence, the
building needs control. The building has four zones; North and South with windows (i.e.
perimeter) and North and South without (i.e. the core). Unfortunately, only the rooms
without windows have sensors (and the asbestos prevents putting more in), so there are
inadequate sensors for effective control. Therefore, the most effective way to time the
chilled water is for the superintendent to walk around and call up the computer operator
when chilling is needed. To assist with this, the superintendent can log on to the
Facilities Maintenance Department computer, though he can't change anything.
One possible way of controlling the building temperature is to put sensors on the fan discharges for the building. Unfortunately the superintendent doesn't know whom in the Facilities Maintenance Department to ask about this. Similarly, he would like to use re-heat on the North side of the building in Winter but doesn't believe the building design will allow it, but he isn't sure.

They put film on the outsides of the existing single windows and storm windows on the inside. The windows adjacent the South face building pillars promptly cracked. This is thought to be due to differential heating of the glass on the shaded zone of the pillar.

The start of the heating season is very difficult because of the building's height. The upper floors are frequently cold until the system is purged properly. Local control of the system, once it is working, is achieved by adjusting dampers in each local air handler. Unfortunately these adjusters are often broken so they have to be wedged into place with sticks. However, the building is not thermally symmetrical. That is, the upper floors and outer offices need less heat in Winter and more cooling in Summer than the inner and lower ones. Consequently, the sticks have to be re-wedged at the start and the end of the heating system. This would not be a problem if everyone in the building knew this, but in fact, about 20% of people are new each year. Hence, The superintendent spends a lot of time at the start of the heating season showing people how to adjust their sticks.

There is an Facilities Maintenance Department engineer who walks into the mechanical room every day and checks all of the equipment. He does things in the building in response to the superintendent's requests, the preventative maintenance program, or information from the computer.
The preventative maintenance program for the building is extensive. If it were completed there would be many less problems with the building. Unfortunately, it never gets completed. The main filters in the building air handling equipment don't get changed as regularly as they should. This has led to clogging of the filters in the office air handlers which had not been cleaned since the superintendent came to the building (several years earlier). Similarly, when the city water duty pump broke down, the Facilities Maintenance Department simply switched to the standby and didn't repair the duty. It was only when the standby started to leak that they fixed the duty pump so they could replace the standby. I visited the mechanical room and was shown where one of the pump motors had been replaced in a retrofit five years earlier and just left on the floor. The superintendent feels that preventative maintenance items that get done continue to get done while those that tend to be avoided, like cleaning the filters in offices, will continue to be avoided. He also explained that the roof on his building leaks, despite having been replaced recently (because it leaked). When the repairs (to the fixed roof) had not worked, it had taken several years to get funding to fix it again.

There appears to be little communication with the schools to determine preventative maintenance needs. The superintendent noted that "if someone came and sat down for two hours and asked me the problems, they would get done." He also felt there was a shortage of both labor and available budget to get those things done. The overall preventative maintenance schedule for his building is based on a building inventory that was completed four years ago by a private contractor, and excludes things such as windows and roofs. He believed that, if carried out, a preventative maintenance program would yield significantly better maintenance and hence space quality.\footnote{It is interesting here that one of the big advantages of preventative maintenance is that it will increase comfort and reduce the superintendent's work load.}

379
The superintendent found the maintenance budgeting process mysterious, but said he would like to become more involved in it as he felt he had local knowledge to contribute. However, it was clear to him that under the current budget, there was insufficient money to do all the scheduled maintenance, let alone that which is really needed.

All works in the building have been, and are, severely limited by the presence of asbestos in the ceilings. A Cambridge ordinance requires that it all be removed, so strategies are being developed. One option is to move people around a floor at a time, taking advantage of a floor that is currently vacant. Another is to vacate the building entirely and put it to another use, either for different departments or possibly as residential space. In either case, the removal of the asbestos will allow vast improvements in lighting and facilities control.

c) Canaday Hall

The Faculty of Arts and Sciences' most recent new building is Canaday Hall, a Harvard Yard dormitory. There are conflicting stories about its history, essentially some people say that it has poor construction as an intentional management decision to see whether or not low cost buildings do in-fact have short life cycles and high maintenance costs.

However, another interpretation is as follows:

Donors don’t like to donate dormitories, and so this was funded with a bond issue at a time that the Faculty of Arts and Sciences was $3 000 000 in debt. To cut costs, they decided to not include a basement in the building, and instead to build a slab on ground. The university administration thought this was unwise since space in Harvard Yard is scarce. So they donated $500 000 and took the basement for offices, for which they wanted air conditioning and high quality amenities. The housing
department has a policy of not providing these to students, so they were cut off at
ground level. The university then insisted that it look like it belongs in Harvard Yard,
so a lot of emphasis was put on the envelope, and particularly the roof (which leaked
anyway). The school then designed the rest of the building within the envelope on an
extremely limited budget. Consequently, it was built to an extremely low standard with
poor systems and partitions (single thickness plaster board).

The building has been a failure as a dormitory, and is very expensive to maintain
and operate.
III. THE SMALL PROFESSIONAL SCHOOL

A. STRUCTURE AND FINANCING

The Small Professional School, one of the two smallest at Harvard, comprises six buildings all within 50' of each other. They contain a cafeteria, offices for faculty and staff, lecture halls, a library, and a conference center. Its building administration is overseen by the Director of Fiscal and Administrative Services. He is helped by a staff assistant and a superintendent, a retiree who comes three mornings each week to aid in building operation. No one is explicitly responsible for energy conservation.

The superintendent coordinates all of the building repair in the school. He checks and approves all work orders to be performed by the Facilities Maintenance Department. The assistant prepares the occupancy schedules for the buildings, and schedules space. This is more complicated than in some other schools since extensive use of the buildings by external parties results in erratic space usage.

The largest energy user in the school is the library. ($127 000/$237 000 of the energy consumption.) It is managed under a shared savings contract with Carrier. Savings to the school (i.e. excluding profits to the contractor or the value of capital installed as part of the contract) were $22 000 (total) in the first six quarters of the contract.60

Energy and maintenance budgets are based on Facilities Maintenance Department recommendations. The recommended budgets comprise nine categories, including 'Electricity' ($171 000 for 1987) and 'Heating and Cooling' ($66 000 for 1987) (Giving a

60 The contract is probably designed to give low savings at the start and high at the end. Therefore, the savings may well exceed $14 000 per year later on. Also, these saving exclude the value of the capital equipment installed by the contractor. The purchase price of the system at the end of the contract is $15 000.
total energy budget of $237 000). This comprised 2.1% of the school's total budget of $11 000 000 (which includes faculty salaries) and 24% of the buildings budget (excluding capital expenditures) of $970 000.

B. ATTITUDES

In general, the school believes that energy, comprising only 2% of the budget, is too small to justify more administrative attention. Furthermore, existing staff could use their time more effectively by trying to raise money rather than to save it.\(^{61}\) The Director of Fiscal and Administrative Services was also averse to the suggestion that if an extra employee could save him $40 000 per year, he should increase the staff. He says that an extra employee, with salary, fringe benefits, and support probably costs $25 000. Also, he thought an energy conservation program would make him unpopular with the faculty, staff, and students. He felt the imposition of harsh temperature standards and lighting requirements at a time of low national awareness of energy would be both difficult and unpopular.\(^{62}\) Finally, it is not clear to him that he could obtain a

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\(^{61}\) It is important to note that this perception of the problem involves a potential confusion of recurrent and once-off savings. The Director of Fiscal and Administrative Services said at the close of one of the interviews that he could raise $30 000 faster than he could save it. This is possibly true, but it doesn't necessarily hold that he could raise $750 000 faster than he could save $30 000 (assuming endowment is spent at a rate of 4%). When I suggested this is the calculation he should be using, he disagreed. He said he was talking about raising recurrent funds (which is done by administrative staff) as opposed to raising endowment funds (which is done by senior faculty). As such, a one-to-one comparison is more appropriate. While I sympathize with the fine distinction he is making, I see two flaws in his argument. First, I'm sure that donors hardly distinguish between the two. Therefore since the donor makes little distinction, money raised for operations is not raised for the endowment. Second, energy conservation which involves technological change changes consumption 'permanently'. Therefore it should be factored up.

\(^{62}\) Since energy conservation often improves comfort, this provides three important insights. First, it shows that a person with these responsibilities can be in a position where he doesn't understand the real issues involved. I had a similar feeling in another interview in a small school, so this is very likely a small school problem. Second, it shows that the Facilities Maintenance Department possibly has trouble
Peter Cebon (1990)

return of 10% per annum on any time or money he invests in energy conservation. He said that he had extremely limited investment funds available, so he wouldn't be interested in anything that didn't start paying a return almost immediately; suggesting a three or four year maximum pay back. On the other hand he could borrow, but that required large projects (> $50 000) and a strong case that he doesn't have the resources to research. In other words, the Director of Fiscal and Administrative Services says he is interested in buildings and their operation, and the incorporation of energy into improvements and remodelling. However, the constraints on his time and other priorities of his job force him to neglect this.

This is surprising. Susan Hill (the Facilities Maintenance Department supervisor for Education) claimed that pays her own salary in the 10 minutes she spends daily preparing time schedules for computerized control. Ms Hill also noted that she had to put considerable effort into persuading and training the administrative assistant and reassuring her that her efforts have paid off and the time is justified. Ms Hill believed the Small Professional School did not think that it had the staff to do energy conservation work properly, but once they started doing their own scheduling, they realized that it wasn't such a major issue.

C. ENERGY CONSERVATION PROGRAM

1. Components

Small projects and replacements are identified almost exclusively by the working foreman (from the Facilities Maintenance Department). For example, he has instituted a small and simple lighting retrofit project in the school. Generally, if the maintenance transferring information across to him, and finally it shows that none of the Faculty of Arts and Sciences lessons have been transferred to the Small Professional School.

However, non-maintenance capital works, for several years, have been very limited in the school.
staff come to a consensus that it is not worth fixing a broken component, the Small Professional School will replace it. The information and recommendations come from the mechanics and move up through the bureaucracy to a decision point. The decision point is determined by price.

Generally there are sufficient funds to do things that are recommended, so there is no financial constraint. The funds come from monies raised through research, tuition, or from the endowment. The small schools, Education, Design and Divinity each have an endowment of about $20,000,000, which provides an income of about $800,000. If the schools overrun their budgets in a given year or lack funds for their works programs, the Harvard corporation will lend them money.

The Small Professional School does not have a fully developed preventative maintenance program and does not know whether or not one is needed.

2. SYSTEMS

When the Faculty of Arts and Sciences came off the Summer steam, the Small Professional School carried out some works to mitigate costs. One major project was a conversion of absorption coolers to chillers on a couple of buildings. This removed the need for steam, for absorption, from a major boiler in Summer. Many of these projects are identified by consultants, either as part of the two to five year maintenance audits that the university mandates, or as special projects. For example, at the time of the interviews a consultant was examining the central air conditioning system to see if improvements could be made. However, consultants for these audits are not briefed to identify energy savings.

65 There were two other stimuli. First, the equipment was old and worn out and due for replacement. Second, there was undoubtedly pressure from across the campus, particularly from the President, to do energy conservation works.
At the time of the interview, December 1987, the school was faced with a replacement/repair decision for a major boiler set which it owns jointly with two other administrative units in the university. The broken boiler was one (N° 2) in a set of three. A second (N° 3) was also in dire need of work. A repair would cost $18 000 and last for up to 20 years, but probably much less. The school strongly favored repair over replacement. There were three reasons for this.

* The failure was unanticipated, and couldn't have been predicted. For the number two boiler, there would be a delay of at least six months before a new boiler could go in. At the start of the Winter, this is not a wise strategy.

* Any decision would require three 'votes'. It is much easier to get three approvals on an $18 000 expenditure than on $200 000.

* The Director of Fiscal and Administrative Services did not think that a replacement would be cost effective.66

By the end of the research the situation had changed, as had the prices. The third boiler (N° 1) had also failed and so they had the choice of replacing one and three ($120 000), replacing one and fixing the other, or fixing both. By this stage boiler number two had been fixed.

They were considering cogeneration as a replacement option, but not seriously. Since they were no longer use steam in Summer, there is some question about whether or not cogeneration presents a cost-effective option. One of the key determinants of changes in the boiler system is whether or not someone has the time to explore different options. In this case someone has time to do energy analyses, fill out grant applications, etc. Therefore, there is a greater chance that if cost effective alternatives exist, they will be implemented.

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66 He is probably right. However, the assertion was made without any calculations. For a replacement to be viable, fuel and maintenance savings over the present boiler would have to be about $14 000 per year over the life of the boiler, which probably is not achievable.
3. Control

Schedules are produced for building operations. Because the space is used by many external groups on nights and weekends, these tend to be fairly complicated. The school likes to keep tight control on the scheduling because there are many discretionary decisions. The schedules are given to the Facilities Maintenance Department for all buildings other than the library, which are sent to the shared savings contractor. The schedules give both the occupied times and the times desired for different temperatures.

Scheduling the computer is difficult. The rooms have to be translated to point lists, and the point lists are out of date. Either the school can do the translation, or they can leave it to Facilities Maintenance Department. The current facilities management system has a software interface for this, but it is very primitive. The Small Professional School has found that the Facilities Maintenance Department is not sufficiently reliable, so the scheduler does it herself.

For the buildings that are controlled by the Facilities Maintenance Department, there are often problems with the system not being controlled to schedule. For example, if heat is requested for a space for an evening, it will be provided, but it may not be turned off, especially if the operations shift changes in between.

Apparently, Carrier have done a much better job than the Facilities Maintenance Department in operating the building. One Facilities Maintenance Department interviewee felt the management of the Delta is poor. It seems that if one shift overrides the timetable to turn something on for a special event, and the next shift forgets to turn it off. The current software system won’t do one-day overrides of the

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67 As did the superintendent of the Science Center, Stephan Engel, and the Director of Fiscal and Administrative Services in the small professional school.
schedule. There are about 20 manual overrides to be done on a given night, and the manager of the system doesn’t see how that could justify buying extra software.

No one had ever written an operating schedule for the library prior to the shared savings contract. With the benefit of 20/20 hindsight, there was no need to go to Carrier. All that was needed was for someone to sit down and write a schedule. The shared savings contract for the operation of the Gutman library ends soon. The school is currently assessing control options within the context of broader decisions about the operation of the building.

When the Carrier contract expires, they have three choices: 1) to stay with Carrier on a fee basis, 2) to go back to the Delta, 3) to go to a direct digital control system. They have been quoted $50 000 and $35 000 for two different direct digital control systems. They don’t know which of these would be most appropriate, given different staff time requirements for the two systems.

While they think direct digital control may be the appropriate solution, there is a lot of question about who would run such a system and how it would be financed. Particularly, who is going to do the scheduling. If the scheduling is just as complicated as the Delta, will they end up with a system that is run in exactly the same way, nullifying their investment.

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68 There is an information/incentive problem here. The school did not know it could save money by writing a decent schedule for the building. Similarly, even if it did, it does not have the in-house skills to train its own staff to write one. Hence, it is unlikely to see scheduling as an issue unless advised by either the Facilities Maintenance Department or a contractor. Also, such a scheduling exercise is could possibly not be perceived as being in the Facilities Maintenance Department’s interest, other than to provide job-satisfaction. A pro-active approach would require extra staff resources to train and encourage schedulers. The consequence would be both an increased workload and increased scrutiny of the staff on the Delta.

69 It was clear in the interview that they were having trouble understanding the implications of the decision. For example, they did not emphasize the other control advantages and the possibilities for remote scheduling for the direct digital control
4. New Buildings and Capital Renewal

Major capital renewal and new construction over $50,000 is reviewed by the Planning Office that is part of the central administration. Capital is replaced when large failures occur, potential failures are observed during the five-yearly maintenance audits, or when interior spaces are upgraded. No new buildings have been built for several years, and none are foreseen.

Projects for consultants to evaluate are either generated by the Director of Fiscal and Administrative Services or one of his staff. In other cases they will be generated by other administrative staff and rarely by the faculty. Occasionally students will make suggestions, but generally they are in the school for such a short time (one year) that they don't make good ones, and it requires excessive effort to cultivate them.

Once projects are identified, it is not difficult to engender cooperation within the school, especially if works are carried out over the Summer or during the mid-Winter break.

5. Standards and Users

Generally, heat will be provided to 68–72° during scheduled occupied periods, (i.e. 8–5 Monday to Friday, and other times as requested). At other times, it is set back to 55–60°.

Users are not involved in energy conservation, except in terms of their suggestions.
6. Information

The Director of Fiscal and Administrative Services had mixed opinions about the information he had available to make management decisions. On one hand, he felt that he was given more than he needed, especially for his energy consumption. The Facilities Maintenance Department supplies him with extensive computer analyses of all his utilities broken down by buildings with graphs, summary statistics and comparisons over time. Similarly, he gets extensive data on building maintenance which he finds quite inaccessible and feels he needed a two-hour course in reading. On the other, he felt that good advice was scarce. The Facilities Maintenance Department cannot supply the information he needs. They are experts in running a system, not in repairs and replacements. This is exemplified by the library decision described above. If he wanted specialist knowledge in amounts less than justified briefing a consultant, it was unavailable. "If there were an energy ‘swat’ team available, I’d pay for that, but given the (other) things I have to do, I don’t have the time." Similarly, he would be happy to pay $300 for a quick audit of one of his buildings. The Facilities Maintenance Department cannot always supply the information he needs.
IV. THE FACILITIES MAINTENANCE DEPARTMENT

A. EARLY STRUCTURE

Before restructuring, the rest of Harvard saw the Buildings and Grounds Department, reasonably accurately, as self-serving. There was minimal trust and a strong belief that the faculties were paying too much for a poor, overstaffed, monopoly service. There was conflict between the faculties and the Buildings and Grounds Department over the ownership of buildings and equipment. Although the faculties owned the buildings, the Buildings and Grounds Department was extremely proprietous. Given responsibility for maintenance, the staff felt that they should determine maintenance schedules and budgets, and expected the faculties to agree. At the same time, the price of steam had risen from $1.00 - $2.00 /mmBTU to $14.00 - $15.00 /mmBTU. So, the cost of running each dormitory had risen to about $30,000 - $40,000 per month.

The Buildings and Grounds Department itself had limited competence, and therefore could not provide useful input into plan review and the like. Even if it had the competence, faculties didn't trust it enough to invite assistance. At various times it has had an engineering section which tended to focus on project management, overseeing installation and upgrades. The engineering section was never a forceful proponent of modernization or change, though it tended to be fairly aggressive toward the smaller schools. Since it was fairly ineffective, and very expensive, positions weren't refilled on vacancy. Similarly, because of the high cost of services ($60 - $70 per hour), the schools preferred to ask building managers and contractors for advice instead.

Just after restructuring, the Facilities Maintenance Department employed a mechanical engineer to do technical work. He tended to be very slow and methodical,
and therefore of little utility. He was not replaced when he retired three or four years after joining the Facilities Maintenance Department.

B. RESTRUCTURING AND CURRENT STAFFING

During the early 1980's, and starting the day the Vice President for Administration took office, the Buildings and Grounds Department was restructured into the Facilities Maintenance Department. This precipitated by the cost of the low quality services and its attitude towards the schools and their buildings.

There was large staff attrition. For example, structural trades (particularly painters) were off–loaded to a preferred contractor who, not being unionized, could cope with seasonal work and lower industry wages. Other functions were diminished significantly. "We thinned out our ranks to what we called minimum staffing level, and sometimes cut our throat a little below that." This allowed the Facilities Maintenance Department to show that the changes were more than cosmetic, and that it had a service to offer. The faculties critically evaluated the new organization and decided to support it. Budgets were then increased. "Right now I think that we're at a comfortable valley, and we go to the outside for the peaks, if you know what I mean."

To facilitate the restructuring, and particularly to change attitudes, those staff not brought in from outside were re–trained to be much more sensitive to the schools' needs. In many respects they have "gone overboard in the wrong direction". The Facilities Maintenance Department staff are now so cautious they hesitate to suggest works to the schools. The schools, on the other hand, feel that they don't know enough to prescribe programs for the Facilities Maintenance Department.

As part of the restructuring, the Facilities Maintenance Department actively recruited staff for strong liaison roles from the schools. This has had many subsequent
benefits such as making it much easier for the Faculty of Arts and Sciences to reassess its preventative maintenance program. Before the restructuring, communication was so poor that such a reassessment would not be possible.

The general structure of the Facilities Maintenance Department is outlined in section I. of this appendix, so it won't be repeated. In addition to the director, an associate director and the two managers who oversee one third of the campus each, and a geographically based operating staff, there is a purchasing officer who negotiates prices for items the staff want. The purchasing office tries neither to ensure people are making good purchasing decisions nor to optimize certain key components.

In about October 1987 the Facilities Maintenance Department re-deployed an engineer who came from the medical campus. Although employed on very short notice and virtually unintentionally, he filled a void in the organization doing staff engineering work. This included trouble shooting mechanical maintenance, reviews of plans, energy audits, and preventative maintenance. His employment is more in the interest of the graduate schools than the Faculty of Arts and Sciences, with its own analytical abilities. Currently, his time is charged to overhead, not the individual schools. In addition, there are two engineers in the planning office who review plans and oversee utility distribution. Because they are not on the Facilities Maintenance Department payroll, they haven't tended to ensure that the Facilities Maintenance Department sees plans before construction.

C. SERVICES PROVIDED

1. ENERGY CONSERVATION

The Facilities Maintenance Department has no direct incentive to conserve energy. All costs are passed through to the customers. For the one thing it
manufactures, chilled water, they budget to just break even on capital and operating costs.

While the Facilities Maintenance Department has no direct interest in energy efficiency, department policy is to think in a conservative manner. Energy conservation is perceived as being in Harvard's best interest. Some managerial staff in the Facilities Maintenance Department spend a lot of time making it easy for the schools save money. However, this is very much a matter of individual preference. So, one staff member might encourage people to do energy work; another might pursue deferred maintenance; a third might be interested in gardens and shrubbery.

2. Operations and Maintenance

The installation of the Honeywell 2000 (about 1971) precipitated an increase in the quality of the maintenance on campus. There was little point in having the computer operate machinery if equipment wouldn't respond. "But, it could only shut off steam automatically if the valve in the building was a tight valve. If the valve leaked by and the valve didn't actually go off, that's when mechanical maintenance came to the top of the list again. I'm not saying it fell by the wayside in the 60's, but basically in the 60's energy was cheap, so no one really cared about it."\(^{70}\)

Most of the Cambridge buildings use the Facilities Maintenance Department for daily HVAC operations. Similarly, the Facilities Maintenance Department does all non-structural maintenance up to major repairs. All day to day, breakdown, and preventative maintenance "which isn't that great"\(^{71}\) is done by the Facilities Maintenance Department, in consultation with the faculties, and charged on a time and materials basis. The Facilities Maintenance Department doesn't keep a central database with

\(^{70}\) Facilities Maintenance Department employee

\(^{71}\) Thomas Risbey
equipment specifications and part requirements as is maintained as part of the MIT preventative maintenance system. Consequently, staff on all jobs must go out to a job and assess it before determining what parts are needed.

For very small jobs, the working foreman just approves the work; for larger ones, the school is contacted. Unless there are some intervening circumstances such as a planned replacement of equipment that the Facilities Maintenance Department doesn't know about, the schools almost invariably approve projects. As noted in the 'James Building' case study above, the preventative maintenance work that is scheduled is rarely done, and there is a feeling that if it were done, break down maintenance problems would be much less severe. If an after hours problem needs immediate attention, the Facilities Maintenance Department staff gathers information and then calls the relevant superintendent for approval before doing anything.

The Facilities Maintenance Department claims it tailors services to the needs of the schools. For example, 75-95% of Faculty of Arts and Sciences work orders either come from or are approved by the building superintendents. The remaining work orders are either generated in the dormitories, where after-hours responses are more direct, or in the mechanical rooms, where mechanics will often write work orders for themselves. While these rooms are operated for the Faculty of Arts and Sciences, the mechanics still have a strong sense of propriety. In other schools, the services are offered differently.

There is a conflict. While the schools determine the budget, and hence the amount of maintenance done, the Facilities Maintenance Department is responsible for the equipment. A Facilities Maintenance Department manager argued that their personnel feel they have failed if the equipment does. For example, if a toilet blocks, the plumber who fixes it is likely to feel he has failed because it is blocked and therefore irrespective of how well he fixes it. This has created dissatisfaction among the mechanical staff. However, since it is impossible to work out whether to blame the
school or the Facilities Maintenance Department for their dilemma, the issue remains both unvented and unresolved.

In general, the Facilities Maintenance Department believes that the preventative maintenance problems arise from separations of ownership, management and responsibility for the buildings. For example, when one of the staff retired from the buildings and grounds, he was called in and asked to develop a preventative maintenance program for the biochemistry building, the most complicated building on campus. While the program was thorough and realistic, it was unacceptable to the client. It would have required three full time staff for that building alone. It is unclear whether the Faculty of Arts and Sciences rejected the program because they couldn't afford the extra people, or because they thought that Facilities Maintenance Department was feather-bedding. (It was probably both, see later). In general it has been very difficult to develop preventative maintenance programs for other buildings.\textsuperscript{72}

However, for the Facilities Maintenance Department, the principal reason for having a preventative maintenance program is one of reliability. Well maintained equipment leads to lower staff dissatisfaction, and hence higher morale, so I was told.\textsuperscript{73}

\textsuperscript{72} It is interesting to note a key difference between MIT and Harvard here. At MIT, they had no trouble getting money for an increased preventative maintenance program. It could be written into the operating budget (and get support) without any trouble. At Harvard, it is very hard to get preventative maintenance money, but easy to get money for capital renewal, so long as the bid for new capital comes from within the school. If the school recognizes the need for preventative maintenance, that changes. However, there may be a real problem selling preventative maintenance within a school. It involves an increase in the operating budget and, probably more significantly, commits the school to supporting increased staff outside its control.

\textsuperscript{73} Alternatively, it could lead to boredom because nothing breaks.
a) Data Acquisition

Following the installation of the Honeywell 2500, in 1975, both the Faculty of Arts and Sciences and the Buildings and Grounds Department recognized that

"the Honeywell 2500 was only as good as the equipment it was controlling. In other words, the mechanical equipment had to be in good shape for the computer to show us the savings. And, at the same time ... record keeping of utilities ... was then monitored on a regular basis. So ... they started to monitor and track somewhere around '76, so when we hit the energy crunch, we had covered some ground."\textsuperscript{74}

This was initiated by a senior administrator in the Faculty of Arts and Sciences and one in Buildings and Grounds.\textsuperscript{75} They started proper monitoring, and now collect daily electric usage, steam usage, water usage for each building. This was inspired, in part at least, by the realization that their data was not nearly good enough to assess the effectiveness of their programs.

While there had not been accurate metering before this, there had been charging by measure on the basis of poor records. There had always been meters. It was only in the late '70's that people started paying attention to them. Previously, guesses had sufficed if the meters were broken.

The computer is used to collect data on temperature, air pressures, humidity, and mechanical equipment status (on/off). In addition, it meters energy consumption for the major chiller. Equipment consumption readings are taken daily for two reasons. First, it forces an operator into every mechanical room daily. This ensures good monitoring of equipment. Second, it enables them to pick up some of the mechanical problems on a

\textsuperscript{74} Facilities Maintenance Department employee

\textsuperscript{75} The interviewees emphasized that there were two actors, one in each entity. It would seem (quite reasonably) that for any externalized information transfer, you need a bridge within the organization. That is, you need a key person, who cares, in each of the two organizations.
daily basis, rather than waiting until the end of the month to pick them up. At one stage they tried to measure condensate returns with the computer but that slowed the system too much and stopped the daily visits to the mechanical rooms. Data is stored and used to create daily, weekly, monthly and annual reports. The daily reports, corrected for down-time and combined with manual readings, are aggregated for monthly billing.

Rapid changes in status are used as a basis for checking systems. While operators check buildings manually, the computer prints three types of reports (on three different printers). They are critical events, a regular printout of all computer actions, and trend summaries for the various parameters for the various buildings.

b) Staffing and overtime

One of the consequences of all the changes, and the restructuring of the Buildings and Grounds Department, was an increase in the quality of mechanics. Because the schools now have superintendents, and because the mechanics are scheduled to visit each mechanical room daily, there is no excuse for problems which go unnoticed. "So, the quality of mechanic's better now, because he knows he's not going to be around here if he's not. He doesn't put blinders on. He doesn't need the foreman to say, here, this is your job, do it. He does it not because of fear of the foreman, or discipline, its because he honestly knows this is his job now."

76 To pick up an equipment fault you would need to take a reading, compare it to the day before, make a compensation for changing weather (or compare the relative change to other equipment) and see if it is sufficiently different to justify further investigation. Making that decision would be premised on available time, etc. It is surprising but they still manage to pick up some acute problems this way.

77 This is an interesting contrast to MIT which saw one of the virtues of computerization being that it eliminated the need to have people walking around the campus the whole time.

78 Which begs the question of what his job was before.
The Facilities Maintenance Department maintains a certain number of mechanics at the base level required to fulfil their operations and maintenance needs only. These staff are allocated to three shifts daily with most of them on the day shift, and a minimum number on the afternoon and night. While the computer is capable of replacing staff on off hours and weekends, a certain staff is required to ensure the safe and continuing operation of the university's steam and water mains and high voltage power lines. The off-shift staff check the equipment, read meters, service the chemical water treatment equipment, and answer calls, particularly students' calls from the dormitories. The meter reading schedule guarantees that each mechanical room is visited daily.

If the Facilities Maintenance Department needs extra staff for extraordinary work or to fulfill contracts with the schools, discussed above, they contract out or use overtime, at their discretion, to fill the gaps. "So much overtime is good for morale. Too much overtime is poor for production." Overtime is allocated through these jobs plus call ins, emergency jobs on weekends and holdovers in the afternoons.

One of the problems that could arise under a geographically based system such Harvard's is that an area could require either half a person or more or less than is allocated for a particular specialty. While the Small Professional School believes this is a problem, the Facilities Maintenance Department believes it has sufficient flexibility to move staff around to avoid any significant disparities between labor demand and supply. However, they do believe that there is more work to do than labor available to do it. Staff have some discretion in self-assigning overtime to overcome this problem. The Small Professional School disagrees. It sees one of the chief limitations on their program being that they have work for 2 1/4 electricians but access to only two. To an extent, this is alleviated by putting on Summer contract staff.

79 Facilities Maintenance Department employee
Peter Cebon (1990)

c) Work orders

The work order system is highly decentralized and is kept completely separate from the automation system at Harvard. Work orders are generated from several sources including building users, superintendents, preventative maintenance, and the automation computer system. Included in this process, the calls in from the individual buildings are logged, aggregated and analyzed for trends. The work orders are sent by initiators to the part of the organization they think is most appropriate. That group then either deals with the problem by ascertaining its priority, or passes it on to the right group. Most work orders take two days to process and deal with.

D. ATTITUDES

There is a very strong series of attitudes that permeate the whole of the Facilities Maintenance Department. Over the past ten years, it has been transformed from essentially a self-serving organization to one that sees itself as having a pivotal but subsidiary role at Harvard. "We try to operate the university from the shadows, not to be noticed, not to interrupt the daily routine of the institution. In other works, a good maintenance department, it shouldn't be seen and shouldn't even be heard."80 Another staff member commented,

"We're a maintenance and utility department working for a customer who is energy conscious. There are situations in universities such as ours where they have maintenance and operations and utilities departments working for faculties that haven't involved themselves in being energy conscious, but assume that they are. There are still those situations. People say our product is education, it is, but if you can become maintenance conscious, there's more money to give to the education part of the university."81

80 Facilities Maintenance Department staff member
81 Facilities Maintenance Department staff member
V. COORDINATED ACTIVITIES

A. SYSTEMS CONTROL

1. HISTORY

The first computer system, installed in the 60's, was a Honeywell 'Selectographic'. Principally, it was installed to reduce the amount of time workers spent opening and closing valves and dampers, since these could be done automatically and centrally rather than remotely and manually. It also had a clock attached (I think). The system cost about $500 000 and paid for itself fairly rapidly in reduced operating costs.

In about 1971 or 1972, it was upgraded to a Honeywell 2000. It was in place by the energy crisis and was very useful for tighter control. It was more sophisticated than the 'Selectographic', but was still little more than a very large time clock. It was upgraded in 1975 to a Honeywell 2500, a significantly larger and more sophisticated machine. The 2500 appears to have been poorly designed, since only three of the six produced ever came on-line.\footnote{It appears that Harvard was successful where others failed because of "extraordinary persistence" by the staff. An alternative explanation is that this technology is very controlling of workers who sabotaged it.} With the 2500's commissioning, the control system was expanded; many miles of wiring was run around the campus. The 2500 operated with a central computer and data gathering panels (dumb multiplexers) in each building it controlled.

With the installation of the 2500, it became obvious that the operational efficiency of the campus was being impeded by the quality of maintenance. The critical problem with the equipment went from being control to being maintenance. The computer was serving two functions. On one hand it saved effort by allowing people shut off valves and systems remotely. On the other, it saved energy by controlling
equipment. This required good maintenance, so maintenance was upgraded. As staff were moved from operations (opening and closing valves) to maintenance (fixing the problems the system identified) smaller night and larger day shifts were created. Currently, there are 12 - 14 HVAC people in the buildings daily, including six or seven on preventative maintenance, and about four at nights.

In 1978 or 1979 Harvard decided to upgrade the mainframe portion of the system. They investigated other vendors and settled on Digital hardware with software by a firm called EMS, who were later bought out by Staefa to form Staefa Controls. The original Honeywell data gathering panels remained in the field. This system had more functions as well as more capacity. For instance, it had master/slave functions and the ability to produce trend summaries.

In addition to remote control, the Staefa is used to measure chilled water consumption by the different buildings. It was used for a while to measure condensate returns from the steam system, but that slowed the system too much. It produces alarm reports and daily, weekly, monthly and annual summaries. There are three types of alarms. One is a constant dump of everything the machine does, one is a listing of critical alarms, and one is a trend summaries.

It has limitations however, particularly in the controllers. They need equipment in good working condition to work properly, so maintenance improved again.

Harvard's next change was to start changing local dumb multiplexers to smart multiplexers (SMUX) as local direct digital control systems. (That is data gathering panels in the buildings that can act upon gathered information. So, for instance, they can turn on fans in response to changes in local temperature.) The schools are purchasing these, not the Facilities Maintenance Department. They can be operated independently of the mainframe if necessary.
The SMUXs cannot communicate easily with the Staefa/EMS system. Because they are proprietary, each control system requires a different interface. As a short term solution, they all have one binary point connected to the DEC mini. If anything in the building needs attention, that goes into alarm. The operator dials into the building system, using a telephone and modem, and investigates the problem. This is reasonably satisfactory, but limited in the functions that can be performed.

If the university could standardize on one system, this interface problem would not be severe and maintenance, training, inventory and programming language problems would be reduced considerably. However, it doesn't want to do that for two reasons. First, no one wants to deal with a monopoly supplier, since they tend to be expensive. Second, the schools feel it would be infringing on their rights to manage their individual needs as best they can if the Facilities Maintenance Department prescribed particular systems. Most of the systems currently installed on campus are made by Powers. Others are by Honeywell and American Energy Management (one each). The Facilities Maintenance Department is currently looking toward a new mainframe that can provide a better interface than the current system.

Also, pneumatic controllers have been replaced with digital systems (direct digital controllers) in about 12 buildings in the last three or four years. The actuators, that is the devices which actually open the valves or move the vanes, are still pneumatic.

In summary, there are currently two modes of operation. The Staefa/EMS controls about 5-6000 points such as pumps and blowers start and stop, equipment alarms, fire alarms, temperature, and the like. This operates in about 95% of the

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83 This presents an interesting 'tragedy of the commons'. The individual schools derive all the benefits of making their own decisions, while the Facilities Maintenance Department absorbs all the externalities. This is discussed under hypothesis three.
buildings. The other 5% (but growing) have direct digital control systems, owned outright by the schools, with one binary point connected to the main system.

In addition to alarms, calls come in over the telephone from users. Harvard's diffuse management structure makes it impossible to impute meaning to the number of calls received, since there are several local people who can resolve problems without it going through the control center. For the record, they receive between seven and fifty calls per week per building, (the higher number for laboratory buildings.)

The cost of operating the facilities management system is shared between the schools by floor area. In addition, they are charged about $50 per point per year for servicing. This includes calibration and testing, maintenance of the central system and overhead charges. It excludes maintenance of the individual points, which is charged as a maintenance service.

2. Issues

The automation staff in the Facilities Maintenance Department see little value in direct digital control in the dormitories. The building systems lack the complexity to justify the cost. However, if a group of buildings were being renovated simultaneously, it may become feasible.

The rapidly changes in computer control technology which make it possible for the individual schools to buy and operate building based control systems has created a strong incentive for the Facilities Maintenance Department to improve its skills in this area. Staff feel that unless they can provide a marketable product, the schools will do all their own control work. Unfortunately, staff have tended to be scared of computers and therefore only interested in doing minor programming. However, people are much less scared now than they were in the past, and therefore some are enrolling in operations and programming courses.
The Facilities Maintenance Department currently has two people who can program the various direct digital control systems. So, for instance, when the law school system didn't work terribly effectively after being programmed by the contractor, they were able to go in and improve it. Currently, about 75% of the programming is done by the contractors and 25% is done in-house.

Eventually, the Facilities Maintenance Department hopes to have the operators doing the programming, that is either the people who operate the mini or especially trained people working in the different geographical areas on campus. However, several of the schools have indicated that one of the advantages of direct digital control is that it enables them to do the programming themselves. For minor problems, the operating engineer should be able to bring a local system into control. Since people know the operating engineer or the superintendent, communication of local problems by word of mouth is seen to be adequate.\footnote{\textsuperscript{84}}

For the schools there is a trade off. It is cheaper for them to monitor their own control systems and they have more control, particularly in their ability to change schedules at will and with known reliability (though not necessarily more reliably than could be done by the Facilities Maintenance Department). However, getting the Facilities Maintenance Department to control the system allows specialization of operators, particularly for programming, 24 hour monitoring, and consistent year-round control. Local control is susceptible to people being sick or on holidays. So, on campus at the moment, some of the buildings are operated by the schools (for example the Design School or the Sackler Museum), the School of Education has a building operated by external contractors and some are operated by the Facilities Maintenance Department.

\footnote{\textsuperscript{84} Worth noting is that the separation between operation and ownership removes all incentives for the people programming the machines to be anything other than extremely conservative. No one at Harvard is doing local optimization of the systems. No one in the Facilities Maintenance Department an incentive to.}
Peter Cebon (1990)

The staff of the schools are not unionized, while those in the Facilities Maintenance Department performing equivalent jobs are. However, there have not been any demarcation problems over this. The union appears to have decided it is not a big enough issue.

Some schools for some buildings, don't feel that they want to transfer responsibility for the control to the Facilities Maintenance Department. For example, in late 1987 the Faculty of Arts and Sciences was investigating a direct digital control system for its most complicated building, Biochemistry. It has 15 air handlers, a reheat system, waste heat extraction equipment, and so forth. With a building this complicated, the Faculty is quite happy for the Facilities Maintenance Department to monitor and respond to alarms, but it doesn't want it programming the systems. It appeared likely to contract the services out to a third party with specialist knowledge. The Faculty did the same thing with its swimming pool and athletics center which has a cogenerator attached to the heating system. The school has no hesitation in doing this. It draws a precedent from its policy of contracting out servicing of environmental rooms.

Similarly, the both schools studied don't want the Facilities Maintenance Department to be the interface between the users and the systems. They want to have a person who has an interest in the schools to decide when heat and cooling should be provided. They won't provide cooling for one person, but they might for a dozen.

The schools' ability to purchase their own systems creates a conflict, in that the individual schools are now capable of substituting a service that the Facilities

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85 The Harvard clerical workers subsequently unionized.

86 This is a good illustration of the way Harvard's decentralization mitigates very strongly against specialization. The Facilities Maintenance Department does not have the resources to manage complicated tasks, just as the smaller schools don't have the skills to analyze them. Interestingly, the decentralized structure enables the schools to contract them out without having to worry about union demarcations or other problems.
Maintenance Department has traditionally had to supply. However, since local systems have benefits and costs, they attempt to combine the benefits of both. To do that effectively, the Facilities Maintenance Department needs a transparent interface to the newer systems. It is investigating hardware and interface software, and the possibility of mandating that the faculties limit themselves to one of three manufacturers. Particularly, the systems operators, operating the Staefa, won't have to learn the operating languages of the other manufacturers. But, they will be able to monitor and operate continuously the buildings with direct digital controllers.

However, it's not all together clear that the faculties that install the direct digital control's in the buildings really care whether or not the Facilities Maintenance Department develops these capabilities. As one interviewee said, "They care when they have a flood and nobody found out about it, but ...it's quite possible that they don't want us to operate the building, change set points, override programs, or the like. So, that is one of the real dilemmas."

B. OPTIMIZATION OF THE OVERALL SYSTEM

Below the Vice President, everyone is pursuing their own interest, as defined by the organization. No one spends time working out what is best for Harvard; that is beyond their job.

Some sort of overall system optimization occurs, but rarely through anything other than conflict. For instance, as the Faculty of Arts and Sciences started to get its buildings working well it forced the Facilities Maintenance Department to look at the distribution system. It then pulled itself off Summer steam forcing the price up by several orders of magnitude for the Law school, forcing it off Summer steam also.
Peter Cebon (1990)

Because different schools use the distribution system, and because its annual maintenance cost is essentially constant, it is often difficult to determine the economics of changing from steam to gas for hot water. The calculus involves more than just the rate and the number of units being used. The change in overhead rate also has to be considered. The mathematics is very complicated.

At the interface between administrative bodies, there is a lot of discussion about who should do the analysis, and the availability of someone to do it is key to whether it gets done. The boiler replacement example in the Small Professional School illustrates this. System improvement is being considered only because there is someone at Radcliffe who has time to do the analysis.

C. OPTIMIZATION OF LABOR AND EQUIPMENT

Each school has a staff devoted to maintenance and operations. These vary in size from a school like the small professional school with a department head, an administrative assistant and a superintendent, all devoting only part of their time to operations issues, to the Faculty of Arts and Sciences which has a full time operations staff, including several people concerned only with energy. It is possible for these offices to perform the same tasks as equivalent offices in the Facilities Maintenance Department, especially in evaluation of projects and accounting for work done. However, if people trust each other, there is no need for duplication. Ideally the schools should be staffed to perfectly complement the Facilities Maintenance Department. In the Faculty of Arts and Sciences there is an energy monitor for each building, or possibly floor, as described in section II. Because this task could easily spill over into that of either the superintendent or the supervisor for the Facilities Maintenance Department, demarcations are made by discussion.
The overall coordination of the university systems is the responsibility of the Vice President for Administration. During the restructuring of the Buildings and Grounds Department to the Facilities Maintenance Department in the early eighties, the Associate Vice President formed a Facilities Policy Committee comprising the Facilities Maintenance Department and the schools to resolve demarcation issues, particularly those between the Facilities Maintenance Department and the schools. Generally, the Facilities Maintenance Department has full jurisdiction up to the wall of a building. Everything beyond that is the responsibility of the school. The committee still meets.

This does not mean that all conflict was eliminated. For example, in the past there has been heated discussion about who should determine the preventative maintenance schedules for the plant. The school had financial responsibility for the equipment while the Facilities Maintenance Department had physical responsibility. To compound the problem, the Facilities Maintenance Department wasn't popular at the time. The preventative maintenance program for the Biochemistry building, described in section IV., exemplifies this.

Finally, there is the risk that holes will be left between the responsibilities of the various departments. The Faculty of Arts and Sciences won't carry out any analysis that isn't completely within its responsibilities or hasn't been agreed to by the other parties involved. The Facilities Maintenance Department, since its restructuring, is very hesitant to strongly advocate programs to the schools. Hence, there is a real risk that large systemic efficiency gains will be overlooked. The same applies in the selection of equipment. I would imagine that there are many instances where cooperative purchases or shared use of existing equipment would benefit many of the parties involved. However, the existing divisions create obstacles to that.
VI. OTHER ISSUES

A. COMMUNICATIONS AND INFORMATION TRANSFER

The need for strong day to day communications between the Facilities Maintenance Department and the schools was emphasized by several of the interviewees. The staff of the Facilities Maintenance Department see it as necessary for survival. They feel that they need to be kept "in the loop" so that they can sell their services to the schools. Once they are excluded, it is impossible to compete with external contractors.

For large scale activities, one of the principal means of formal communication across Harvard is through inter-school committees. While this has its strengths, especially in including external parties in an otherwise internal process, like including people from the Buildings and Grounds Department in the Faculty of Arts and Sciences committee to oversee the energy initiative, it also has weaknesses. First, any party that isn't on the committee isn't privy to the information. So, for example, the Law school didn't realize the significance of the Faculty of Arts and Sciences energy initiative. Second, if something falls outside that structure, the information doesn't get transferred. For example:

"The faculties themselves do anything (bigger than routine and preventative maintenance) from renovations to office spaces, to perhaps putting new roofs on, to installing direct digital control systems, to steam trap replacements, often of their own accord, often not having us do the work or passing the expense through our system."87

The interviewee agreed extremely strongly that this created potential for a "cavernous communications gap". He gave the example (in a later interview) of a decision by the Faculty of Arts and Sciences to change light fixtures in all its corridors.

87 Thomas Risbey
There was no discussion, and there were many problems, including things like severed wiring, as a result.

However, the communications gap runs in both directions. While information about action is kept by the schools, and the Facilities Maintenance Department has trouble acquiring it, the Facilities Maintenance Department has technological information that the schools may need but can't get. For instance, we saw above that the superintendent for the William James Building was interested in putting a discharge sensor on one of the fans in his building, but didn't, because he didn't know with whom in the Facilities Maintenance Department to discuss this.

For local or general information, there is no central clearing house to provide analysis. As described above, even the work order system is so diffused that it can't be used as an analytical tool. Similarly, if the Facilities Maintenance Department comes across information about products and processes that may be of interest to the schools, they don't have specific people to contact. The people who make the implementation decisions are diffused within the school structures.

Consequently, an innovation made in one school tends to stay there and is just as likely to come into another from the outside (suppliers, trade magazines, trade shows, moonlighting employees etc.) as from the original school. However, mitigating against this, the middle management of the Facilities Maintenance Department, liaisons with the different schools, keep in reasonably close contact, and pass information to each other. Additionally, the schools look to each other for standardized decisions. For example, the Law school decides annually whether to heat hot water in Winter with steam or gas on the basis of the Faculty of Arts and Sciences decision.

Finally, lots of energy conservation ignorance, myths and misconceptions can remain in the schools for a lot longer than they would if communications were better.
For example, I spoke to two people who are influential in energy conservation decisions, but knew very little about the issues. One admitted the fact freely, and added that he didn't know where to go for good information. The other viewed the problem in much the same way as Dean Nankin did fifteen years ago, and therefore was having a lot of trouble understanding why anyone should be interested in energy conservation (it would just make the place dark and cold in these days of cheap heat) or what the significance was of the various options being presented in the school.

One obvious solution to this problem is to create a consultant position within the Facilities Maintenance Department. This would presumably be an engineer or very experienced tradesperson who would provide advice to the schools. That position was created (by accident - as described in section IV) approximately simultaneously with the interviews for this case. There had been no difficulty keeping him fully occupied reviewing drawings and solving particular problems that have arisen. As described above, previous engineering services offered by Harvard have been unsuccessful.

In describing the need to maintain the buildings properly, one Facilities Maintenance Department staff member discussed the need to be vigilant, because "if we don't find it, the faculty will. So, the more we find, and keep ourselves above water, the better off we are."

The need to keep the users, and particularly students, aware of energy conservation issues, especially in the dormitories, was emphasized by one interviewee. Noting that the contact person with the user (the student in this case) is the maintenance operator he described what happens with a cold complaint. However, implicit in his statement is the need to also keep the operators conscious.

"And I'm sure, to some degree, any maintenance operator who has to deal with these every day on his shift gets sick of having to walk up to the top floor of a building that he knows is cold, and would much rather shoot the heat on, and be done with it. But, I really think that making the management of energy in buildings such a hands on kind
of thing has made 90%, if not 100% of the people who work for these guys, conscious of it and behind it."

The Facilities Maintenance Department pays all of the utility bills and then bills the schools. To assist them with their energy management, the Facilities Maintenance Department also supplies monthly printouts giving tabular and graphical information about consumption for that period and the year to date, with comparison to previous years, for each building. As described above, the schools feel this provides more than enough information for this function.

B. THE PLIGHT OF THE SMALLER SCHOOLS

The organization and staffing of the Facilities Maintenance Department is driven by the needs of the Faculty of Arts and Sciences, its largest customer. Hence, it is not surprising that a consultant position was not created in the past, the Faculty of Arts and Sciences didn't need one. However, overhead is not recovered to reflect the differential of services and need. Consequently, the smaller schools end up paying relatively more for less service.

At the time of the interviews, the new head had just been appointed to the Facilities Maintenance Department. It is my understanding that he had observed this and was looking at options to alleviate the problem. The preferred solution was some sort of contract system where the individual schools contract for different services for different fees. Similarly, Harvard unofficially acknowledges that there are systemic biases against the smaller schools. It compensates for these, in part at least, by the corporation making them loans for projects and then showing little hesitation in waiving the loan after a period (generally about ten years)\textsuperscript{88}

\textsuperscript{88} This is an interesting application of economic theories of welfare economics. The University is effectively making a lump-sum transfer from one school to the other and therefore changing relative wealth without bringing about other changes.
C. THE ROLE OF THE INDIVIDUAL

One thing that is borne out over and over again by the study of Harvard is that all changes occur because of motivated people in key positions. If those people are not there, nothing happens. Consider for example two interviewees.

Stephan Engel has very shrewdly entered into shared savings agreements with the different buildings. While the economic appropriateness of this is described below, the political sense of it should not be overlooked (and can be explained in terms of transaction cost minimization.) By carrying out his program in active partnership with the faculty, Engel empowers himself considerably, because the capital requests now come from the schools rather than from a facilities office that has been relegated to an uninterested Associate Dean.

Susan Hill discussed her role as energy coordinator at the school of design, and talked about the need to explain to people why it isn’t possible to cool a building (at $1.00 per minute) for a few people on a weekend. She also pointed to the stream of letters she sent to guards to thank them for turning off lights, and so forth.
VII. OTHER SCHOOLS

This section details incidental observations that arose during the interviews. They help fill in the Harvard picture. They are anecdotal and incomplete, but useful nonetheless.

A. LAW

The difference in emphasis between the schools, and the difference in their energy policy as a result can be seen when you compare the Law School to the others. While the Faculty of Arts and Sciences has a strict daytime temperature setting of 68° and a night setback of 64°, and there are state and federal laws mandating a maximum Winter temperature of 68°, the Law School has chosen to not set back the heat in the evenings because it would rather not deal with complaints. It can be inferred fairly safely that the school has a similar attitude towards day time temperatures.

The school has done significant energy conservation work, however. In fact, it will do anything the Facilities Maintenance Department suggests so long as it will not discomfort faculty and students. One of the major projects was a downsizing of the exhausts in the kitchen.

Surprisingly, the possibility of inconveniencing staff was also not an issue in a 1987 retrofit of the air-conditioning system. It disrupted the work of all the faculty, but proceeded anyway. The other interesting aspect of that retrofit is that it is an installation of a true four-pipe system, as opposed to the one they had before.  

Conversion to a four-pipe system when you have other options, as you would in a complete retrofit, is surprising because these systems are not terribly energy efficient. With these systems, there are two pipe loops that supply simultaneously hot and chilled water to a space. The conditioning task then involves selecting the right relative quantities in the two pipes. It is easy to understand the inefficiency if you think of what happens on a day when you need no heat or cooling. Then, you supply exactly equal quantities of heat and cold.
B. SCHOOL OF PUBLIC HEALTH

The Harvard School of Public Health responded to the Faculty of Arts and Sciences energy conservation initiative by asking the Faculty of Arts and Sciences for assistance. It eventually decided to enter into a shared savings contract with Scallop Thermal Management (a subsidiary of Shell), and this has resulted in $2–$3 000 000 in savings (or 30%) over the past few years. Scallop owns all of the equipment it has put in place, and, under a separate arrangement, has undertaken to maintain the school’s mechanical plant for it. This has been very successful.

Since the shared savings contractor makes a profit, it could be construed as disadvantageous for a technically competent and large institution like Harvard to enter into a shared savings contract when the corporation is happy to arrange financing, or loan the money itself. There are however, two reasons why the Public Health School did so. First, it was seen as a lot less interventionist for an external contractor to come in and audit the buildings than for someone from inside Harvard. Second, it was the first time Harvard had gone into such a venture, and since the school had developed the program and wanted to try it, the administration didn’t want to stop it.

C. DESIGN

When Susan Hill was an employee of the School of Design, she supervised the renovations of the building. She noted that it is considered controversial to renovate a building while the architect is still alive, especially since the school had to borrow heavily from the University to pay for the works\textsuperscript{90}. The renovation included the following:

\textsuperscript{90} I understand that the loan is still outstanding and is soon to be retired by the Harvard Corporation.
* Re-zone the building. Particularly, set it up so that the auditorium (which has very high or very low loads) is zoned separately from the rest of the building.

* Provide comfort heating and cooling on demand. To do this, a 2-hour tickless timer, designed by a Division of Applied Science Employee was located and purchased.

* Give the guards specific instructions about lighting and send them thank-you notes when they did it.

* Motion sensors were experimented with, but they didn't work well. (These were fairly early ones, so there is a possibility that the newer ones work better)

* The studio lights were carefully zoned so that large areas didn't need to be lit all the time.

* Put a light/flow switch on the chilled water system so that people could know that when the light is on, they shouldn't open windows.
APPENDIX D. THE UNIVERSITY OF MASSACHUSETTS AT AMHERST

I. INTRODUCTION

This appendix summarizes the data gathered at The University of Massachusetts at Amherst in twelve interviews over two days plus telephone follow up interviews. Data is presented virtually without analysis, as that is presented in the main thesis, except in areas where the significance of the data is not immediately obvious and the lessons are beyond the scope of the main thesis. The appendix was written in early 1988. I have left in people's (then) future plans despite the fact that the subsequent state fiscal crisis probably eliminated all of them.

A. THE CAMPUS

At a given time, there may be 30 000 people on the 1273 acre rural campus. The university has 30 000 students (including 5 000 graduates), and about 3 000 staff. Of the approximately 250 buildings, 140 are heated. Annually, fuel costs about $11 000 000 (1987 dollars).

Of the 8 000 000 square feet of internal space, 24% is unallocated. That is, it is devoted to corridors and bathrooms (20%), custodial (0.6%), and utilities (4%). About a third of the remaining space (25.5% of the total area) is residential. Offices take up 12.8% of the space, laboratories 10.6%, support (preparatory laboratories, darkrooms, etc.) 8.7%, general use (campus center, student union) 6.1%, special use (athletics,

\^C.f. M.I.T.'s 9 000 000 square feet total space.
specialist laboratories etc.) 5.5%, and the remainder (classrooms, health care, library and study, remodelling, and other) 7.1%.²

A few new buildings have been proposed, including new buildings for engineering, polymer science, and possibly a sport/entertainment complex. In addition, space is constantly being renovated and upgraded. New buildings, upgrades and generally increased intensity of energy usage (particularly with the proliferation of computers), is often stretching both chilling systems and electrical systems to capacity.

B. COMPARISON WITH OTHER CASES

This case has an emphasis different from the others. In the other cases, most of the effort went into investigating the inner workings of the energy management organization, its relationship to physical plant functions, and its interaction with other parts of the university. The University of Massachusetts at Amherst, in contrast, is strongly influenced by its slow and the unpredictable external environment. In particular, resources for capital works and ongoing maintenance are hard to secure. In addition, the organization does not have a history of flexibility.³ The university does not have a clear incentive to save energy, but chooses to anyway.

Hence, in this, there is little discussion of when equipment is or is not changed, or whether the energy manager has any input in the selection of architects. Instead, the emphasis is on the historical evolution of energy management and how it has been both constrained by, and has flourished within, the external environment.

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³ As we will see below, the organization often must restructure to accommodate any change. Often this has required key staff members to retire.
II. ORGANIZATION

A. OVERALL STRUCTURE

The Commonwealth of Massachusetts operates two major universities on three campuses. The University of Massachusetts has campuses at Boston and Amherst, while the University of Lowell is in Lowell. The three campuses have a common set of Regents, housed in downtown Boston, who oversee the universities and act as the liaison between the university and the state legislature.

At Amherst, a central administration, housed in the Whitmore building, oversees the campus. Broadly speaking, it oversees three areas; academic operations, administrative operations, and housing. It includes a building authority which issues bonds to pay for dormitories, dining commons, and other facilities like the Campus Center.

One central administrator is responsible for writing annual appropriations requests and for working with bond issues. He is the liaison between the university and the building authority and ensures that the building authority’s capital program meets the needs of the university. He holds the central administration responsibility for energy management.

The housing department is responsible for housing many of the 30 000 students on campus. It is financially autonomous, and obtains most of its operational services from the Physical Plant Department.

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4 There are many smaller schools also.
B. THE PHYSICAL PLANT DEPARTMENT

The Physical Plant Department, with a staff of 700, is headed by Frank Andrews. Mr Andrews came to The University of Massachusetts at Amherst in 1984, at age 31, from the University of Connecticut, where he was Assistant Director of Physical Plant. He had joined Connecticut after finishing his M.B.A. (His undergraduate training was in engineering.). He was working at Connecticut during a period of significant reorientation of the Physical Plant Department. He was apparently hired to bring about a similar reorientation at Amherst. The Physical Plant Department before 1984 was characterized by several interviewees as run down, inefficient, and internally divided.

One might expect an organization like the Physical Plant Department at The University of Massachusetts at Amherst to suffer from very rigid organizational structures and decision making. However, this appears to not be the case. Andrews, in his own words, "encourages failure" because he wants to see a constant stream of new ideas. He believes that constant innovation is much more important than occasional error. He also believes in reorganizing, and does so every two years. "By reorganizing, what you can do is you can move people that are in the way over and give people who have been waiting a chance to really excel." Finally, he allows his managers to manage, and to make decisions and move people around.

The Physical Plant Department provides heat, light, and custodial services for academic, administrative and housing space on the campus. To do this, it operates a large central boiler plant and a set of distributed chillers. In addition, it does most minor capital construction on the campus. However, it does not construct new buildings. It is divided into five divisions; Engineering, General Services, Grounds and Custodial, Operations, and Planning. In addition, there is a small staff that works directly for the Director. One of its tasks involves designing the new work order management system. Engineering is responsible for the design of facilities on campus. General Services runs
the Physical Plant Department, including the control of work orders, inventory and ordering. Operations is responsible for the construction and operation of all facilities on campus. Planning deals with long-term issues.

Space allocation is carried out external to the Physical Plant Department. In late 1987, the space allocation section completed a computerized inventory of all the space and all the academic equipment on the campus. However, they did not include the equipment under the ægis of the Physical Plant Department.

The Operations division is the largest in the Physical Plant Department. It has three major responsibilities; operations, maintenance, and vehicles, with a shop for each. Each shop contains smaller shops of appropriately skilled trades-people.

In the Operations Division has been constantly restructured as the energy management program has emerged. The current head was promoted to his present position soon after Frank Andrews took over as Director, after six years in the Physical Plant Department. Simultaneously, Eric Hartley was brought across from the central administration. In mid-1987 he took responsibility for Operations and Maintenance when the incumbent became ill. Prior to that, he had been responsible for utilities and operations. This responsibility has been taken over by Teresa Koppen, who also oversees the operation of the existing central plant and the design and construction of the new one. The prior manager of operations and maintenance has joined the staff responsible for scheduling of operations and maintenance. He is apparently well suited to the job as

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5 Capital projects larger than $25,000 value are administered by the Division of Capital and Physical Operations (DCPO) in Boston in conjunction with the construction group in operations. They are designed by external consultants selected by the Design Selection Board. Jobs smaller than $25,000 are generally designed by the engineering division and constructed in-house by the operations division. Sometimes they are sent out to bid, but this is generally avoided since it is slow and requires free capital. Maintenance projects (smaller still) are engineered and carried out by the operations division.
"you need a strong heart and a thick skin and you can't take it all too seriously." In February 1988, Mr Hartley took over responsibility for maintenance.

Since Andrews became director of the Physical Plant Department, it has gone from being the highest staff turnover department on campus to one of the lowest. Similarly, the number of complaints from users has dropped markedly. However, there are still minor problems of antagonism and division within the staff. This was being addressed seriously in January 1988.

1. History of Energy Management

Before coming to The University of Massachusetts at Amherst, Eric Hartley worked as an engineer for Johnson Controls. He was hired in 1979 as the campus energy coordinator. At that time there had been a campus committee of faculty, physical plant, and some administrative people dealing with energy issues. "They ran around and put up stickers on the light switches that said, please turn the switch off. ...They instituted intersession program (and had physical plant people) run around and turn off whatever phantom lights they could." Similarly, they were fairly judicious about setting back temperatures and times for heating and cooling. Hartley believes that there was a lot of pressure to create a staff position since the committee wasn't working too well and the state was leaning on the university to audit all the buildings. Simultaneously, they needed someone to apply for Federal and State energy grant monies which were becoming available. These grants required building audits. One the Physical Plant Department staff member reported to the committee, presumably seriously, that it would require 10 full time engineers and 100 full time staff audit the buildings. So, they hired one person.

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6 Eric Hartley
7 Eric Hartley
Hartley was hired as a staff associate to the Vice Chancellor for Finance. He audited buildings using students for credit and staff volunteers. They minimized auditing and maximized paperwork and "I spent a lot of time in Boston with the state energy office". Over a couple of years he raised $450 000 in grants for retrofits. They were for changing incandescent lights to fluorescent, insulating buildings, and putting small heat timers in 29 buildings (for $80 000). The buildings had originally been turned on in the fall and off in the Spring, but the timers allowed daily cycling of heat, though they didn't allow central monitoring. In addition, he down-sized fan motors and installed controls which allowed chillers to be cycled on and off and chilled water temperatures to be varied.

The Physical Plant Department started to resent Hartley, and he them. Physical Plant saw him as intrusive because he was from Whitmore, but effectively controlling part of their work. He found them tiresome and frustrating because they weren't doing enough. Also, the Physical Plant Department probably found him threatening because "I was working directly for their Director of Physical Plant's boss, so in certain sense I was a spy as well. ... I saw his boss every day. So if I chose to I could tell him exactly what was going on here because I saw it, which might not be the way it was happening at all, but it was as I saw it."

Four or five years later, the old director of physical plant retired. After Frank Andrews had been in the job for a week, he asked Hartley, who had been on his search committee, to come to the Physical Plant Department, and keep his responsibility for energy while managing utilities.

About a year and a half later, the money for an energy management system suddenly came through, on about the fourth attempt.\(^8\) An engineer was employed for

\(^8\) As discussed later, funding from the legislature is very unreliable.
the design, as discussed later. However, as the design evolved, Hartley and Andrews discussed implementation extensively. There was no clear reason why this new computer system would not suffer the same fate as the Supervisory Data System (See later) that preceded it. They decided that the system would have a better chance of success if it was designed and commissioned from within the operations section. So, Hartley took over operations as well. In addition to the control advantages this presumably offered, this also enabled him and the design engineer to get a feel for the way operations worked and what its real problems were.

Steam traps are devices which prevent incoming steam and return condensate from mixing. If one fails to close, steam escapes into the condensate return line. If one fails to open, there are pressure surges up the condensate and steam lines. There are 6,000 on campus,\(^9\) with 150-200 in the power plant alone. All of these require maintenance, as trap failure is very expensive.

One of Eric Hartley's largest grants was for a steam trap maintenance program. Prior to its inception, 40% of traps were estimated to have failed. So, they replaced 500 of them and set up continuing maintenance for $280,000 (half each from the federal government and the state) including labor, design, specification, a truck of which many interviewees were very proud,\(^{10}\) and equipment. Engineering students and internal labor were used to keep costs down. The annual pay back was about $230,000.

While the large trap program enabled the Physical Plant Department to check the trap problem, maintenance is made more difficult by differences in design and manufacture of the different traps. Since new installations go out to bid, and there are strict bidding rules for the state, large variations in brands occur across the campus.

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\(^9\) C.f. 600 at Tufts.

\(^{10}\) Indicating the equipment shortage discussed later.
This increases the required inventory of spare parts. To get around this problem, the Physical Plant Department purchases them in ones and twos, as needed, and always purchases the same sort. They hope to put strict constraints on trap design for the new power plant.11

2. OPERATIONS

Of Operations' three major sub-divisions; operations, maintenance, and vehicles, vehicles is irrelevant to this study. Work in the Operations and Maintenance sections is broken into six classes; power plant, emergencies, maintenance services, maintenance contracts, operations and general maintenance. Maintenance services are repetitive contracts given to outside vendors for specialist services; such as maintenance of environment rooms or transformers. These are re-bid every three years. Maintenance contracts are one-off contracts for specific maintenance services. General maintenance, performed in-house, has several classes. It includes capital projects up to $350 000, renovations and alterations funded externally (through research contracts and so forth), routine maintenance generated from the operations desk, and small alterations and maintenance jobs (up to $5 000). Here, we only look at the routine operations and maintenance functions.

a) Service Provision

Operations and maintenance were separated in 1984. Previously, when they were combined (and organized geographically) the maintenance people reported being overpowered by the operations tasks. People spent all their time responding to trouble

11 This is clearly the same problem that Harvard with its control systems and discussed by Perrow (1968) (See Chapter two). Because the maintenance of the traps is complicated and labor intensive, the Physical Plant Department would like to standardize and simplify it as much as possible. At Harvard, faculty purchasing policy prevents this and makes computer control much more difficult. Here the state's contracting policy complicates the task.
calls, so very little maintenance was being done. ‘Fire-fighting’ is considered much
better work, since it is more varied and enables workers to measurably improve the
user’s environment. Maintenance, on the other hand, is generally predictable and
thankless. Consequently, a group of people were separated to do maintenance, filter
changing, coil cleaning, lubrication, and repair maintenance. This decision was
originally unpopular because staffing levels were kept constant. Senior management felt
that the staff were over-attacking trouble calls, so no increase was necessary. This was
also an opportunity to overcome some job classification problems. Previous
classifications had resulted in an excessive proportion of the staff having supervisory
responsibilities, which in turn created unnecessarily long chains of command.

While this has resolved many of the problems, it requires much more active
communication between the staff. Sometimes disputes arise along the line between
operations and maintenance, with each trying to thrust responsibilities onto the other.
This is exacerbated by long-running interpersonal disputes. This was exemplified during
one of the interviews when senior and middle management disagreed, rather vocally,
about whether water treatment or refrigeration (or both) were responsible for
Winterization of a cooling tower.

In January 1988 these two functions were brought closer together by putting
them both under Eric Hartley. However, the demarcation will be maintained in the near
future. At an appropriate time, Hartley hopes to start moving people between the two
shops, something that they haven’t been able to do in the past. Eventually, he hopes to
computerize the whole process so that staff can be allocated between the functions with
reasonable accuracy. This will occur as an adjunct to the computerization of the
preventative maintenance program.
b) Operations and Routine Maintenance

Operations are the day-to-day activities associated with running the plant. They include things such as turning equipment on and off, keeping it running, and conducting minor repairs if machines break down. Tasks vary from small, like changing light bulbs or unplugging toilets, to large, like keeping water treatment plants and boilers operating.

The needs of energy conservation can be very different to those of efficient labor utilization. While good maintenance makes tasks easier and reduces energy consumption, operation for energy conservation increases work loads.

"If you're just an operator, the best thing you can do is turn on a fan the day the building was built and never turn it off. ... One of the hardest thing on a big motor is the cycle, so let it run. Overheat the people because you get few complaints about overheating people. ... They can open the window."[12]

c) Preventative and Deferred Maintenance

When the prior manager of operations and maintenance arrived in 1966, he found that a lot of the machinery was grossly under-maintained. For example, there were large tonnage absorption chillers that had not been cleaned in six or seven years. Consequently, their tubes were clogged, so their efficiency was very low. Similarly, there were cardboard filters that had rotted.

He constructed an inventory of the campus's equipment, wrote to the manufacturers to find suggested maintenance schedules, and compiled the data. He then produced a maintenance schedule for each piece of equipment. As he was unable to procure a computer, he scheduled the maintenance using a modified "Addressograph" envelope addressing machine. A separate address plate was made up for each piece of equipment. The plates were then selectively punched to correspond to the weeks in

which the equipment needed servicing. Every Monday, the week’s cards are selected and printed. The resulting card describes the equipment, its location, and the tasks that need to be performed.

As he sees it, there are four problems with the maintenance program at present. First, the man who had previously been responsible for managing the system has recently retired and has not been replaced. Consequently, it is slipping in its operation. Second, he feels that the maintenance task is under staffed, an opinion held by many interviewees but not senior management. Staffing levels are approximately the same as they were in 1972, despite a significant increase in both campus size and building age since then. Third, he sees an acute shortage of tools and materials. It is not unusual for the equipment budget to be exhausted relatively early in the year. Finally, there is very little standardization on the campus. Consequently, staff need to be more broadly trained than would otherwise be necessary and inventories are much larger than is needed. For example, vehicles on campus are made by an enormous variety of manufacturers. So, whenever a new building is commissioned, the first thing the Physical Plant Department does is change the locks to be compatible with the rest on campus.

One problem they have with maintenance of the central plant and distribution system is that it is very difficult to shut down the equipment. They partially shut down the central plant, and the distribution lines for about a week and a half each year. At this time they can still provide low-pressure steam to those buildings which use it on a severely reduced basis. However, every year when they do the overhaul, they are inundated with complaints, even though they warn people in advance. Although the shut down occurs in the quiet of Summer, academics areas still doing research, and people

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13 These three themes, contention over staffing levels, shortage of inventory, and non-standardization of equipment, arose throughout the interviews.
are visiting for conferences. Presumably, they have similar problems when they shut down smaller systems, though, in these cases, the shut down is quicker and people are less perturbed.

The Summer shut down is quite a complicated operation. All of the staff and materials from several shops have to be organized and prepared. Tasks have to be given priorities and coordinated. They pack every valve they cannot access during the rest of the year, whether it needs it or not. After they finish, new problems emerge because the equipment cools and reheats. These have to be attended to.

One final area needing maintenance is the steam and electric manholes. The maintenance task is sufficient to keep three or four workers busy full time. This would involve packing valves, painting, cleaning, and rust removal. It is not performed at all systematically.

Deferred maintenance is a big problem on the campus. The combination of shortfalls in annual appropriations and aging of the capital stock has led to vast excess

14 ANALYTICAL NOTE: What appears that the system has become too tightly coupled. The university cannot function effectively with the steam lines down. Consequently, since the campus must run for 365 days of the year, these systems must also. It appears also that the central plant and steam system is configured so the whole plant has to be shut down. The new plant will presumably be designed so that part of it can be isolated, though that leaves problems with the steam system. At the periphery they have two options. Either they can put backup or regional systems in the buildings; local boilers, gas hot water etc., or they can get users to purchase alternative systems.

If they pursue the first option, they complicate considerably the technological system that they must deal with. They must deal with a vast number of small and remote boilers. These require extra attention, like an annual service, and making sure that they are turned off in the fall. Also, installed, it probably pays to use them all Summer.

The second alternative involves getting users to pick up the load. They can only do this in specific instances; electric distillation equipment and so forth. In many cases, this may provide the cheapest global solution. However, if they do this they lose steam load, which may be important for cogeneration, and they certainly lose control over the equipment, which may or may not be important, depending on the people involved.
Peter Cebon (1990)

maintenance needs. These funds are appropriated through the DCPO, while the annual funds come from the legislature directly. The first major deferred maintenance request was made in 1980. The mechanical and architectural portion of the request was for $18 000 000 (1980 dollars) over six years. However, there were errors in the submission, particularly in underestimation of the cost of roof insulation. Also, the staff were unable to complete the tasks allotted for a given year. By 1982, the bill had risen to $39 500 000 (1982 dollars). In late 1987, the university assessed its deferred maintenance needs for the next decade and estimated about $500 000 000 of works. However, it could not carry all of these out without shutting down the campus, so it asked for $251 000 000. The regents then submitted a request for $186 000 000.

One of the large deferred maintenance items is underground piping, particularly steam mains. As one interviewee said.

"Our South West steam line was like a sieve. That's one of the amazing things about steam. As long as you can get us eight pounds (pressure) down there we're O.K. ... We put these vents in the ground to emphasize the steam that's leaking on this campus. ... We have miles and miles of underground utilities that have to be repaired."

These leaking steam lines were a dramatic symbol on the campus when the interviews were conducted, in January. One of the leaking mains is outside the front of the Physical Plant Department. So, while most of the campus is white, their entrance is green. Just near the front door there is an eight-foot high orange and white striped vent with steam wisping out the top. Even if they tried, the Physical Plant Department could not publicize the problem better.

Some of the largest deferred maintenance items are a set of buildings that are cheaper to tear down and replace than to rehabilitate. There are five buildings on the campus whose repair bills are so high that the cost of rehabilitation would exceed $60.00 per square foot (for dormitories; $200 for laboratories). This is estimated to be the cost of constructing new buildings. Therefore the Physical Plant Department has proposed
building new buildings and demolishing the existing. They are not interested in refurbishing the buildings to a lower grade usage since that would increase the floor area, and hence operating cost, of the campus.

*d) Staffing Levels*

Staffing is reportedly very inflexible. It is apparently very difficult to hire or fire. For example, when Andrews did remove one person, it took about a person-year of staff time to complete the process. Andrews took over as Director with an increase in his staffing budget to give him some flexibility.

With the level of control that they have at the moment, their staff needs are determined principally by the precision of their operations and the quality of their maintenance. In many buildings, they just open the valve at the start of the season and close it at the end. However, the variable Fall and Spring weather forces them to open and close the valves several times at the start and end of the heating season. This takes an enormous amount of time. If this operation were performed daily instead, their needs would increase significantly. Similarly, they do not look for finely resolved temperature or ventilation control, but are happy if they are within two or three degrees of their target. This reduces staff loads. With the introduction of the energy management system staff requirements for this will diminish. Despite the fact that the new energy management system threatens operations staffing levels, the union has not opposed it. Apparently, it would appear too unreasonable to object to a technological change which will vastly improve the quality of service and reduce energy consumption, even if it takes away jobs and diminishes work quality.\(^{15}\)

\(^{15}\) While it is impossible to say whether the new energy management system will increase job quality, the workers apparently perceived that the original Supervisory Data System did not.
Staff needs for maintenance are expected to drop with the introduction of the energy management system. Because the system will be showing up problems earlier, it will be much easier to deal with them when they arise and see whether or not they have been fixed. However, the campus is currently under-maintained. Consequently, it is very hard to tell whether or not the current maintenance staff and those who come from operations will be sufficient to meet the maintenance needs.

Operations and maintenance staff needs increase with the campus floor area and space use intensity. Similarly, some energy conservation technology such as heat recovery coils, requires a lot of maintenance. Since there has been an active energy conservation program, they have installed these coils in all buildings where they have to waste a lot of heat.\textsuperscript{16} This would seem curious since it significantly increases the difficulty of operating the campus while the university has no incentive to save money.\textsuperscript{17} However, as stated above, staff levels have been frozen since 1972. Staffing for the new work order system is discussed below.

Staff savings have often been made through automation. For example, the operations staff initiated automation of water treatment. Since management approved of the idea, this technology was adopted very smoothly. Unfortunately, communication of the implications of this to the other shops did not occur as easily, so some of the side benefits were not realized.

The Physical Plant Department differs from the physical plant departments at the other universities studied in that at Amherst they do a significant proportion of capital

\textsuperscript{16} For example laboratory buildings where they can’t recycle any of the heating or cooling air.

\textsuperscript{17} This reasoning will become apparent after the discussion of capital allocations
construction (most jobs up to $350,000) using in-house labour.\footnote{This is apparently because it is slow and difficult to obtain capital for contracts and then to put jobs out to bid. Furthermore, because the university is in a small rural center, outside contracting for anything other than large jobs is unlikely to attract particularly low bids.} This requires both extra staff and extra administration.

Virtually every interviewee commented on current staffing levels. There was little consensus about whether or not they are too high or too low at present. Generally, people closest to the shop floor thought they are too low. When asked why, some thought there were simply insufficient people, while others felt the staff didn’t work terribly hard. Those that made that claim saw it as a function of being a state institution. They saw management as the task of keeping the 30% who obstruct the work out of the way of the 20% who do it. All of the interviewees thought, however, that inventory and equipment shortages were as critical, if not more critical, than staff shortages. Consequently, any judgement of staffing levels is speculative.

e) Metering

Metering is very political, specially surrounding the Housing Department. They are discussed there in the main. However, it is still relevant to the Physical Plant Department.

They are not going to meter every building with the new energy management system. They feel that will never have the resources to maintain meters in 440 buildings, and the resources could not be justified in any case, since users don’t pay for utilities. In fact, for political reasons, they would rather not have accurate information. However, they are going to meter the buildings when they bring them on-line. They will install portable meters, look at the building before, bring it on-line, fine tune it, and look at the building after. From an operational point of view, there is little value in
the meters also. Steam metering is difficult to operate or maintain, as is condensate metering. It gives little useful information for the problems they face.\textsuperscript{19}

3. ENGINEERING

The engineering division of the Physical Plant Department is much larger than that at any of the other case-study universities, with twelve professionals, in addition to the two in operations and those in managerial positions (17 in total). The engineering division carries out all design, excluding major buildings and other large projects. In addition, some of these projects are designed in-house. The engineering division supervises designs carried out by consultants.

The general design rule in the engineering division is to add 25\% to whatever they did in the past. There are two reasons for this. First, loads are growing throughout the campus and that therefore equipment capacity should be increased to match. Second, equipment reliability is enhanced if it is over-designed.\textsuperscript{20}

However, whenever energy can be conserved without threatening reliability or service, the more conscientious engineers will design for that. So, for example, some of the electrical engineers design exclusively with fluorescent lighting. Similarly, one always includes a requirement that all light switches be labelled with 'turn off the lights' as part of her specifications.

Communications between the operations division and the engineering division are limited. Most of it is informal, springing from the energy management system’s designer

\textsuperscript{19} For example to see that the steam lines leak badly, they don’t need a meter. They simply have to look at the steam rising from the ground where the snow has melted.

\textsuperscript{20} There is a case for down-sizing so that equipment runs at close to peak efficiency. However, that would imply a desire to save money by limiting supply (and hence demand), and an ability to replace capital stock more regularly. Their incentive structure runs the other way. They are best designing for maximum reliability and minimum disruption and ignoring energy consumption.

436
having worked in engineering for a time. However, there are some formal communications as discussed below. It appears from the interviews that the engineers feel they get limited feedback from operations on the quality of their design, and that their work could be improved if feedback were better. They also suspect that there are many operations problems they could help solve if invited.

Traditionally, design of facilities at the university has been strictly on a first-cost basis with minimal input from the Operations Division. Whenever programs needed to be changed, the landscaping was the first thing to go, followed rapidly by roofing standards and facilities. Now, the initial design is likely to be better, and the academic program is more likely to be cut than the facilities.

There are two reasons for this. First, the level of competence and credible specialist skills in the operations division has risen markedly over the past few years.\footnote{There are several professional engineers in operations, some with advanced degrees. One had industrial experience before coming to the university. Some of their skills are not duplicated elsewhere in the Physical Plant Department.} Consequently, the operations division is much more interested in design and can now bring a lot more to the table. It has gone from being a group which has not participated at all to one that actively participates in the design process, from conception to completion. For example, at the time of the study, two buildings were in the conceptual phase. The operations people were actively participating in the design and layout of the equipment, and were going to design the control systems.\footnote{Generally, this is done by a supplier.}

They are finding that participation of the operations people in the process tends to reduce the capital cost, rather than increase it, and increase the amount of space available for academic programs, so long as they are included in the process early enough. For instance, outside engineers tend to over-design plant, since they are paid
on a percentage basis and are fairly conservative. On review, this plant is often reduced in size, and reconfigured to be more flexible.\(^\text{23}\) Similarly, the energy manager found, and stopped, a building being designed with electric heat. One interviewee suggested that the operations division never participated in design review in the past because it had never asked to, indicating that there was little interest before.

Second, the faculty have learnt from experience that operational factors are important. They are sick of dealing with leaking roofs and malfunctioning equipment. They are aware that costs avoided in construction must be met during operation. For instance, in 1987 the school replaced the deck of the Fine Arts building for $3,000,000. This building was only thirteen years old at the time, but costs had been cut during initial construction. With a deferred maintenance bill of $281,000,000 hanging over their heads, a lot of which is due to poor construction, people (faculty included) are a lot less hesitant about slashing an academic program before facilities than they would have been in the past, though there is still some opposition.\(^\text{24}\) Similarly, because of lack of incentives, they will reduce programs for energy conservation. So, for example, not all buildings that should get heat recovery units or variable air volume air-conditioning.

The inclusion of energy considerations into design doesn’t always improve operations. For instance, the Physical Plant Department is insisting on heat recovery units in a new animal building (which vents 100% air). These are notoriously difficult to maintain. Similarly, they are insisting that all new fumehoods be built with 70%

\(^{23}\) For example, they may insist on two small chillers instead of one large one. As well as having a lower operating cost, since they can run closer to peak efficiency with less cycling, this increases flexibility. One of the chillers can be operating while the other is overhauled and systems do not have to be shut down completely.

\(^{24}\) In terms of the main argument of this thesis, deferred maintenance has become aligned with academic objectives. Facilities are at such a low standard that academic programs are impeded. Consequently, the academics are happy to reduce their programs to create a working infrastructure.
unconditioned air being used to provide ventilation.\textsuperscript{25} Both of these are uncharacteristic of their behavior in general, because their principal concern is with ease of operation.\textsuperscript{26}

If given a choice between the two, given their incentive structure, they will choose operation. There is a general feeling that they cannot rely on the quality of operation and maintenance in the Physical Plant Department. While management, though presently very good, is not assured in future.

\textsuperscript{25} The air is brought in through a vent running counter to the flue. This air does not have to be heated or cooled like air which is brought in through the laboratory itself.

\textsuperscript{26} The heat recovery unit is interesting in one other respect. If they feel that they cannot operate it, they can simply pull it out (as they did at Tufts). This will not affect the operation of the building. They may treat a very energy efficient, but complicated, chiller differently.
III. BUDGETING

Budgeting at the campus can be divided into revenue and expenditure. These are unrelated. One hand, the university collects tuition, which it transfers to the state with any other income (about $25 000 000 annually). That is, tuition collection is completely independent of the operation of the university. It is simply a tax on people who obtain an education. The university is the tax collector. On the other, it receives an annual appropriation from the legislature and an annual deferred maintenance appropriation from the DCPO (about $150 000 000 annually).

The university's enabling legislation very strictly regulates the use of this money. The money for the Physical Plant Department is allocated among sixteen different line items. Internal transfers between line items in the budget are not permitted. So, the Physical Plant Department cannot decide to spend money on capital works to save fuel. If it does save money, say through a shared-savings contract, it must return the fuel savings to the state at the end of the year. The next year's utility budget will be reduced accordingly.

There is currently legislation before the house to enable these internal transfers to occur, especially for energy conservation. However, it has not passed despite several attempts. Apparently it gets caught up because the university, being a responsible state institution, should be as efficient as possible - in theory anyway. Therefore there is no need for this legislation. However, that argument ignores the difficulty of getting

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27 As of May 1988, there was discussion of the possibility of the university being able to retain some of the fees it collects.

28 At Amherst, they can get around this a little because they burn coal. Therefore if they save some fuel they can simply build a bigger stockpile. However, this strategy is only useful if the fuel allocation is threatened for other reasons.

29 Such a bill was passed in California several years ago.
capital appropriations through the legislature. Similarly, legislators are apparently much more interested in balancing the annual budget than in long-run optimization of the universities, so they would prefer to get the money back. If the whole function occurs within one line item, then the legislature doesn't mind. So, the operations people could decide that the best way to maintain a fan is to replace it with a high-efficiency low-maintenance unit. Then, they trap all the savings. This can only be done with small items.

The University of Massachusetts Building Authority, which runs non-academic facilities, is completely different. It is a self-funding statutory authority that collects rents from the students and other tenants (such as the campus hotel and the dining commons) and uses these to pay its operating costs and the cost of bonds that it has issued to finance construction.

A. CAPITAL BUDGETING

For the main campus, capital funds for energy conservation come from one of three sources. Either they are appropriated by the state, or they are raised through conservation grants from either the federal or state government, or they enter a third-party financing agreement. The university cannot commit itself to debt, so it cannot issue bonds or take out loans.

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30 It does have some validity however. The University of California installs the cheapest lighting possible when they build a building. This allows them to have a bigger academic program within their capital budget. After a year of operation, their operating budget is increased to account for the new building. They then retrofit with high efficiency lighting, increasing their capital budget for energy conservation with the savings.

31 However, as many of the projects they are performing at the moment pay back in less than a year, this argument also appears weak.
State capital appropriations are extremely unpredictable. The Governor's office presents a bill to the house. The house passes it if it desires. There is no guarantee in a given year that the legislation will be put up by the governor, that it will make it to the floor, or that it will be passed by both houses. Consequently, the university may go three or four years without a capital allocation, and when capital is allocated it could be either very little or a lot. At other times, it may be granted its full request three years running. The university must assign priorities to the money. While, for social reasons, they will favor energy conservation, their dominant interest is in operating ease. So, programs that make the university easy to operate or more comfortable to be in are favored. Notwithstanding, crises are generally good for capital appropriations. So, the South-West steam line rehabilitation was funded when the university suggested it would have to close if the line failed. The operating budget is dealt with separately and is passed yearly.

When money is appropriated they run into another problem. The fiscal year starts in July, but money doesn't get appropriated until later, September or October. So, jobs cannot go out to bid until the start of the Winter. Unfortunately, the university would much prefer to build in the Summer when conditions are better and students are fewer.

Competition for energy grants is extremely fierce. They are ranked by the granting agencies, so projects with very short pay-backs tend to be favored. Consequently, granted projects tend to have pay-backs of about six months.

The university does pursue third party financing on occasions.\textsuperscript{32} It is important to realize that the university has no financial incentive to enter into such a contract. It

\textsuperscript{32} The contractor designs, finances and constructs works for a share of the savings.
must return all savings to the state. However, it is a method of getting certain types of works completed. This is discussed below.

The housing department has the same options except it cannot go to the state for money. Similarly, it can retain the proceeds from shared savings agreements. Instead it must raise capital through bonds (via the The University of Massachusetts Building Authority) or through shared savings or energy grants. Rents are used to service debts. However, the reader should note that the dormitories, being self-supporting, have much quicker access to funds.

1. DESIGN PROCEDURES FOR STATE WORKS

Capital projects larger than $25 000 carried out by the state are bid under the auspices of the DCPO in three stages. First a project is put out to bid as a study. A consultant is appointed and feasibility is determined. Then it goes out to bid again and a designer is appointed to draw up a construction contract. In the third phase, the building is constructed.

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However, since they only pay for 17.9% of their marginal energy usage, they are unlikely to enter into a shared savings agreement.

POLICY NOTE: A much better way of allocating costs would be to use the 17.9% as a base rate for cost allocation, rather having housing pay a fixed percentage. If energy were conserved on the main campus, the rate would rise (though the bill would stay the same). If it were conserved in the dormitories, then the rate would drop. The actual recalculation of the rate is not overly important. The important thing is that the marginal change in the bill approximates the marginal saving. There are two reasons for doing this. One is that it would mean that the housing department would face the full marginal cost of its consumption, and could choose to do energy conservation works to drop its bill. Currently, it has the opposite incentive. That is, it should not do anything and let the main campus do the works. Then its bill would drop without doing any capital works. The second reason is that the dormitories would become attractive for shared savings contractors. It would now be in their interest to pursue work in the housing, and bring about savings.
While this system provides the checks and balances that people want, it has major faults. First, it is very slow. For example, the Physical Plant Department staff estimate that after the state approves the money for the new central plant, designer selection will take eight to ten months. Design will take another twelve. Then it must be built. In addition, this very slow process can lead to poor design. A job may take five years from conception to completion, by which time it is obsolete. For example, in one of the buildings a chiller was too small by the time it was installed because they had increased their computer usage considerably.

Second, unless it can show incompetence, the state must choose the lowest bidder. Similarly, the state must accept the cheapest materials that meet the specification. Writing a specification to deliberately exclude all but one supplier, without good reason, is illegal. These provisions mediate in favor of second rate design and construction using second class materials, fixtures, and fittings.

Third, the system precludes ‘turn-key’ projects where one contractor completes both the design and construction under one contract. These contracts are preferable in situations where there needs to be a lot of interaction between the designer and the contractor, or where the project must be built on a short time scale. They are poor in situations where the client needs to be involved extensively in the process.

Fourth, complex contracting systems can lead to cumbersome administrative arrangements. In one instance a supplier of batteries for emergency lights offered to maintain the lights as a variation on the contract, as an alternative to day-labour. The administrative sensibleness of this approach is self-evident. The Physical Plant Department wanted to pursue this option, but had to put it out to bid. Unfortunately,

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34 I presume this came out of the Ward commission in the 1970's.
the supplier lost, so now they have to deal with a maintenance contractor other than the supplier.

Finally, the method of appropriation encourages first cost, rather than lifecycle accounting. Since money for construction is appropriated separately from money for operation and maintenance, the temptation is to build a structure that has good academic facilities but is expensive to run, rather than one that is a little more limited but cheaper to operate. The Physical Plant Department tries to overcome this by incorporating the operators in the design process. (discussed above)

2. THIRD PARTY FINANCING

On first glance, there appears to be a strong disincentive for the university to enter into a shared-savings agreement. They have capital equipment which they retrofit. The contractor installs the new equipment and shares the savings with the university. The university must then refund the savings to the state, and has its utilities budget cut because it is using less fuel. At the end of the cycle, the university ends up with lower budgets (and hence less flexibility) and the contractor has made a profit.

If we look a little closer, there are advantages for all parties in the contract. The state avoids having to go out and issue bonds to finance works, an effort in itself. It also avoids having to appropriate money to service them. While on average, this costs them more, it appears to cost them less since the bond issue is visible while a reduction in operating costs is hard to see. Because state funding takes three years on average to come through, shared savings contracts may be cheaper for the state in the long run. It has the additional ideological advantage of making the works appear to be a private sector project. Finally, the implied discount rate for shared savings is different to that for capital works. One interviewee suggested that legislators are not interested in any project with a payback longer than their term, two years, implying a hurdle rate of 50%.
For a shared-savings contract however, the state will accept a return that satisfies the contractor. This more likely to be 20-30%.

The university derives the benefits of capital renewal that reduce its operating costs and increase the quality of the service it can provide. It gets something built away from the constraints of the DCPO design and review procedures. So, design and construction are quicker and more streamlined. Similarly, it doesn't have to wait for the state to appropriate funds. It can make way for other projects on its priority list, or it can complete projects that would otherwise not make their way onto the list. Consequently, the university will enter into shared savings agreements as the method of choice whenever they will yield the project they want. The contractor has a profit incentive.

There was little doubt in any of the interviewees minds that if all of the state's constraints were removed, self funding or state funding would be far preferable. As one interviewee put it:

"In my opinion, if we had a good set of engineers and the state provided the power plant, I can see no reason why we can't run the plant for less than what a third party could do it for unless there are certain tax structured gimmicks."

He added that it is likely to be cheaper for the state since it issues tax-exempt bonds and doesn't take a profit, while a contractor operates in the private financial market and does.

Third party financing is only attractive when you can measure the savings. Consequently, at The University of Massachusetts at Amherst, with its lack of metering, there are very few situations where a contractor would want to enter into an agreement. The new central power plant is one such case. It is discussed below. (Section IV)

35 Central administrator
B. OPERATIONS BUDGETING

The operations budget comprises labour and equipment, which includes spare parts as well as tools. One of the things that prevents determination of whether they are understaffed is that their equipment budget is inadequate. They have asked for an increase for each of the last four years. As Frank Andrews said, speaking figuratively, "I think out problem here is we have ten people with only eight hammers." because "..people vote. Hammers don't." Similarly, it is common to run out of spare parts before the end of the year. This completely frustrates any maintenance programs in place. They cannot procure only specialist tools through their capital program. So, for example, if their new energy management system required three trucks to transport service personnel, they could not put the trucks into the contract. It is possible to get equipment through grants, as with the truck they obtained through the trap program.

Their operations budget and their capital program are unlinked. Hence, while they have increased the amount of space on campus in the past few years and have increased the usage intensity of some space, their operations budget has not been increased.

Despite these problems, Frank Andrews feels that he has been successful in raising money, and particularly in asking for exactly what he needed and then using it. This has given him a reputation for honesty that has made his budgets more flexible. The university is tending more and more to allocate the money in lump sums rather than to specific needs.

1. ASBESTOS

One of the biggest inhibitors of effective operations and operations budgeting is asbestos removal. This is being approached in two ways. There is a team that is
removing asbestos in a systematic manner. Also, the plant removes asbestos when workers encounter it in the course of their work.

The systematic asbestos removal program started in 1986. At that stage they could remove about $10,000 worth of asbestos for $100,000. Most of the removal was on underground pipes, which used the asbestos for insulation. Unfortunately, at that stage they could only afford to re-insulate about half of the pipes. The other half were going back into the ground uninsulated, and hence are a major source of heat loss from the system.

In addition, they come across asbestos in their day-to-day operation. One interviewee described what happens when an asbestos-lined flange breaks:

"You have a flange suddenly bust out and leak steam. ... You gotta fix it and it's only a matter of spreading the flange and replacing the gasket, but there is asbestos on the flange. Now you're supposed to get plant A's notification to DEQE, I believe it's 10 days, to the EPA, and that's after you select the contractor. You can get emergency dispensation but you still have to notify. Now you have to have an outfit that comes in here that takes air samples of the background ... asbestos level, and then those people who are going to take the asbestos off have to come. (In) the first place you have to shut the steam down which is sometimes almost impossible, and they don't want to take it all apart. It's very hard to do because if they use golf bags ... where they've got their hands inside the bags, the plastic will melt, and if they don't do it with bags, they have to built an enclosure around it with plastic and wood and everything like a cocoon then they go in there with their suits on and their respirators and their air supplies and they have to have a shower outside of it where they change before they come out of there. They have to dispose of their asbestos properly and then you have to have another air sample taken before you can fix that flange that's leaking in there. ... That costs you $2000 (for) a job that you could have done in three quarters of an hour. That is a big big handicap that costs a fortune."

Asbestos removal of this kind is extremely expensive, extremely unpredictable, and extremely time consuming. There are too many asbestos-lined flanges to justify

__36 Teresa Koppen__
systematic removal. This problem has completely upset operations budgeting for the past few years. The budgeting system is insufficiently flexible to deal with it.

C. UTILITIES BUDGETING

The university receives an annual utilities budget from the state. It uses this to purchase coal and electricity. If the budget is too high, it uses the excess to purchase coal. If it is too low, they run down their reserves. In contrast, The University of Massachusetts at Boston must return monies if the price of oil or electricity drops and go back to the legislature if either rises. The legislature is not particularly rational in determining the utilities budget. For example, in 1988 it reduced it by $600,000 because the price of oil had dropped. Unfortunately, The University of Massachusetts at Amherst is on coal, so it must absorb a decreased supply. On one hand, this is a rationalization for their energy conservation program. Because the budget does not correlate well with fuel prices, the university is vulnerable to price changes. Therefore, if they actively pursue conservation, there is much lower probability of the system failing. On the other hand, everyone knows that the state would never permit the university to close because it ran out of coal. Notwithstanding, the ability to maintain a reserve, and an energy conservation program which tends to make it larger, gives the university a modicum of independence from the legislature.

Variations in coal prices completely overshadow energy consumption changes. Consequently, it is impossible to see energy conservation initiatives in the annual fuel bill. However, it can be seen in gross fuel consumption. The differential in fuel consumption over the last four years is estimated at 4% per year. (16% change over four years). Similarly, since individual buildings are not metered, energy conservation cannot be seen in local consumption.
D. INCENTIVES FOR ENERGY CONSERVATION

The Physical Plant Department has no direct incentive for energy conservation. If it saves energy, its utilities budget is reduced. However, there are several indirect reasons why it should choose to pursue conservation, both on the personal level for the staff involved, and on the university scale.

For the staff involved in energy conservation, it is a tremendous managerial and technical challenge. They are dealing with a large and unwieldy campus. Their job is to make it run well. Energy conservation is the vehicle they use to do this. They couple this with a ethical belief that this should be pursued. Looking at the world around them, they see a moral imperative to save natural resources. This is also the impetus for housing to do unpopular things like install restrictive shower heads. Finally, energy conservation provides excellent opportunities for someone who wants to establish a strong track record. It is one of the few areas in university administration where staff members can bring in large external grants and measurably reduce overhead. "It looks good on your resume if you say that you brought in a half a million dollars in grants and you saved two million dollars in energy."37

The university is not interested in any energy conservation initiatives that will not improve either the ease of operations or comfort. So, for example, although the lighting in the Physical Plant Department itself is very poorly designed, there is no talk of replacing it. Similarly, they would not be interested in adding a control system that complicated plant operations. In addition to insulating its utilities budget from Boston, there are enormous incentives in operations. If it can improve the ease of operation of the campus, the Physical Plant Department reduces both its staff requirements and the

37 Eric Hartley
complaints it receives. Since the energy intensity of space use is increasing and the number of buildings is also on the rise, but staff levels are frozen, the Physical Plant Department is forced to keep increasing staff productivity levels. It does this through capital works to renew equipment or improve its control. However, it is very difficult to raise capital. The legislature is hesitant to give it out, and the university cannot borrow. If it presents a capital program in terms of energy conservation, it is much more likely to get the money from the legislature, since the government can legitimately take the money straight out of the utilities budget. Similarly, it can give shared-savings contractors an opportunity to replace old and inefficient capital stock, bringing money onto the campus.

1. OTHER PROJECTS

Throughout the interviews, projects that have been performed or are seen as future priorities were mentioned. Some of these haven't been discussed above. This section presents a short list.

There have been numerous mechanical retrofit programs. These have generally resulted in massive reductions in plant size. For example, in one building they changed 2*150 hp supply and 1*100 hp return fans for 2*75 hp supply and 50 hp return. The users didn't notice the difference.

They are looking to reducing summer steam usage by providing gas hot water for the dormitories and closing the steam lines. This will reduce heat loads considerably. They are worried, however, that the steam lines may corrode if closed down in the Summer.

\(^{38}\) The number of complaint letters dropped from 25 to two or three per month from 1984 to 1988.
For the major HVAC facilities, which have multiple units, they are looking towards cycling the loads by turning units off for periods of about 15 minutes every two hours. This will enable them to run the equipment at higher efficiencies. To do this, they need a sophisticated automation system, which they are installing, as discussed below. Similarly, they want to rationalize their chilling by putting in a chilled water loop around the campus. This will enable them to cycle the chilling load between units to minimize costs. This is particularly important for cogeneration in Summer.

Lighting retrofits, steam traps and pipe insulation have all been targeted for shared savings contracts. Since electricity is much cheaper at night, they are looking for ways to use off-peak electricity.
IV. HOUSING

A. ORGANIZATION AND OPERATION

There are three financially independent departments within the university; housing, food services, and auxiliary services. Auxiliary services runs the campus center and the campus center parking garage. In the housing department, there are two major operating divisions; maintenance and operations, and residential education.

The dormitories are located in four areas at the edge of the campus. Each of these areas has an operations manager, an assistant operations manager, a janitorial supervisor, and a housing officer. A typical area has a staff of about 35 janitors and ten tradespeople. Between them they maintain six buildings; three high rise (22 stories, 576 students) and three low rise (four stories, 300 students) housing a total of 2600 students. The low-rise buildings have single and double bedrooms sharing a common bathroom, while the high rise have single and double rooms with one bathroom per floor. This staff is responsible for services inside the building, and is considered adequate. If a problem is too large or complicated for them, they will go up through the hierarchy to the central housing office. Physical Plant will then be brought in to assist. If they have insufficient staff to complete a job, they are expected to defer it and do it later. In emergencies they call in people from other areas, or if that is insufficient, they call in physical plant. Within these areas there are clusters of two or three dormitories. Their staff share responsibility for day-time operation.

A parallel structure within the residential education division manages behavioral and educational programs. This division deals with students. Students report problems to the residential education staffer (one per building) who will report problems on to the maintenance and operations supervisor.
1. Division of Work with Physical Plant

Physical plant interacts with the housing department in three capacities. It services specialist equipment and equipment under its control (like building air-handlers), it provides emergency services, and it does minor construction (like office renovations or lighting retrofits) which it sometimes chooses to contract out. In the latter two cases housing purchases the services. To alleviate staffing problems, the two organizations coordinate their operations so the physical plant staff stay occupied and aren't over-worked.

In late 1987 there was a minor conflict between Housing and Physical Plant. If Housing employed the physical plant staff during the day, they had to pay an overhead multiplier of 1.55. After hours, on the other hand, they had to pay a salary multiplier of 1.50 and no overhead, and they didn't have to pay for supervision. Consequently, it was cheaper to do lighting retrofits at night. For Housing, this had the advantage of allowing them to hand-pick a lower cost staff. The Physical Plant staff had an opportunity to do unsupervised overtime in a relatively good environment. There were two problems with this. First, the Physical Plant Department was unable to get good staff for overtime. Second, there were staff shortages for emergencies. Frank Andrews solved the problem by charging housing overhead for the staff time.

B. Capital Works

The housing department has a limited incentive for energy conservation despite being financially separate from the rest of the university. It pays a lump sum of 17.9% of the campus energy bill, so for investments to be justified, they need a payback of less than a year. Consequently, the capital program is dominated by concerns for operation, maintenance and occasionally comfort.
To guarantee maintenance, they try to make the user-accessible components virtually indestructible. As one interviewee said:

"... in dorms around here, the 1% of the students that 1% of the time get over-intoxicated 'cause their girlfriend just divorced them or something and they flunked an exam and their mother's doing something wrong, and they go berserk and start ripping the place up, the first they seem to take out is the light fixtures. Second is the plumbing fixtures."\(^{39}\)

Consequently, they are putting effort into retrofitting lighting. When they retrofit, they generally try to put in energy efficient fixtures including electronic ballasts and PL tubes (which have very low maintenance requirements). The primary criterion, however, is indestructibility. Consequently, the fitting of choice is a four foot tube. However, there are no mechanisms to ensure energy efficiency is considered. Consequently, a $40 000 project at the start of 1988 was yielding lights that were uglier and glarier (and quite possibly less efficient) than those they replaced.

In early 1988 there was a proposal to convert a dormitory from steam to hot water. However, the principal proponent felt it was unlikely to be funded because of the low incentive to save money and the university's low emphasis on user comfort. They had previously attempted to put variable range switches on radiators in the dormitories to increase comfort and reduce energy use. Unfortunately they had to accept a low bid product. These taps broke.

\(^{39}\) Housing department central office manager.
1. Energy Problems

The primary energy problem with the dormitories is with air loss from the buildings. This comes from three sources; infiltration, stack effects, and open windows.

They believe that they have very big infiltration problems in the dormitories. However, as there is no metering available and windows are often open it is very difficult to tell. There had been a program to reduce this, but it was stopped when it was impossible to assess the results. They feel that with the new energy management system they will be able to attack this problem systematically.

There is a stack effect in the tall dormitories. They studied one of the towers and found a positive stack effect at the bottom of the building and a negative one at the top. So, the air was being sucked in at the top and at the bottom and expelled in the middle.

The open window problem is caused, indirectly, by the infiltration and the stack effect problems. Because there is heat loss from some parts of the building, they need to keep the heat up everywhere. In addition, if given a choice they will always overheat rather than under. "It's the low complaint way. ... Keep the heat up so that everybody has more than they need and then those who's too hot can open the window."  

After heat, the next greatest area of energy conservation potential is lighting. The strategy is very simple. Lights are designed throughout so that they reach about 60% life by the end of a year. They are changed every Summer. Lights in public

40 A tall building can act as a large chimney. Heat differentials create differences in pressure which, in turn, cause air to move. Generally, the stack effect will result in the building sucking air in the bottom and out the top.

41 Energy management system designer
places, including corridors but excluding external areas, stay on all the time for eleven months of the year. They are turned off in January when the students are away.\textsuperscript{42} The external lights have a time switch on them which an electrician changes monthly.

Finally, they try to control domestic hot water by controlling temperature at the heat-exchanger\textsuperscript{43} and the flow by using low-flow shower heads. The students complain however that the flow is insufficient.

C. INCENTIVES FOR ENERGY CONSERVATION

1. INCENTIVES AND METERING

Metering is more important for housing (and dining and auxiliary services) than for the main campus. Housing pays directly for its energy services, while the legislature pays for the main campus. So, it is interesting to consider why housing pays a lump sum of 17.9\% of the campus energy bill, how that figure was arrived at, and what the implications of this are for energy conservation.

Several of the interviewees were very aggressive when asked about metering in the dormitories. It is an intensely political issue. The initial allocation rate came about several years earlier when the administration tried to develop a rational allocation formula. They found that with the differences in fuel uses and changing prices and coal inventories, the non-coincident financial years of the state and the trust funds, and the fact that there were elements of the distribution system that serve housing exclusively but are the responsibility of Physical Plant (such as the South-West steam main), it was very difficult to ascertain what portion of the cost was being generated by housing.

\textsuperscript{42} Although the interviewee did not say so, they are presumably turned off for part of the Summer as well.

\textsuperscript{43} However, the water is still within the temperature range specified in the sanitary code.
Eventually, the executive decided to estimate the rate on the basis of past consumption and arrived at 17.9%.\footnote{There was implicit suggestion from several of the interviewees that this rate is possibly too low. However, this is not the principal problem with this allocation method. The problem is that it skews the incentive structure. See previous footnote.}

Several years prior they installed meters in some of the dormitories, essentially for management purposes. In about 1985, the state audited the university, and concluded, from the metering information that they had, that they dormitories use more than 17.9% of the energy services, and therefore the students should pay more for energy services and the state should pay less. "The administration was in a real tizzy about the whole thing." The university then pointed out that the metered data could not be considered accurate because of maintenance and calibration problems.\footnote{While electric meters are reasonably easy to keep accurate, steam meters are both very expensive and very difficult to maintain.} The state dropped the issue. What is surprising is that it didn't turn around and fund selective metering on the campus to see if the allocation rate was appropriate.

This policy has several implications for energy conservation. The first is that the housing department has virtually no incentive to save energy. For its energy conservation works to pay, it needs a rate of return of $100/17.9 = 5.6$ times that of any other agency. Therefore, it will be looking for a simple payback of about ten or eleven months before it can justify expenditures. (Put differently, a project with a payback of five years pays back for housing in $5 \times 5.6 = 28.0$ years.) Therefore, despite nominally having a financial incentive, housing will only look to energy conservation if it is an added benefit of a program to reduce operations and maintenance costs. So, once again, we see lighting retrofits to reduce vandalism, not to save energy. Second, the lack of meters and the financial structure make it impossible for the housing department to pursue any user-oriented incentive-based energy conservation initiatives. Third, housing
has an incentive to save energy anywhere on the campus, not just in the dormitories. If it could, it should fund any project with a payback of less than eleven months, irrespective of location. Fourth, the Physical Plant Department has a central university responsibility for making the cost of education as low as possible for the student body. Therefore, since housing and the physical plant are coupled like this, physical plant has almost as much incentive to pursue energy conservation in the dorms as elsewhere on the campus. Consequently, some of the energy conservation grants have been spent in housing.

Elsewhere on the campus meters are thought to be of limited use. They are a useful managerial tool for seeing the effectiveness of one management strategy when compared to another. However, they are expensive to install and maintain. Without direct allocation of cost to buildings, this cost is not seen as justified. They are only an indirect conservation device. "You'll never win a conservation competition with meters." Similarly, it is very difficult to calculate a payback for installation of meters. So, granting agencies are not interested in them. Therefore, metering tends to be close to the bottom of any appropriation request.

2. DESIGN

One other reason why people appear to be sceptical of using direct costing for energy in the dormitories is that they appear to be poorly designed. Therefore, people appear to be unwilling to punish the tenants, and would prefer to waste heat. Many of the dormitory buildings are 22 stories high, and were designed with four zones. Unfortunately, due to poor maintenance, they are operated as if they had only one. The heat is pumped to the top and then comes to the bottom. This is unfortunate since the heat tends to rise anyway. In addition, the stack effect moves the air around. Finally,

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46 It may be forbidden from doing this by law however.
there is an overhang underneath the second floor. Therefore, the tops of the buildings are much hotter than the bottom, and the second floor is particularly cool. So, it is not surprising that they choose to operate the buildings so that user comfort is maximized. This invariably means that windows will be open at the top of the tower.
V. CENTRAL PLANT AND DISTRIBUTION

Utilities, distribution and generation are managed by Teresa Koppen. Prior to taking that position six months prior to the interviews, she was chief engineer at the power plant. She held that position for five years. Before joining the university, she was shift supervisor at a power utility in Stonybrook, Massachusetts. Her responsibilities include production of steam and chilled water, some power generation, steam and electricity distribution, fuel contracts, and planning for the new central plant.

A. THE CURRENT PLANT

The central plant at The University of Massachusetts at Amherst has eight boilers with coal handling and exhaust equipment, absorption chillers and a power turbine all piled into one small building. In addition, there are centrifugal and absorption chillers scattered around the campus.

Of the eight boilers housed in the central plant, two (20 000 lbs/hr boilers built in 1948) have been pulled out of service. They cannot meet emissions standards by themselves and it wasn't feasible to add control equipment. The three main boilers were installed between 1957 and 1959, are coal fired and are rated at 85 000 lbs/hr each. They were able to supply that output (or slightly more) for peak loads until the emissions control equipment was added. With the emissions equipment, their combined capacity is 185 000 lbs/hr. They have underfeed stokers and are supplied air by two large fans each which can either be driven off a steam turbine on the boiler or with electricity. So, the boilers can continue to run in a power outage. The boilers take about 24 hours to extinguish themselves if they need to come out of service. In 1970 they added a 110 000 lbs/hr package unit which runs on coal and/or oil. It has exceeded its rated life of 10-12 years, so they have down rated it to 75 000 lbs/hr. In 1987 they added two Zerinky-Stone package boilers, each of 60 000 lbs/hr capacity.
Their total capacity is 380 000 lbs/hr. On one day of the interviews, in January 1988, when the students were away, the steam load was 284 000 lbs/hr.

The exhaust of the coal boilers passes through a bag house; a large structure with twelve modules, each containing 164 filters of 24' length. The gases are helped through with two 300 hp fans. The bag house removes particulates from the exhaust, but allows Sulfur Dioxide to pass through. Therefore, they burn low Sulfur (0.6%) coal to meet air quality criteria.

The coal boilers are fed by a primitive fuel handling system which consists of a series of conveyors from a storage hopper up to a bunker about three stories above the boilers. There are several openings, but they do not line up with the boilers. From the bunker, the coal is dropped into a lorry of 3600 lb capacity and wheeled to the boiler. It is then off-loaded onto the grate. There is only one lorry. It must make about 100 trips daily in Winter. The coal supply to the boilers cannot be interrupted, because if there is a gap in the coal on the grate it is likely to damage the boilers. Teresa Koppen discovered that the plant had operations and maintenance problems about a month after she started in February 1982.

Because there was no spare lorry, it was never overhauled properly. In between fillings, it would get small modifications, but nothing major. In March 1982, at 3:30 one Friday afternoon, with two boilers running hard, one of the axles snapped and the wheel fell off. Koppen immediately called operations and had them lower the campus load. All the maintenance staff had gone home for the weekend, but one of the firemen could weld. He tacked the wheel back on, but it failed as soon as they tried to move the lorry again. Koppen had called for a welding crew and also she called a local engineering firm. The welders welded the wheel back on. The engineering firm rigged up a chute

47 Presumably the supervisory data system was still in use at the time, so they were able to shed load very rapidly.
which can be moved in front of one of the bunker doors and then directed onto the grate in an emergency. The chute was used for the next week while the lorry had its first proper overhaul in 25 years. The chute is still used for emergencies, but the trolley is used routinely as it requires less staff to operate.

She told another story to illustrate the poor maintenance in the plant when she arrived.

"Well there was one valve here, in the back of the header, for the line that goes to the back of the Graduate Research Center, that was a 12 inch valve (700 lb mass) at the end of the header, that they had used leak sealer, (Silicone sealant) ... It looks like a porcupine quill. And they drill it in there under pressure and they force the stuff in. ... Which is okay if you absolutely have to do it because you can’t shut this down, you can’t do it any other way. But then you should at the first opportunity replace it. ... Not leave it, because the first time that shut this valve down or whatever you have, it’ll cool off, when you put it back on it will leak worse than before because you broke the seal. This valve back there had 3 or 4 of those porcupines in it. It was blowing like a son of a gun. You couldn’t go near it. You couldn’t hear yourself talk. That’s how bad the steam was leaking out of the valve and out of the flange and out of the packing. I would never have told a man to even go there and close that valve. Never. Because I would be afraid to. So we shut this one boiler down that fed that section of the header, ... and I had it replaced with a new 10 inch valve. We had a 10 inch valve I got it rebuilt. ... and we were in business"

Soon after arriving, Teresa Koppen instituted a preventative maintenance program. In her first year, apart from the annual shutdown, they replaced or rebuilt 32 valves as a single contract. Also, she started to purchase replacement valves in advance, using her power plant operations budget or her emergency repair budget. However, she still feels extremely constrained by lack of funds for capital renewal.

1. COGENERATION AND CHILLING

The steam is generated at high pressure. From the back of the boiler it is run into one of a pair of steam turbines where it is used to generate electricity. (The University of Massachusetts at Amherst currently generates 2.2 MW of the 15 MW
Peter Cebon (1990)

average/ 19 MW peak load, or 16% of the load on average.) From the turbine it is either sent off around the campus as 15 lb steam, or it is run into an absorption chiller to make chilled water.

In addition, the campus is dotted with about 20 chillers to cool particular buildings. Some are absorption chillers, running on central steam, and some of them are centrifugal, running on electricity. The university would very much like to put all of these chillers on one loop, as it would give them much greater operating flexibility, efficiency and reliability, especially if they decide to increase cogeneration and decrease the use of Summer steam for heating. However, the funds are not available. This would require significant excavation as well as extra pipe.

B. 1973 PLANT

The university realized in the mid-sixties that the central plant had insufficient steam generating capacity. The legislature had decided that the campus should be expanded to educate 40,000 students, and the building was not big enough. It was also getting old. In addition, land in the center of the campus, where the Physical Plant Department is, was at a premium. Finally, they were using soft coal at the time, so the plant would spew ash all over the campus.

So, in 1966–67 they started designing a new power plant. At the same time, they started to run down the maintenance of the old one. They wanted a facility to expand the plant, so they chose a site on the periphery of the campus, 1.8 miles from the existing central plant and adjacent the railway track (so they could bring in fuel by train if they chose). By building on the top of the hill they could minimize the size of the chimney. They were worried about transmission losses as the steam came down the hill, but decided to accept them. Similarly, given differentials in cost of transportation, (and presumably the polluting ash) they decided to build a 100% oil-fired facility.
There was anxiety at the time about the cost of the facility; if it was too expensive, the state may not fund it. So, they decided to minimize costs. One of the cost minimization decisions was to run a single pipeline, without expansion loops, in a filled trench from the boiler house to the electricity generators in the valley. Instead of having expansion loops, they would use bellows joints. The way these joints were designed, they had to face in one direction. Again, to minimize costs, they used the minimum number possible.

They constructed the plant and the line. During construction they had trouble aligning the pipes in the line, since they had to trench to a depth of about 20' in places. Wherever it did not align, there was a risk that the pipe would become constricted.

The plant was commissioned in the Winter of 1973/74, just as the price of oil rose sharply. On commissioning, the Physical Plant Department decided to send some steam up the pipe from the old plant to warm it up before the start of transmission. Unfortunately, the bellows joints faced downwards. A water hammer was set off, and the bellows joints, facing downwards, were not able to absorb it.\(^{48}\) The pipes cracked.

Given the problems, and the prospect of a constant procession of oil tankers across the countryside to the campus in the middle of shortages, and the fact that the

\(^{48}\) A water hammer is a shock wave that is caused by a sudden change in pressure acting on a compressible fluid in a constricted space (like a pipe). The change in pressure may be caused by the opening or closing of a valve, or another similar thing. It results in a dynamic pressure wave, of much greater pressure than that suggested by a static analysis (about 100 times as large). The wave travels at the speed of sound in the fluid. Water hammer often occurs in domestic plumbing. It is the loud banging you hear when you open or close the faucet rapidly.

In the case here, the valve was opened at the bottom of the hill and high pressure steam tried to make its way into the pipe. However, it met low pressure steam and pushed against it. This forced the low pressure steam to expand against the wall off the pipe, pushing it out, and expand against the layer of steam behind it. The layer behind did the same thing. This resulted in a wave that shoots up the pipe, forcing the wall outwards. The wall cracked under the pressure. If they had been facing the right way, the bellows joints would have absorbed the pressure wave.
Peter Cebon (1990)

legislature changed its mind about the campus size and decided to keep it at 25 000 students, they decided to abandon the plant and bring the old one back into full service. The attorney general sued the engineers and settled for $1 000 000 damages. By staying with the coal plant, they saved $8 000 000 in fuel.

C. PROPOSED PLANT

If the present plant's capacity could be frozen, then, with the anticipated savings from the energy management system, it would be possible to keep running the plant with the existing equipment. However, the existing equipment is old, the capacity of the boilers is diminishing, and the metal is starting to fatigue. The plant has to be replaced. In addition, they are generating electricity with 195 lb steam. They could get much greater efficiencies if they used 650 lb steam.

They have two options for financing the plant. Either they can go to the legislature for funding, or they can pursue third-party financing. Since the plant is very expensive (about $40 000 000) and the plant has a payback of about four years, they are currently looking towards third-party financing. It is likely to free up other capital appropriations considerably. The plant would generate about 40 MW (approximately twice the campus electricity demand). They have received funding from the DCPO for a consultant to pre-design the plant and to advise on the best method of funding. While state funding is a better economic alternative, it will take much longer and will prohibit turnkey construction.49 They are unsure when the campus load will exceed its capacity. Turnkey has some advantages (and disadvantages) over having a separate designer and contractor. The principal advantage is that there is no separation of responsibility between designer and contractor, so mistakes that get designed in have to be constructed out for no cost. The principal disadvantage is that the designer has no incentive to make

49 Where one party finances, designs and constructs the works.
sure that the contractor does a good job. There is more interest in doing a low-cost job. In this case, it appears that turnkey construction may be preferable, since the university has a competent engineering staff that can keep track of the design and construction.

D. THE STEAM DISTRIBUTION SYSTEM

The campus has twenty-six miles of steam and condensate lines. The distribution system for steam operates at three pressures. Some of the buildings receive steam at 15 lbs pressure, while others receive it at 85 lbs, depending on their needs. The 85 lb steam is needed for laboratory cage washing equipment, distillers, and sterilizers. In addition, the whole South-West of the campus receives steam at 100 lbs pressure. It is passed through hot water converters in the buildings. They have problems with asbestos insulation and linings in the joints and with lines leaking badly, as discussed above.

As much as possible, the steam lines have been constructed in loops. This permits them to service a section of the line without cutting off steam to a section of the campus. To service a particular valve, they have to close two valves, one each side of it. Unfortunately, these valve often do not hold, so steam escapes past. Therefore servicing them is often difficult, as they have to shut off multiple valves. They also have trouble servicing valves on the branch lines. To do this they have to cut off the steam to the buildings on the branch.50

1. SOUTH WEST PIPELINE

The South West Pipeline provides an excellent example of appropriation in response to crisis. The pipeline has received a lot of publicity. It cuts a swathe of green across the campus in Winter as the leaking steam melts the snow and feeds the

50 Clearly, an effective preventative maintenance program would be useful here.
Peter Cebon (1990)

grass. These photographs have been published in trade journals. There is little doubt that it is cost effective to replace the pipeline.

However, the university was unable to obtain funds for the replacement until they warned the legislature that there was a risk of the pipeline collapsing. They had had to repair it in the past, and this had involved trenching to 30'. They felt that if it collapsed, they would probably have to send 5 000 students home until it was fixed. The new pipe will take about three years to install. As one interviewee described it:

"We got the appropriation to repair the South-West steam lines when there was a possibility that we were going to have to send 5000 students home. ... We didn't know when it was going to (collapse). ...You know the thing is 25 years old. ... Your problem is you feel like Peter crying wolf. You don't know if it's going to happen in the 26th or the 30th year, but you know it's going to happen. So, you have to act like it's going to happen the day after tomorrow in order to get the appropriation."

51 Central Administrator
VI. WORK ORDERS AND FACILITIES CONTROL

A. WORK ORDERS

1. HISTORY AND CURRENT PROBLEMS

Work orders are used for routine maintenance; small jobs assigned to one shop and not charged to any account; and for work requests, large jobs charged to non-physical-plant accounts. While the new system will continue to accommodate these large jobs, it is the maintenance oriented tasks that are the target of the management reforms.

The principal problem with the existing system is that it offers no management controls. This can be traced to its history; it just evolved. As problems were identified, the system was modified. Consequently, the various elements don't work well together. Currently, the work order system is very simple. If someone isolates a problem, say an operator sees a leaking valve or a student rings in a problem, they, or the official requesting, write a slip, the work order people log it, and it is dispatched to the shops. Similarly, the addressograph machine generates preventative maintenance cards and they are dispatched to the maintenance shops. Until now, no one has looked at the system as a whole.

The other problem they have at the moment is that the preventative maintenance staff often make repairs on broken equipment. That is, a motor that may be due for balancing actually needs rebuilding. The preventative maintenance mechanic may elect to fix it on the spot. Under the current work order and staffing arrangements, this would be quite sensible, since the work may not be done for several weeks otherwise. The delay would result in wear and tear on the machine as well as discomfort to users. However, if that approach is taken, the repair is charged to overhead rather than a maintenance account, and there is no control over work processes. This prevents repair
costs being tracked. As the Physical Plant systems analyst, argued, "Without ... an automated work order system, it is very difficult for them to process the amount of stuff that they process." "The key thing (is) that whichever happens, (repairing the motor on site or repairing it later) that the work order would be submitted." Throughout the interview it was unclear whether the new work order system was meant to solve the problem of long delays between submission and completion of work orders, and if so, how it was meant to do it.

In summary, the current system has two major faults. First, it is very difficult to keep track of the equipment that is in use, its maintenance history, and the costs. Second, it is very difficult to make staff accountable for the use and allocation of time.

2. New System Under Development

A new integrated work order system, which will allow them to track maintenance, is being developed by the systems analyst. With the new system they will number all the equipment and form a database. This will be stored on one of the large PC-like file-servers on their computer network. Work orders will be submitted on paper for three reasons. First, for legal reasons they need funding signatures. Second, for practical purposes, they don't want people sitting over the computer dictating work orders to an operator. Finally, they would like some sort of a paper trail in case of system failure.

a) The Need and Uses for Data

The new system is directed at two distinct groups of people. For one group, it is simply a more elegant way of keeping records and keeping track of work orders in progress. As this is their principal task, it will make their jobs much easier. For the second group, it will be a sophisticated management tool. It will be able to yield information about the equipment; such as machinery on which they spent more than 20%
of the cost or more than $5,000 on maintenance in the last year, and so forth; as well as work breakdowns by trade, time of year, or by building; and other managerial information.

Being able to compare maintenance to capital cost is particularly important in the state system. It will make it much easier to replace two groups of equipment that need to be renewed, equipment they know needs replacement and equipment they don't. For equipment they know they need to replace, they need to persuade the state of the fact. "It's very very difficult, especially in a state system to argue that an entire cooling system, let's say, in a building needs to be replaced. Unless you can go armed with all sorts of information." In addition, there is undoubtedly other equipment, which they have not identified, that has exceeded its economic life. The new system will allow them to identify that and take their case to the state. It is when this equipment is renewed that the Physical Plant Department has an opportunity to put in more energy-efficient plant.

Since the new work order system is going to be following the equipment more closely than the old one, it is going to need a staff expansion to input the information and keep it up to date. In addition, since management are going to be receiving new information, they are going to need training on its use. Otherwise, they will not take full advantage of what the system is offering over the present system.

b) Emergency Work Orders

Emergencies will call for a different system. Currently, a call comes in to the operations desk and a paper work order is written. It is sent down to the shop and the shop supervisor gives the order an appropriate priority and dispatches someone (or pages someone if they're in the area). Under the new system, the call will come in to the desk

52 The systems analyst
and the operator will enter the information into the system (presumably after writing a paper work order, or getting a hard copy with the use of a printer). The operator will telephone the shop, and depending on availability and priority, staff will be dispatched. Critical emergencies, like pipe bursts, will be dealt with immediately. Others will be dealt with within a few hours.

c) The Role of the Developer

The systems analyst reports directly to Frank Andrews. She sees this as vital to her job, because otherwise she could appear to be partisan. This would embroil her in the political fight that accompanies the change. The following quotations illustrate the need she sees for having a staff position, and the problems that entails.

"There's a lot of questions about whether or not you want that centralization. But any time you're setting up a centralized system like that, there's going to be resistance from almost everyone. Some people at very low level and some people on a very high level ... because you are asking people to give up the ways they have learned to manipulate the system. Of course, what I have from a computer point of view, is that sooner or later they'll find a way to manipulate the new one too but it is a question of control when you come right down to it. That's what a computer automated system allows you to do. It allows you to control your work-force, control inventory, control ordering, control all kinds of things. And there's bound to be resistance to that."

"I've developed two or three other work order systems to give them something to look at. People who are inside the system have a very hard time breaking out of it and coming up with something new. So I've done that, I've given them things to play with. One of the things I always ran up against, every time I did that... Let's say there's five areas. For every two areas that liked this, the other three areas don't. Everybody has got their own vested interest in the system. Everybody has their own things they want to hide. Everybody has certain things they want to control."

"For instance, you can see that if I worked with the director of general services, it would be her automation staff again, operation automation attempts. By working for Roger what happens is, there is no way any one division head can claim me and there is, and it has helped tremendously in keeping automation from being politicized. ... I'm seeing automation becoming a political tool and so by working for "Frank" I have avoided a great deal."
"I am an advocate for every division inside physical plant and ... unfortunately chiefly "Frank's" advocate for the fact that he wants a centralized, unified automated system."

B. FACILITIES CONTROL

1. HISTORY

a) The Supervisory Data System

In 1968 or so, the university installed a supervisory data system (SDS). It was a remarkably ambitious project of central control. They tried to monitor all sorts of HVAC equipment throughout the entire campus (about 30 buildings). There were a couple of phases of expansion and it cost several million dollars. The mainframe was a Honeywell Selectographic. There were a couple of wires strung all over campus for temperature sensing, and 216 conductor cables trunking out from the main plant. The system reached its peak in the early seventies, and worked well for as long as it had a lot of political support. The pneumatic systems required recalibration and adjustment monthly or they stopped working. Apparently, with changing personnel and particularly changing physical plant directors, it rapidly lost its political, and hence financial and maintenance, support. The director in the late seventies apparently wasn't particularly interested in energy conservation and the SDS was very maintenance intensive. By the end of the seventies, only the bare bones remained. A committee appointed in the late seventies to study the energy management system didn't initiate anything. Support was lacking; people were soured by their experience with the SDS, and there was little political backing at senior levels.

According to Eric Hartley, who worked for Johnson Controls for several years, their experience with the SDS there was typical of many places. It was the rule, and not the exception that these systems did not work. He identifies two reasons for this. First,
the technology was not nearly as good as the technology is now. So, while it was not impossible to get the systems working well, (The University of Massachusetts at Amherst managed to run theirs for a couple of years) this was a major inhibitor. Second, and more important, he sees the problem being in the way these systems were installed and implemented. As he saw it:

"I think what happened here, although you hear many stories depending on who you talk to, ... was, you had pneumatic mechanics, mechanics who knew pneumatics, knew thermostats and valves (and that) kind of stuff, and all of a sudden this electronic stuff was handed to them by an engineer. That's what happened here, this was designed by one of our engineers, and it was a type of guy who goes out in the field a lot but he doesn't spend a lot of time relating well to the mechanics, so the pneumatic technicians are very threatened by him and they made sure it didn't work. The guys in the field made sure it didn't work. ... The technology at the time (had a) pneumatic system controlling the dampers and valves and the air handling and then the system, even if they were designed at the same time, was laid over the top of it. ... It didn't really control the valve but it made adjustments from afar to the thing that controlled the valve, and it also turned things off and on. ... These guys were running these systems as they always ran them and someone else from somewhere else could interfere. There were the SDS operators and the pneumatic control guys. They were two separate groups controlling the same thing. ... The pneumatic guys were making the system work day to day and the guys who were running the SDS were sort of diddling ... from half a mile away. It was real easy for the pneumatic guys to over come that. They just cut lines, screwed it up so badly it wouldn't work. That's what happened in most of the Johnson installations at the time."

Hartley felt that the system probably wasn't brought in very well. He doubted that the salesman or the engineer was conscientious about implementation. He thought it was possible that in some cases the mechanics simply didn't understand the system, so they set about sabotaging it. Eventually, the university was spending a lot of money for a limited amount of control, so it decided to drop the system.

b) Control at Present

Control is presently poor. In many buildings with four or five zones under-maintenance has resulted in them being treated as single zones. "They set the valves and
let the zone valves run wild and reset the water temperature centrally for the whole building, once.\textsuperscript{53} The difference between a one and a five zone building is thought to be about three or four degrees. "Well, in a dormitory and you shoot for about 75 and it falls to 72, nobody will complain. If it goes up to 78 or 79 or 80 (nobody will complain)\textsuperscript{64} Many steam buildings are turned on in the Fall and off in the Spring, as described above. Virtually none of the buildings have time clocks on their heating. Those that do have long thermal lags because of their high thermal mass, so they tend to stay hot will into the evening. They are heated twenty-four hours daily. In addition, the dormitory towers have architectural problems, as described above. Finally, the steam heated buildings are generically difficult to control irrespective of the control system used.

Some of the buildings have temperature controllers, but these are often broken. This is apparently because the feedback system for the operators is such that they can use two operating rules:

"Do whatever is possible to first of all, minimize work, for myself, and (second) to make me look like a hero as much as possible. Now I'll translate what that means. That means don't fix anything that's broken unless somebody is complaining about it. And if possible, it's nice to have control systems that require your constant tweaking as long as it's only a simple, open the valve, close the valve, 'cause then you can look like a hero. Somebody calls, 'Oh it's too cold, it's too cold. Call Joe, call Joe.' Joe comes. 'Not to worry' and he opens the manual valve that bypasses the control valve 'cause he's never fixed the control valve. The building heats up, it's wonderful. 'Oh thank you Joe, thank you Joe, you're our savior.' Two days later the weather changes, the building is too hot. Joe says, 'Not to worry.' He comes back and closes the valve. He keeps on walking back and forth and (opening and) closing the valve but he never repairs the control valve."\textsuperscript{65}

\textsuperscript{53} Energy management system designer

\textsuperscript{54} Energy management system designer

\textsuperscript{55} Energy management system designer
c) Standards

Temperatures are set high to avoid complaints. In Winter, buildings are heated to about 75°. They try to control the heat to within about three or four degrees of that. The temperatures are controlled by two standards; the Massachusetts habitation standard, which sets a minimum temperature, and the federal standard which sets a maximum. However, they are always above the federal maximum. In some buildings, temperatures are uncomfortably high. One building is at 80-85° from Fall to Spring. They were unable to control it with a heat timer. Another set of buildings are traditionally cold. They are only heated to 65°, and no one complains.

With the new control systems they hope to drop the temperatures to 72° with a spread of about a degree in the water heated buildings and a few in the steam heated. At night, they hope to set back the temperatures.\(^{56}\) However, the habits of students, when combined with the enormous thermal masses of the dormitories will probably prevent going to 64°. By dropping the temperature, they think they will be able to close all of the windows that are open in Winter (the major source of heat loss). They think that once they have closed all the windows, the savings from an extra drop in temperature from 72° to 68° would be marginal. Even if it weren't, they do not think they could bring the buildings down to 68°, even if they had tight enough control. They fear there would be an uprising. There is a strong expectation that the campus will be warm, as the following two anecdotes illustrate.

"So "Eric" bought some heat timers and we were calibrating them ... Once they went in the students came back from intersession. ... I remember getting a call, this particular student said he was freezing to death. It was part of my job, that the technical consultant in housing had to go to his room and find out just how cold it was and that kind of thing. And this guy sitting on his bed in his underwear, said, 'it's cold in here.' It was like 70°. The thing was working perfectly. His window was closed. But the guy was just used to

\(^{56}\) They currently do some setting back with the heat timers.
being like 85° and he couldn't stand the idea that he has to wear his clothes."

"(The Energy management system designer) and I went out on a call one day 'cause it was so cold in one of the academic buildings, someone was sending their department home. We went through and asked people around the building and we came to a student studying in a room and we said, 'How is it in here, how's the temperature?' And he said, 'It's really cold, I had to close the window.' It was about zero out that day."

It will take some sort of externally imposed standard, like President Carter's in 1976, to bring the temperature down the extra four degrees. However, it will be much easier if they have very tight control on the temperatures.

d) Objectives (Who or What's being controlled)

The new energy management system seeks to control three distinct groups; the equipment, the maintenance staff, and the users.

Equipment control will be improved in two respects. First, Frank Andrews has placed an absolute criterion on commissioning that all the dampers have to be complete and working, all the damper motors have to be working, all the fans and pumps have to be working, and all the filters have to be cleaned. In other words, all of the systems have to be working completely before they can be automated. This is probably where they will make one of their biggest savings. Second, once the equipment is working, it will control temperatures as designed. This is discussed above.

Maintenance staff will no longer be able to get away with not fixing things that are broken. If they alter any of the bypass valves, it will show immediately on the computer. If they fail to fix something, the computer will continue to tell you it is broken. Unlike the pneumatic systems, this technology is alien to the mechanics and is

57 Housing department central office manager
58 Eric Hartley
maintained by a completely different part of the Physical Plant Department. (The fire services shop) Even if they tried to alter a controller, it would show immediately. It is not that the new computer will tell what's broken, it's that it will continue to tell what's broken. "I already know it's broken. I can walk around campus and know what's wrong. We have enough people around here who know what's wrong. I don't need to spend $500 000 to tell me what's wrong." However, the new system will tell you what is wrong much more quickly, independent of changes in the environment, and independent of someone claiming to have fixed it.

For the users, the control is subtler. They will no longer be able to request extra heat and have windows open. In some of the buildings there will be good enough control to prevent that. However, in others, particularly those heated with steam, they won't do so well. One of the problems is that the taps in the rooms are on/off, and not metering, so the users cannot control local temperatures very well. Notwithstanding, in the heat timer program they did manage to close windows in most of the buildings for a period, before maintenance started to slip again.

2. The New Large System

As part of its computerization, the university is installing a large computerized energy management system and a series of smaller microcomputers. The installation of the large system is phased. The first phase was let to Johnson Controls in January 1988. Later phases are funding dependent, so their timing and contents were unknown at the time of the interviews.

The large energy system is being funded with a $750 000 grant from the state and a capital contribution from the dormitories. The smaller system is costing $225 000.

59 Frank Andrews

60 The steam heated buildings are being managed on the "small" system.
and is being paid for with an $80 000 grant from the state, some matching funds from the Vice Chancellor’s office, and $45 000 from the operating account.

a) Design Process

The energy management system designer was hired about three years prior to the interviews, with a Professional Engineer certification and a master's degree, to design the energy management system. However, he spent his first nine months working in the engineering division (of the Physical Plant Department), designing plumbing and HVAC systems. Prior to that he worked for two years as an energy consultant, performing audits and the like. The design took about two years, but he had other responsibilities. Construction will take a year.

Contrary to state norms for a project this size, the energy management system was designed in-house rather than by a consultant. Physical plant management felt that there would be so much work involved in telling a consultant what they wanted that it would be easier, and better to do the design themselves.61 It was also designed in the operations division, and not in engineering. They feel they ended up with a much better design than one of the large consulting firms would have produced. The contract came in under budget.

Throughout the design, the designer has tried, as much as possible to involve the staff from the shops:

"Throughout the design process I've made an attempt to involve our building operators as much as possible. First of all, asking them about existing conditions, what works, what doesn't work, the

61 i.e. Two sets of information had to be brought together; technical information about the nature of the engineering systems etc. and specific information about the locale. When you hire a consultant you are assuming that the technical information and skills she has are more important than the contextual information she doesn't. In this case, the local information was harder to acquire than the skills, which could be bought on the job market. In-house design had the additional advantage of strengthening and broadening the plant's engineering base.
manner in which we currently operate our buildings, asking them for their advice on what would be a good way to operate it with a computer. And I would like to involve them also in the day to day operation of the computer system. ... I want to encourage them to use it as a diagnostic tool, as a monitoring tool, to make their work easier."

Rather than being worried about resentment of the energy management system from the shop floor, he appeared more concerned that the staff would not make the most of it.

b) Phasing

The first phase of the project consists of twenty-three water heated dormitories and three academic buildings. Dormitories were selected as the principal beneficiaries of the project. Their financial independence enables them to raise some money to fund it. This was combined with other monies from the state and the university. They hope to expand the system as money becomes available - this is the priority energy conservation program for the next few years. Money will either come from regular operating funds, or it will be appropriated.

c) Phase One

(1) Hardware

Johnson Controls almost certainly won the contract with a surprisingly low bid. At the time of the interviews, the deal was still being finalized, so it was unclear what equipment they were going to use. The designer had wanted multiple source the hardware, to guarantee future flexibility, but as Johnson had a promising new generation of hardware about to be released (but not for this contract) he wasn't as worried as he'd been. While they were almost certain to be using the old-generation equipment, he was
trying to avoid their old Texas Instruments head-end computer, with its 85 lbs hard
disk.\footnote{I would imagine this could be very difficult under the state system.}

The central computer will serve a supervisory function over the remote panels.
It will log data, record alarms, and provide a point of central access to the field panels.
Every building will have at least one field panel, most will have more. Each main group
of mechanical equipment will have its own field panel capable of functioning on a
stand-alone basis. All of the dormitories have four or five zones (although they are
being maintained as if they only had one). These are all getting one field panel for the
main mechanical room, as they are relatively simple buildings. The academic buildings
each have five or six mechanical rooms. They are getting one panel for each mechanical
room plus one for the rest of the building.

(2) Other

The contractor is required to produce all construction drawings on a computer
drafting system, and provide the university with hardware and software to use the
drawings. The Physical Plant Department is not interested in going to a facilities
management spatial database to manage the equipment. In addition, the contract
includes software to time the operation of individual pieces of plant. The new
preventative maintenance system will be built around that output.

The energy management system will be maintained by the fire and security shop,
which is experienced in the maintenance of micro-computer based fire alarms.

One pivotal part of the installation contract is Frank Andrews’s insistence that all
systems be in good mechanical condition when computerized control begins. The
designer has identified a string of problems in the contract; worn steam valves, broken
dampers, damaged temperature sensors, and so forth. These have all been written into the specification. In addition, the contractor must identify anything else that is wrong. These will probably be fixed as a contract variation.

4) Commissioning

The energy management system's central operations desk will be in a highly visible spot in the Physical Plant Department's operations division. Initially, and probably later also, system changes will be made there, rather than at field consoles, so they can be documented and controlled. However, operators will be able to perform system diagnostics from terminals around the campus. Similarly, the housing office operators will have access to the system. Only a select number of people will know how to program the computer; many more will be able to change temperatures and schedules. Since preventative maintenance is going to be computerized and tied into the operation of the energy management system, it will be controlled from the operations center also. Other physical plant functions that fall outside the operations division, such as work order management or dealing with users, will stay outside. People will be rotated through the system operation job, so anyone who wants to spend a couple of months operating the computer will be able to. Similarly, people will be encouraged to come in and see what is going on throughout the day or night. The operations center will be sufficiently staffed so problems with either the control system or the energy system can be addressed as they occur, rather than being deferred.

While the energy management system designer is a little anxious about worker obstruction to commissioning the system, he anticipates some trouble but is "new enough ... and naive enough to know that I think that I can get people to work with me rather than against me." Eric Hartley is much more confident:

"I don't think it's going to get stuck because a lot of it depends on personnel and I just don't see that happening here. We've got a relatively new director of physical plant who's 100% behind this. He
worked for a private place and he helped set it up, so "Frank's" very much into it, and (he's) not afraid to train new staff, either. He's not going to stand in our way. And that's pretty much true all the way down the line. There's not a lot of resistance to changing things right now. There's not a lot of resistance to trying something new so I don't see people getting in the way. Organizationally, we sort of have it all. Organizationally it can't be much of a problem because we've got operations, we've got maintenance, we've got the energy management function, we've got the electronics technicians, they all report to me. Maintenance will be reporting to me ir a few days. So they all report to me, so it can't be a big problem"

When asked if he thought the fact that he controlled all of the relevant staff just as the energy management system was coming on line was a coincidence, he replied, "No ... Someone's done it that way. We've worked it out that way."

As they commission the energy management system and start bringing the temperatures down they anticipate that there will be problems which they will have to fix. So, rather than the system coming on suddenly, they are going to lower the temperature slowly and deal with the complaints as they occur. This will probably require several people from the Physical Plant Department to go across to housing on contract to seal windows and fix radiators, as the job will be too big for the regular staff. This will require a lot of service people to spend a lot of time visiting rooms. Hopefully, by the start of the first Winter the problems will have been sorted out.

The users will not be told that the energy management system has been commissioned. As the housing office interviewee said, "If you do an outreach program, you wind up reaching the people who won't complain anyway, the kind of concerned people....the people who are going to be a pain in the ass aren't going to pay attention and they're going to be a pain in the ass regardless." He added later,

"I think we're just going to do it and deal with the complaints as they come in. We used to do that with our intersession program; send a letter out to the whole campus community saying we're going to be turning down the heat in all these buildings, if you have any problems let us know. We needed three full time people, practically, to deal with the people who called up and had complaints. Now we do it and don't tell anybody about it and we hardly hear anything."
(1) Training

Having observed the failure of many energy management systems while working in industry, Eric Hartley and the energy management system designer are devoting a lot of effort to ensuring the staff are happy with the machine. The see themselves as having a much easier job than the installers of the SDS for several reasons. First, many of the operators now have computers at home, so they're a little more familiar with the technology. Second, the direct digital control technology is not overlaid over the top of the control system, as the SDS was; it is the control system. They are forced to make it work. Finally, because the university had massive expansion in the 1960's, large numbers of staff who joined then are retiring. So, the work-force is getting younger and there's very little resistance to the new technology.

However, they are trying to incorporate everyone into the energy management system as it comes into service by having an ongoing training program. Training is included in the contract for the system and is being offered to virtually anyone in operations, maintenance, the electronics shop or the fire shop who wants it. In effect, everyone except the most resistant will be trained. Most will be trained in relatively simple operations such as reading a temperature schedule, more will be able to change temperature schedules, and a few will be taught how to program.

3. The New Small System

In addition to the large computer system, they are fitting 63 steam heated buildings with what they call the small computer system. The buildings affected will be 30 that had the original heat timers plus 33 additional ones. The buildings generally have very simple systems, often just a single valve on a steam line. So, they don't need something as complex as offered by the large energy management system. About 20 of
the buildings are more complex, having air-handler and the like. They will probably be up-graded in the future. However, these cheap controllers provide a good stop-gap.

The unit they intend to use costs about $1000 ($2000 for a building system including sensors, modem, etc.). It will accept eight inputs, such as temperatures and flows, and stores complete histories for two of them for 48 hours. It also stores 35 days of minima and maxima for all eight. It has eight output tracks, so it can control eight pieces of equipment. Something based on a personal computer would be excessive for the job they have here, and the PC-based systems are more expensive. The controllers will be hard-wired back to the central computer and accessed daily by telephone. The day's data will be dumped into the main energy management system so it can be analyzed.

C. CONFLICT BETWEEN THE WORK ORDER AND CONTROL SYSTEMS

As we have seen, two different systems, both designed to manage information about the operation of the plant, are being developed simultaneously. On one hand, there is a work order system that is designed to take information from human sources and computerize it for output to the shops, principally in the operations division. It will be operated, 24 hours per day, from a desk at the front of the Physical Plant Department by the General Services Division. On the other hand, there is an energy management system, designed to take information from telemetric sources and computerize it for output to the shops, all in the operations division. It will be operated, 24 hours per day, from a desk at the back of the Physical Plant Department by the Operations division.

In many cases, they will be processing the same information. While plugged toilets and broken windows will not show on the computer screen, cold rooms will, as temperature alarms, broken motors, or whatever. Several people in Operations were
asked about taking on the general desk function. They were not interested. So, ignoring the fact that there will be people sitting up all night at opposite ends of the same building, there is a conflict emerging. Calls will come in and alarms will sound. The energy management system operators will want to dispatch people to deal with the problems, but will be forced to go through the work order people. The work order people will want to control the dispatching. Since there will be time lags, there is a good chance there will be multiple work orders for the same task as the work order people have written the work order and sent someone while the operations people have sent someone and written the work order. Alarms will be printed out by one computer and then typed back into another. Similarly, the preventative maintenance work orders, while not inherently presenting a conflict, will be generated on one machine, carried to the other end of the building (either figuratively or literally), and typed into another. The net result will be that even if the system works as planned, the principal source of work orders for the work order desk will be the operator of the energy management system. This could create internal conflict.

When asked whether she thought this conflict was due to a political problem, the systems analyst replied,

"...generally speaking, my experience in terms of trying to automate anything, where someone, usually the person in charge, wants to centralize (a) mass of information, is that generally the people underneath don't want it centralized. What they want is their own information separately but of course access to everyone else's information."

She added that there were other issues endemic to the Physical Plant Department, particularly the fact that work orders had been recently moved from Operations to General Services.
APPENDIX E. TUFTS

I. INTRODUCTION

A. THE CAMPUS

Tufts is a relatively small but highly diversified university with about 7,600 students on three campuses in Boston, Medford, and Grafton. The Medford campus, the focus of this study, houses the bulk of the School of Arts, Sciences, and Technology (4,500 undergraduates, of whom 3,000 live in university housing, and 800 graduate students). The Fletcher School of Law and Diplomacy has about 250 enrolled students. The School of Nutrition, based at Medford, is responsible for programs carried out within the other schools. The Boston campus houses the schools of dentistry and medicine and related sciences, while the Grafton campus contains the school of veterinary science. Annual operating expenses exceed $180,000,000, and the endowment is valued at about $95,000,000 (1987).

The Medford campus contains fifty major buildings, 60% of which were built since 1945. There are about 110 others that are converted houses, generally two story. 53 of these are owned by Walnut Hill Incorporated, a financially separate subsidiary of the university.¹ There are 2,000,000 square feet of space on the campus.² 41 dormitories take up 20% of the space. Nineteen of these house more than twenty students, and twelve house more than 100. There are about 112,000 square feet of high

¹ The company was formed so that Tufts could purchase properties without altering the local tax base.

² Excluding the Walnut Hill properties.
energy use space (laboratories, animal quarters, greenhouse, data processing, infirmary bedrooms and laboratories - excludes kitchens)

The Walnut Hill Incorporated buildings are maintained by the Physical Plant Department. Typically, they are converted houses (up to 100 years old), with old oil-fired furnaces in the basement and one thermostat for the entire building. Heating is often uneven with the upstairs being hot and the downstairs cold.

B. COMPARISON WITH OTHER CASES

Tufts is the smallest of the universities examined in this study. It has a level of centralization between that of MIT and Harvard. *Per Capita* it has a smaller Physical Plant Department than the others because of its contracting policy, although it has a large custodial staff.

Note that data collection at Tufts was frustrated in two ways. First, its small size limited the number of potential interviewees. Second, two or three important potential interviewees refused to be interviewed, and others objected to being taped. So, while MIT and Harvard had about 20 interviews each, Tufts had only twelve, of which seven were taped. However, four of these, of which two were taped, were of less than twenty minutes duration and were with people not central to energy management. Furthermore, the key informant left the school before the thesis was completed. This prevented checking of some minor facts and the informal follow-up interviews which add some depth to the other cases. It also means that the school has not reviewed a draft of this appendix.
II. ORGANIZATION

A. OVERALL STRUCTURE

Tufts' schools are financially separate. They raise their own fees and pay their own operating costs. However, unlike Harvard, they obtain all of their support services from the central university or from the school of Arts, Sciences, and Technology (which provides health, child-care, athletic and similar facilities at Medford). They do not have the option of duplicating services or of purchasing them outside. Consequently, the Physical Plant Department supplies all physical plant and energy services.

The Physical Plant Department reports to the Vice President of Operations, who in turn reports to the Executive Vice President. Reporting to him are the Directors of Buildings and Grounds for the three campuses, (There was an Acting Director at Medford at the time of the interviews), a Director of Construction and a Director of Energy Management (Steven Rice). Virtually all of the Physical Plant Department staff report to the Director of Buildings and Grounds. The Director of Construction manages a small staff of project managers (five), while the Director of Energy Management has no staff and no budget. There are three professional engineers in the Physical Plant Department; two civil engineers in construction and the Director of Energy Management.

The Buildings and Grounds comprises four groups; grounds, custodial services, project management, and services and trades. Services and trades is headed permanently by the assistant director. He has three people reporting to him. They are a services supervisor who runs the office and two trades supervisors. These shops are responsible for mechanical, electrical, plumbing, locksmith, painting, and carpentry. There is only one HVAC mechanic on the Medford campus and two unfilled HVAC mechanic positions. Similarly, they also have only one painter.
Peter Cebon (1990)

B. THE PHYSICAL PLANT DEPARTMENT

1. ENERGY MANAGEMENT

A) The Energy Manager

The energy manager works with the directors of each campus to exploit the energy conservation potential of their facilities. He also works with the construction department on plan review, and with the budget department on utility cost projections. He provides technical expertise to the Buildings and Grounds sections on the three campuses, and ensures that equipment is installed in a serviceable manner. He also randomly checks that equipment is being maintained and operated properly. He is trying to get involved in systems modernization and in training. As stated above, he has no budget and no staff.

Mr Rice sees the lack of staff under his control as more than simply an issue of status in the organization. He perceives a generic shortage of staff and feels this mitigates against him making claims on resources. He cited the example of having to wait a year-and-a-half before he could get a plumber to redirect a pipe for him so he could get better heat recovery out of a system.

His job goes well beyond energy management. First, he is the only professional engineer outside the construction division of the Physical Plant Department. So, he does all of the systems analysis on the campus. He feels that being the only professional engineer is a mixed blessing, since it makes him a major source of information on one hand, but he finds that there is a lot of resistance to his proposals from other managers on the other. He feels they take longer to appreciate some of the subtler technical arguments than they would if they were technically qualified. Consequently, some projects get lost while others take an unnecessarily long time to be approved. In other situations, he feels that poor decisions have been made. For example, the feels that
direct digital control equipment should have been appearing on the campus long before it actually did. Only recently has senior management is starting to appreciate its lower life-cycle cost.

Second, he is the only person, other than the Director of Physical Plant, with an interest that spans all of the plant's functions. The Director has other concerns, so he sees his role as an integrative one, tying construction to operation, training to maintenance, maintenance to energy, and so forth.

As part of his training initiative, Rice hopes to bring regular video tapes, such as a course on pneumatic controls, to the Physical Plant Department. There are many other video tapes available for free. He has had limited success; the other managers have not been very enthusiastic.

B) The Energy Management Program

After the price shocks of 1973, Tufts did a lot of simple things to conserve energy. For example, they connected flashing lights to thermostats and turned the heat off at night. Then, if a building became too cold, the light would flash and the police would come and turn the heat back on for a while. Similarly, they down-sized lights throughout the campuses (40 Watt tubes to 34 Watts and so forth). This down sizing met with a "tremendous amount of resistance from researchers", particularly in the Medical School. The residuals of those objections still influence energy management policy strongly. This is discussed later.

To obtain a surrogate measure of steam consumption, they installed counters on the condensate return pumps. These would count whenever the pumps went on. This had two problems. First, collecting and analyzing the data was a big task. It took one

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3 Steven Rice
person all his time to read the counters on 30 pumps and aggregate the data. Second, the data were very poor measures of consumption because it was impossible to tell how long the pump was going on for. A pump running virtually continuously would register similarly to one that hardly cycled at all. Later, they installed heat recovery equipment in some of the buildings.

In 1979 they installed a supervisory computer control system funded with a $200,000 Department of Energy - Institutional Conservation Program (DOE-ICP) grant. They also received other DOE-ICP grants, including a large one ($60,000+) to look at steam traps. They used the money to replace 268 traps and insulate 250 valves and fittings on steam lines. They also retrofitted one air handler’s dampers and controllers so it could be operated from the central computer. In about 1985 they went back and re-inspected the ICP steam traps and about 370 others and made an inventory. The inventory includes all but about forty traps on the campus. Similarly it excludes about 100 radiator caps. It is the only inventory of equipment that the Physical Plant Department keeps. In the near future Steven Rice would like to re-survey the traps and assess their maintenance needs. He thinks it is likely that they will need to take on extra staff to maintain the traps, and that justifying another employee will not be difficult.

At the time of the interviews they were progressively retrofitting lights. They were changing incandescent light bulbs in public places to circuline fluorescent fixtures indoors, and low pressure Sodium outside. This was costing about $60.00 per fixture. Rice hoped to raise money through the electric utility (Boston Edison) to change ballasts on fluorescent lights. They will clean the lights and replace the current ballasts with optimizer models.4 Electronic ballasts were unjustified at the current price. It is not

4 An optimizer ballast (cost $20.00) differs from a standard ballast (cost $5.60) and an electronic ballast (cost $65.00) as follows. A standard ballast is a step-up transformer which raises the voltage in the tube whenever the tube is switched on. The optimizer ballast exploits the fact that the elevated voltage is needed only to strike the arc across the tube initially. It raises the voltage only until the arc
that they are not necessarily economically justified, it is that the savings with the optimizer are large enough that the extra money is better spent on more optimizer ballasts than on electronic ones, so I was told.

C) Impediments to Energy Conservation

The Director of Energy Management feels that one of the big impediments to effective energy conservation, in addition to the lack of staff and finances under his control, particularly at the Boston campus, is the lack of sub-metering; that is metering at the laboratory level. He feels that, despite its cost, it is vitally important, at least at a demonstration level. It would enable measurement, not just calculation, of savings. He thinks savings must be demonstrated because people think that conservation options identified in other places are not necessarily effective at Tufts. Hence, sub-metering has much more to do with measurement than billing.

The Boston campus includes 50 or 60 high energy-use laboratories which consume about the same amount of energy as the entire Medford campus. Each is fitted out by the researchers, who buy their own equipment but pay for energy in proportion to space usage. This creates a mismatch of incentives. The university can retrofit at its own expense and charge the cost to overhead. Following the problems with the lighting retrofits of the mid-70's, the Physical Plant Department staff are very hesitant to do that without strong support of the Dean (of Medicine or Dentistry as appropriate). Therefore, they must show savings to do anything. Gross consumption data don't show savings from individual retrofits.

Rice observes a conviction at the school that every academic is a Nobel laureate, or will be soon. These Nobel laureates reputedly have extremely short tempers and are

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strikes, and then returns it to a lower level. An electronic ballast is the same as an optimizer ballast, except it also raises the cycling frequency in the tube. This increases the proportion of light in the visible range.
likely to "pack up and go to some other institution" if you ask them to do things like tolerate retrofits. While this may be true for a few academics, it isn't true for all. If sub-metering were available, the Dean would have the option of deciding on a laboratory by laboratory basis, to do nothing, to retrofit certain laboratories, or whatever.\(^5\) Similarly, systems could be developed to reward conscientious faculty.

At the Boston campus, they have also done fume-hood retrofits where they have replaced fans and ventilation systems. Steven Rice wanted them to install microcomputer controllers on the hoods, but was unsuccessful. As he sees it, the faculty were not interested because they would only reap a very small proportion of the savings despite having to pay all the capital cost.\(^6\) Simultaneously, the safety office, which mandated the work in the first place, was not interested because their interests are better served if the hoods maintain full flow throughout.

Smaller capital projects are generally financed by the person who controls the space (generally a researcher). Because they pay their utilities on the basis of floor area, and not consumption, they have little incentive to install expensive energy conservation equipment (like the microcomputer controllers on fumehoods above) when they are retrofitting. The university does not impose retrofit standards on them. Consequently, many savings are lost during refurbishments.

The Director of Energy Management described another instance where metering would have been useful. When a laboratory building was built, about a year before the

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\(^5\) The interviewee appears to be saying that he feels that by sub-metering, the Dean, who is responsible for costs and accountable to the faculty, can be given a costed proposal as a basis for decision; enabling a sensible decision to be made. Without the sub-metering, the Director of Energy Management has to take responsibility for the project, even though he is not accountable to the faculty.

\(^6\) The cost per hood would be about $1500. The savings per hood would be about $1000 annually of which the individual researcher would receive about $20. The rest would go to the other researchers.
interview, he had fought for heat recovery equipment, and lost. He did manage to persuade them to leave space for it, however. At the time of the interviews he was waiting to meter the building, and run it without heat recovery for about a year before installing the equipment, so he can demonstrate the savings. He saw the need for this very conservative approach when the heat recovery unit in another building was thrown out because it was difficult to maintain. Since there was no way of measuring the energy it saved, the Physical Plant Department didn't appreciate its value.

2. BUILDINGS AND GROUNDS

A) Service Provision

Energy services are provided according to schedules and controlled by the computer. There is no setting back of temperatures in the dormitories, because students tend to be up most of the night. For the rest of the campus they reduce the steam pressure at night. There is a pressure reducing valve, installed when they built the system, at the entrance to each building. By partially closing that valve they can get reasonably good setting back at very low cost.

B) Operations and Routine Maintenance

Buildings and Grounds operates on two budgets. The operations budget, which comes out of overhead, provides for a 'warm, safe, clean environment'. All other requested services, retrofits, refurbishments, etc, come from departmental accounts. Operations work involves repairing or replacing broken equipment. The shops are mandated to "just keep it going. We just repair what's broken." Broken Electrical

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7 The system was designed to operate at high pressure, though it doesn't. Consequently, the pressure reducing valves at the entrance to each building, that are not needed for their intended function, can be used for energy conservation.

8 Shop supervisor
equipment is generally replaced with equivalent stock. So, for example, if a fluorescent tube expired, they would not re-ballast the fitting, but may replace it with an ‘energy saver’ tube. If the ballast goes, they will then consider a better one. Similarly, new motors are the same size as the failed motors they replace. While they may consider using a high-efficiency model rather than a standard one, they won’t see if it needs to be re-sized.

Maintenance at Tufts is divided into two broad categories. Part of the work is carried out by the staff of the Physical Plant Department, working in the two shops, plumbing and heating, and everything else. However, work that ends up in the wrong shop is often completed by that shop anyway. The rest is carried out by external contractors. Management’s intends to move more and more work to contracts.

The work done in-house was described by several interviewees as fire-fighting. The work mainly involves responding to calls that come in, mostly over the phone (100 calls daily) but sometimes on the computer. The calls come in through either the housing office (not the dormitories), or through a designated person (curator) in each building. Except in emergencies, users are not supposed to contact the Physical Plant Department. In addition, the custodial staff will identify problems, particularly plumbing problems, that need attention.

The curator generally has other administrative responsibilities, and may change from year to year in a particular building. Other than calling in problems, they interact with the Physical Plant Department only occasionally. The shops approach the curators only when there is a consistent set of complaints coming from a building, and they cannot find the cause. Then, either a mechanic or a supervisor will work with the curator to find the source. None of the buildings, even the seven story Cabot Center, is

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9 C.f. 250 calls daily at MIT.
so large that they feel they cannot deal with all the problems through one curator. If these sorts of problems arise in the dormitories, they will work through a head resident.

There is only minor concern that people will give up if a problem is not fixed after a few calls. Interviewees felt Tufts is small enough to get around that problem. There is only one person who takes calls, and he can pick up most repeats; either second or third calls from the same person or the same call from different people. In addition, the shop supervisors review the day's work slips every night. Staff make notes on the slip. They are expected to describe the problem and the solution in detail and in a useful form. They generally do so. So, if a building is without heat, they are expected to say why and what they did to fix it. If a systemic problem is identified, they may call in a contractor to investigate. For example, a building that is consistently cold may have problems with its sensing equipment or with its HVAC system. Since they don't feel confident testing the sensory equipment, they prefer to invite a contractor. Occasionally a problem will "fall through the cracks." The faculty generally resolve these with a quick call to the Vice President for Operations.

The work slips are generated by an operator on a computer. They go from the computer to the supervisor. The supervisor hands them out to the shops which allocate priorities. Once a slip comes to the top of the pile it is given to a mechanic who attends to it. If she completes the job satisfactorily, that is written on the slip and it is returned to the computer for cancellation and then given back to the supervisor for evaluation. If she cannot fix it, it goes back to the computer to be re-issued, and the original goes to the supervisor for assessment. If the supervisor has any queries he will take it up with

\textsuperscript{10} It is interesting that this control device is different from but equivalent to the one adopted by MIT and The University of Massachusetts at Amherst to manage their staff. There, the direct digital control system is used to make sure the staff do a good job. Here, within the rubric of facilities management, the staff are forced to do a good job by being made accountable.
the operator concerned. Once he has finished with the slips they are either sent back to
the computer to have the comments typed into the records, or they are thrown away.

The shops claim they have insufficient staff to do a decent job. While people
can keep the equipment going and do day-to-day work, they have no time for any sort
of preventative maintenance program. So, while there isn't a pile of work slips
mounting somewhere, they feel there is a quality problem. Equipment failures are
causing unnecessary discomfort and wastage. This does not make the equipment
uncontrollable in any way, however. They can operate it satisfactorily once it is fixed.
It just breaks down a lot. Apparently, senior management feels that they are over-
staffed because "you've gotten along with this much help all these years."11 The shops
believe this is fallacious because "The place is not only growing, but a lot of stuff has
been let go. We've been patching things up and taping things up just to keep things
running."12 A union representative noted that management would prefer marginal
understaffing to overstaffing since it is much easier to put people on than to lay them
off. Similarly, it is good for morale if there is consistent overtime available. If they
could persuade management, apparently it would not be difficult to create extra staff
positions.

The rest of the equipment is repaired under contract. The contractors have a full
maintenance contract for the equipment. They are expected to keep it running and to
come out to the campus for emergency calls. This approach is being used on all new
prime moving equipment that is being installed (chillers, air handlers, heat recovery
units, etc.) and the energy management system. Management believes they pay
marginally more for this than if they performed the work in-house. However, they have

11 Shop Supervisor
12 Shop Supervisor
seen a 75% drop in the number of heat and cold complaints since this approach was adopted.

The contractors are required to completely overhaul the equipment annually. At the start of the heating or cooling season (as appropriate) they must start it up and test it. They must check it at mandated intervals (one to three monthly depending on the equipment.) There are similar contracts for the filters, with checking frequencies of two weeks to three months and replacement by trial and error. This contrasts strongly with before when some filters were changed only four times in six years.

Management spot checks the quality of this work. Good contractors are very difficult to get, and every new contractor must re-learn the systems. However, over the past few years they have identified some reputable firms and have had little bother with troublesome people. One criticism of this that was raised, however, was that the authors of the contracts know little about equipment maintenance, and so they don’t write good specifications. This is compounded by the fact that while it is relatively easy to see if work is satisfactory, it is extremely difficult to check it to see if it is good. Similarly, it is hard to differentiate insufficient from mediocre work. While there was little suggestion that the contractors' work affected energy conservation directly, at least one interviewee felt it significantly decreased the organization’s ability to learn about its own systems and therefore bring about any systematic optimization or coordination of equipment.\textsuperscript{13}

Tufts has been forced into this approach because they cannot retain HVAC mechanics on the staff. At the time of interviews, two of the three positions on the staff were vacant. One had been vacant for six months, for the third time in three years. There are two distinct schools of thought (and one between them) to explain this

\textsuperscript{13} See chapter four
staff retention problem. Senior management argues it is simply a problem of wage differentials between the university and the booming external construction industry. Tufts pays HVAC mechanics $14.00 per hour ($18.00 - $19.00 including benefits) while the building industry offers $18.00 - $19.00 (if you ask the union or $22.00 - $24.00 if you ask management) without benefits. Staff prefer the higher wages and lower benefits, according to management. The union offers the intermediate perspective. It believes that wages are about comparable once benefits are considered and that there is no retention problem because people prefer the stable environment of the university. However, given the boom, they do have trouble finding people. The third view, offered by at least one interviewee, is that there is significant animosity between union and non-union staff (management). This has led to a mutual lack of respect which in turn has created a poor work environment. When this was combined with other on-the-job problems, such as workers on the afternoon shift being unable to get spare parts because the store was closed, they started looking new jobs. When they left, they used the excuse of higher wages which management chose to accept.

C) Preventative and Deferred Maintenance

With the exception of the overall maintenance contracts on the major equipment, there is very little preventative maintenance at Tufts. "We're in the fire fighting mode, not the preventative maintenance mode ..." What little preventative maintenance that is done on the campus is done by contract. The Director of Energy Management believes this lack of preventative maintenance is a major impediment to energy conservation.

First, he thinks it removes all organizational slack which could be used to solve energy

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14 I accord this little weight for two reasons. First, the interview was short and was conducted over the telephone, so the interviewee had little reason to trust me. Second, there were factual errors in the analysis. For example, the interviewee claimed there was no staff retention problem. Similarly, he could not name the mechanical shop supervisor.

15 Steven Rice
management problems (as with the plumber problem given above). Second, he feels a preventative maintenance program would allow costs to drop because a systematic and organized preventative maintenance program should be cheaper in the long run than random fire fighting.\textsuperscript{16} Finally, well maintained equipment runs better, lasts longer, and uses less energy. Notwithstanding, it would be very easy to determine the cost-effectiveness of a preventative maintenance program by comparing the operating cost of a few buildings, with and without a preventative maintenance program, over a couple of years.

The lack of preventative maintenance has led to difficulties with the systems. There have been simple control problems, such as trying to operate buildings with dampers that won’t close properly. Unfortunately, there have also been some very expensive ones. For example, one building had its HVAC system retrofitted to improve control. The system soon became uncontrollable with rooms overheating and hence windows opening. Its pneumatic control system was driven by a compressor which was supposed to be drained of water and have its oil filter changed frequently.\textsuperscript{17} They investigated and found that the compressor had not been drained regularly. Water had gotten into the pneumatic lines and thermostats, causing several thousands of dollars worth of damage and making the whole system useless.

\textsuperscript{16} ANALYTIC NOTE: This is only partially true. By instituting a preventative maintenance program you will reduce the ‘random’ cost of having a ‘fire-fighting’ program. You would also increase plant life (which may not be beneficial if 1) technology is changing for that equipment, and so efficiency is increasing rapidly, or 2) load is decreasing and so the equipment is becoming sub-optimal) and reduce fuel consumption. However, virtually by definition, you will also spend time doing some unnecessary maintenance. Similarly, without the feeling of crisis, staff may not work as hard. If the unnecessary maintenance could be avoided, and staff maintained their work rates, total cost would (theoretically) drop.

\textsuperscript{17} As air is pressurized, the solubility of water vapor decreases. Consequently, compressors give off water as a by-product.
Peter Cebon (1990)

The Physical Plant Department has recently asked the university for a new $25,000 computer system to run its preventative maintenance program. At least one interviewee found this "laughable" since "they haven’t got a clue what they want to do with it." Whether or not this is true is unclear from the interviews. Similarly, it is unclear whether they wanted to bring about management changes with the introduction of the new technology. However, they currently don’t even have inventories of equipment. It appears that the current problem with the preventative maintenance program is not one of organization and work generation, but has more to do with staffing and possibly personnel management. So, unless these management changes are being introduced simultaneously, the critics appear to be correct.

D) Shifts and Other Staffing Issues

Three people, including a plumber and a pipefitter, work the afternoon shift from 3:30 to midnight. They respond to emergency calls. Everyone else works days. There was a larger afternoon shift in the past, but apparently the workers on it were frustrated by the fact that there were no store facilities available, so they couldn’t get parts. Under the current union contract, staff are not required to work an afternoon shift, though management wants to change that in the next agreement. (Present staff are grandfathered into the day shift however.) Management would like fifteen people on each shift. This would reduce the need for equipment, especially vehicles, and it would enable them to get into places that are either impossible or inconvenient to access during the day.

Many Physical Plant Department functions can be filled by students. Whereas five or six years ago they could get students to read meters and do simple analyses, they no longer can. For example, two student positions have been open for a year. It appears that either there are ample employment opportunities elsewhere, or students are richer than they were. The other problem with student employees is that there is a
fairly long learning curve for most tasks and so students, who tend to leave, take a lot of training for limited yield.

3. ENGINEERING

The Physical Plant Department has no engineering section *per se*. Steven Rice is the only person in the plant who has the skills, a formal responsibility for total systems, and a job description which includes those issues. So, it is not surprising that he does all engineering analysis not performed by consultants. He also intervenes strongly when consultants are briefed.

"What I try to do when I get input is require them to engineer, because engineering firms don't always engineer. ... and I try to make sure that analysis is done ... and that options are reviewed and that there's a basis more than just a personal preference for decisions."

As a general rule, replacement of equipment in the plant is not accompanied by resizing and respecification unless structural work is being performed or space use has changed significantly. For example, if the windows on a dormitory have been retrofitted, they may resize the equipment. Similarly, external engineering consultants recently resized the six boilers they recently replaced in three of their plants. There is very little (virtually none) on-going testing of mechanical equipment to see if it is poorly sized, though they have done a little over the years. One senior manager told me that there was no need to do that since 60% of the major buildings were built after the Second World War, and therefore were well engineered.\(^{18}\)

Tufts has no standard specification for briefing engineers and architects. Similarly, it has no design standards (other than a few safety measures) to which engineers must conform. Steven Rice sees such a specification as extremely desirable,

\(^{18}\) This contrasts sharply with virtually every other interviewee at every other campus. They thought the post-war buildings were consistently both poorly and over designed.
Peter Cebon (1990)

and anticipates it would cover issues like maintenance, materials, controls, insulation, light and energy. He sees that as critically important for maintenance because unmaintainable equipment deteriorates rapidly, irrespective of its initial quality. He sees little possibility of converting another university's specification because, after conversion, they tend to be very weak.

Because new equipment is being contracted out, new systems are being designed to be easy to maintain. Therefore, they are mechanically very simple. Similarly, the construction director felt that universities had trouble maintaining complex systems, and therefore would prefer to design them as simply as possible.¹⁹

¹⁹ This suggests a major impediment to effective energy conservation.
III. BUDGETING

Major capital budgeting is discussed under construction.

A. BUILDINGS AND GROUNDS BUDGETING

As stated above, Buildings and Grounds carries out two types of services; buildings and grounds services, which are paid for out of an annual allocation of about $1 500 000 from the administration, and departmental services which are charged. Even though no money changes hands for buildings and grounds services, time is charged against the individual buildings. This is reviewed by management.

The annual allocation includes such things as regular painting and reasonably routine capital maintenance, such as replacement of a certain percentage of the downspouts, windows or steam lines. Finally, during the year the shops will note areas in which they are having problems and will suggest projects to senior management. Some of these are funded. So, for instance, in 1986 they converted three dormitories from steam heat to hot water. In emergencies, this is relatively easily increased.

B. UTILITIES BUDGETING

There is no utilities budget per se. The Director of Energy Management helps the Buildings and Grounds directors project energy costs for the following year. The final projected amount is allocated. If, at the end of the year, there is a surplus, the Physical Plant Department returns it to the schools. The schools can then choose to allocate it back to the Physical Plant Department or to other parts of the university.\(^\text{20}\)

\(^{20}\) This has had an interesting effect on energy conservation. At MIT, the surplus generated when the price of oil dropped in 1984 was used to purchase a better energy management system. At Tufts, in contrast, the drop in energy prices was generally seen as a brake on energy conservation.
Medford’s annual electricity bill is a little over $1,000,000, of which only a few thousand dollars is a power factor penalty.\textsuperscript{21} They spend $600,000 on oil (#2 and #6) and about $140,000 on gas. The total utilities budget is a little over $2,000,000.\textsuperscript{22}

C. ENERGY CONSERVATION BUDGETING

Energy conservation budgeting is often included as an item in the minor capital program for the Physical Plant Department. There is competition for financing, which is generally controlled fairly tightly by the trustees. The energy conservation projects are listed alongside other capital works projects, with their anticipated pay-back in labor and utilities. It is not unusual for the trustees to reduce the utilities budget by the anticipated pay-back. More recently they have been looking towards bond issues, generally issued through the Higher Education Financing Authority, to pay for energy conservation works. It is relatively easy to raise loans and pay them back with the savings. Finally, energy conservation is sometimes financed as an adjunct to other capital works, such as building retrofits. Energy conservation works which can be included within the budget are carried out.

There is no threshold payback for financing energy conservation works. Generally, each case is argued on its merits. A three-year payback would probably be funded without hesitation. Less lucrative projects' assumptions are examined more thoroughly. For example, a change to direct digital control from pneumatics with the assumption that 1) the pneumatics actually work and 2) you will not go to the extra trouble of reasonably tight scheduling, doesn’t pay back (in energy) in less than three years. However, with the added reliability and flexibility of the direct digital control system, it is more likely that the system will operate effectively and that tight scheduling

\textsuperscript{21} A surcharge paid by users with high inductance equipment such as large motors.

\textsuperscript{22} I know it doesn’t add up
will be pursued, so the calculations become fuzzier. In these situations, rates of return become less and less important in the decisions, when compared to other factors.

The reader should note that energy management at Tufts has no budget that can be used to absorb costs and create flexibility. If the energy manager controlled a utilities budget, he could choose to retrofit some equipment and pick up the savings later. Alternatively, he could use preventative maintenance money to replace equipment and improve reliability. As there is none of this flexibility, many projects get frustrated. For example, Steven Rice had spent a year advocating a $4,000 swimming pool cover with an annual return of $7,000.
IV. CENTRAL PLANT AND DISTRIBUTION

A. THE HEATING PLANT

As Tufts expanded across the streets of Medford it had to decide whether or not to run steam lines under the roads. The management decided not to, and so the university has several separate heating systems. Each boiler set powers a circuit of high pressure pipeline joined to the relevant building by a pressure reducing valve. The end result is a very simple system of boilers and pipelines that will happily run itself. The loop which serves the main campus North of Professor's Row has two 700 hp Cleaver-Brooks oil-fired boilers. One of them can meet all of the load 95% of the time. This gives them plenty of excess capacity, and the ability to overhaul one boiler while the other is running. The secondary loop, South of Professor's Row and West of Packard Avenue, has two oil or gas-fired four pass 250 hp boilers. Oil is currently cheaper. To the East of Packard Avenue a hydronic (hot water) loop serves the Campus Center and other buildings. It is targeted for expansion to serve a new dormitory. The biochemistry building and a few adjacent buildings are fired by two old boilers fired with #2 fuel oil. The gymnasium-swimming pool building to the North of the campus has its own four-pass low-pressure boiler. Several of these boilers were replaced recently, and this has made them much easier to operate. The pipelines that cross the campus were designed very conservatively. They are grossly over-sized.

There is little need for process steam at Medford, since the campus has limited needs for sterilization, distillation, cage washing, or other steam intensive process loads. For those needs, there are electric units. Since they don't need high pressure steam, they run the campus at 11 lbs pressure. Low pressure steam has three advantages. First, the high pressure steam has a high exhaust temperature from the system and therefore lower efficiency. Second, high pressure steam tends to entrain a lot of oxygen, so it has to be
deaerated. Finally, and most important, the law requires permanent supervision of boilers with an operating pressure of more than 15 lbs. Smaller units can be left to run by themselves. So, at Tufts, the boilers can all be supervised from the computer. If anything goes wrong, such as rapid or large changes in temperature or pressure, the system alarms and someone is dispatched.

Generally, steam is shut off for the Summer and small electric heaters are used for hand washing. In 1987, for the first time, they ran a boiler for the whole Summer to heat water for the one dormitory that remained operative. For the swimming pool they used to run the steam boilers all year. However, the distribution system was so poorly designed and insulated that it heated the rest of the complex simultaneously. Recently, they converted to a 50 kW electric heater to keep the pool at competition temperature (80°F) for the Summer. Since there is no competition out of term, they decided to let it drift in 1987. The temperature did not alter significantly and they saved a lot of money.

B. CHILLING PLANT

There is minimal chilling on the campus. The chillers are all attached to particular buildings. There are two in the Wessell Library, and one each in the Cabot Center and the Campus Center. Elsewhere the odd building has a direct expansion chillers. Computer areas also have individual air-conditioners. The dormitories that are used for conferences have heavy-duty wiring and special outlets so that portable air-conditioners can be installed for the Summer.

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23 At Harvard and MIT when the subject was brought up, there was inordinate emphasis on the need for temperature control in laboratories. That seems to not be the case here. Part of that is undoubtedly due to the nature of the research. Tufts at Medford is predominantly engineering-oriented. This probably needs less controlled conditions than the life sciences.
C. COGENERATION AND INCINERATION

Tufts decided cogeneration wasn't feasible when it examined the possibility a few years ago. Now that they may be running one of the boilers all year, they are reconsidering. However, there is only one appropriate site, and they only have room for one piece of equipment. They are also considering a garbage incinerator. Since the cost of hauling trash is increasing, and they are currently compacting it on a site adjacent the main boilers, they feel it may be appropriate to burn trash on-site and extract the heat. They anticipate the incinerator would run for one shift daily, probably a one-hour clean followed by a seven-hour burn. It would cool overnight and the cycle would be repeated. If they burnt for two shifts, there would be a need for a much larger afternoon shift to support it. So, instead, in the off shifts heat would be provided with conventional boilers. There are three problems with the proposal. First, the payback is relatively low, six or seven years. Second, there are several engineering problems, particularly separating, handling, and incinerating waste in the limited space available. Third, they feel local citizens may be concerned about the quality of the exhaust the incinerator would emit.

D. BUILDING SYSTEMS AND DESIGN PHILOSOPHIES

The philosophy embodied in the simple system of boilers extends well into the rest of the campus facilities. For instance, the building systems tend to be much simpler than those at MIT or Harvard. Not only do few of the buildings have cooling, but also there is very limited mechanical ventilation in use, except in bathrooms and fumehoods. Similarly, steam is pumped at low pressure, over short distances, through large ducts. While there is a potential problem with high heat loss through large pipes, they have conscientiously insulated. They are happy to heat the dormitories in the Winter and to encourage Summer school occupants to open windows.
Currently, most of the buildings have simple two-pipe steam heating systems. To improve control they are progressively pulling out the old steam systems and replacing them with hot water heat exchangers and hydronic systems. As they do this, they are either putting electronic thermostats in the rooms, or non-electric thermostats in the rooms and electric ones in the zones.
V. CONSTRUCTION

A. THE NEW BUILDING CONSTRUCTION PROCESS

The costing cycle for new construction was well understood by many of the interviewees. When the building is first proposed, a preliminary study produces a preliminary budget. However, there is enormous pressure to come in with a low budget, since approval of the senior administration is needed before a project can proceed. Once approved, money is raised, design criteria are determined and then an architect is selected.

Steven Rice is included in the group that determines the design criteria. He has expertise in operations and energy conservation, especially heating design. At the time of the interviews 25 building heating systems were under design, re-design or construction on the three campuses. Previously, he felt he was not brought in early enough. The construction director feels this has been rectified.

The architect is selected by a construction committee which includes a member of the university administration, a member of the faculty and a representative of the Physical Plant Department. The selection is made on the basis of a costed bid, past performance (at Tufts), and/or known expertise. With the exception of the Engineering Technology Center being designed at the time of the interviews, energy conservation is not a priority in architect selection.

Until three or four years before the interviews, when there was a change in directors of the Physical Plant Department, the rest of the physical plant had very little input into the design of new facilities. After the change, interaction at a reasonably senior level was facilitated. The senior Buildings and Grounds staff are brought in for the initial briefing meetings with the architect and the engineer, where they add their
ideas. The building is designed, generally taking into account everyone's wish lists (which inflates the budget further). When the building has come in over cost, they start trimming items from the program. They have the option of 1) cancelling the project, 2) removing some usable space from the program, 3) downgrading elements of the envelope, infrastructure, or furniture and fittings or 4) increasing the budget. As they go through this exercise, they find that they have to spend a lot of time appealing to the architect to compromise her vision of the building since she has the most influence on the trade offs of all the parties involved. Occasionally they manage to increase the budget, but that is rare and is generally only for elements that will pay back.

Steven Rice has been instrumental in getting the shops input in the design process. To do this, he has spent a lot of time keeping them informed about what is going on with the projects. Now, when a building has been designed the shops can comment on the specifications and plans. They generally comment in a few areas. First, they try to standardize fittings with the rest of the campus. For example, only one sort of shower valve is used in new dormitories. Second, they try to change high maintenance items. The example given in the interview was changing fiberglass bathtubs to cast iron. Finally, they comment on the big items like the heating systems. In this case they will look particularly towards ease of access for maintenance. This is particularly important since architects often put HVAC equipment in inconspicuous (and often inaccessible) places.

In these design reviews, which generally occur when the drawings are 95% complete, the Buildings and Grounds and energy management people "fight as vigorously as possible" for operationally good buildings, but "generally lose". They have a lot of difficulty persuading the architects to understand the building maintenance problems. Similarly, interviewees felt that the architects were possibly not trained to consider

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24 Head of Buildings and Grounds at Medford.
operations and maintenance in the design. The nett result is often a building that is extremely difficult to maintain.

As things are removed from the program, the first things to go are generally the elements of the energy management infrastructure that show a poor return on investment. So, they will rapidly go from a variable air volume to a constant volume system if it is economic to do so.\textsuperscript{25} This is especially true in rehabilitations of older leaky structures where infiltration is likely to dominate ventilation and heating loads. To counter this, the Director of Energy Management presents cost/benefit analyses to the construction people in the hope that sensible decisions will be made. Unfortunately, the operations people and the construction people are sufficiently separate that these analyses must stand by themselves against forceful politicking from the faculty.

Decisions about which elements of the design remain or go are generally made by the construction and financial people, and not by the faculty. The faculty are only consulted if changes in space allocation or space usage, such as elimination of a laboratory are proposed. As such, the Buildings and Grounds section has better access to decision making than the end-users. Generally, decisions are made to give priority to concerns about 1) space allocation, 2) installed equipment and 3) space use flexibility, in that order.\textsuperscript{26}

So, for example, when a proposed building at Grafton came in $500 000 over budget, they tried to eliminate air-conditioning, but the faculty objected. Then they considered changing the variable air volume system to constant volume and using lower cost wall treatment, exterior treatment and materials. If they still can't get it in under

\textsuperscript{25} For example, in a new building on the Grafton campus they found that a variable air volume system had an economic benefit of $5 000 per year with a capital penalty of $65 000

\textsuperscript{26} It appears that faculty interests are taken care of without needing to explicitly include them in the discussion.
budget they will look to the university to raise more money. If money cannot be raised they will probably defer the project.

B. THE NEW ENGINEERING TECHNOLOGY CENTER

1. PHASE 1

Phase one of The Engineering Technology Center is a new laboratory building with 89,000 square feet of gross space and 60,000 square feet of usable space. It is to be a rehabilitated printing shop on a site adjacent the campus. The building has two very large very strong floors, so it is to be used as a heavy laboratory for Chemical Engineering, Electro-Optics, High Energy Physics, and Condensed Matter Physics. It will also contain a visitor information office. The work is being funded principally with a $10,000,000 grant from the Department of Energy, as a commercial energy demonstration project. One of the conditions of the grant is that they provide quarterly energy consumption reports to the DOE. The money was raised by the senior administration, not the Director of Energy Management.

It is being designed by Canon and Company, a firm with expertise in energy design. Preliminary design was being carried out at the time of the interviews. Design input came from the construction group of the Physical Plant Department and from the DOE itself. There are no faculty involved in the building design other than The Dean of the Graduate School of Arts and Sciences.

Because this is an energy demonstration building they intend to design well beyond the local codes (and those mandated by the DOE), and also to be much more energy conservative than would be suggested by economic rationality. In addition, because of the nature of its occupancy, they intend to make the building very safe.
The dean, the architect, a DOE representative, and the project manager are allocating the space. Because there is a funding shortage, layout is critical. At the time of interview, they were considering simply not renovating a quarter of the building. Other options included raising more money and borrowing. That decision would probably be made by the President or the Trustees.

They feel that being forced to do a very careful energy analysis of a building has raised significantly the consciousness of all the people involved about the importance of design in energy conservation and operations. The dean thought that some of the learning that comes from the project will be transferred across to the other side of the campus via the construction department. Particularly, it would show in the chemistry building, which was just starting a ten-year renovation.

2. PHASES 2 AND 3

Adjacent the site of the proposed building is another suitable for light laboratories. Depending on the success of Phase 1, there is a good chance that the DOE will fund most of that renovation also. Phase three is much more speculative and involves a third building on the estate. It would be used for the computer science and environmental management programs. If the three phases were built, it will increase campus laboratory space by 50%, which indicates, more than anything else, the rate of increase in research at Medford in the previous decade.

C. THE MAYER STUDENT CENTER

The Mayer Student Center is a three-stage project, the first two of which were completed in 1985. Although none of the interviewees said so, it appears that the design flaws that accompanied its construction were instrumental in increasing the input of operations people to construction review.
The building has two principal problems. First, it has over-head air delivery and concealed spline ceilings, twenty-five feet above floor level.\textsuperscript{27} This means that twice yearly, when they change the air filters, a carpenter has to remove part of the ceiling to give the filter-changer access. This complicates a simple task considerably. However, this is not the principal worry with the building. The main problem is that the air handling unit is under the main stairs, which are in the very center of the structure, in a large open space adjacent the cafeteria. The enclosure is so small that half of the unit is inaccessible for maintenance. Also, the entrance to the enclosure is so small that the only way they can change the equipment if it breaks is to close the building and remove either the stairs or some of the walls.

What is particularly interesting is the attitudes of the different people in the Physical Plant Department to this. These varied from one (senior manager) saying that the architects are not responsible for these sort of problems, though he didn't know where the responsibility lay. Another interviewee (also a senior manager) had strongly contrary opinions. He was amazed that the design would even be put up for consideration, and was surprised that Tufts had not sued the architect.

\textsuperscript{27} That is, the pieces that hold the ceiling tiles in place are hidden from view.
VI. FACILITIES CONTROL

A. THE SUPERVISORY SYSTEM

The computer system at Tufts is a Johnson Controls JC85-40 supervisory system. It was installed in 1979 with a DOE grant and is connected to all the major buildings on the campus. The supervisory system differs from a direct digital control system in that the computer is used to change set points at given times. Local controls, which are pneumatic and digital, are used to do the controlling. In that respect it is halfway between a traditional pneumatic system, where the set-points are set locally and manually, and a direct digital control system, where the set points are simply typed into the computer, either as algorithms or as fixed values.

B. CONTROL

The computer has many capabilities beyond those in use, and the existing algorithms could be refined. However, according to one interviewee, the operator has other responsibilities and hasn’t had time to learn the system properly. Hence the system is used at a minimal functional level.

The computer works out the best time to run equipment for the schedules it has been given, and does this on the basis of the inside and outside temperatures and the temperature required. Generally, it will come on about 15 minutes before services are scheduled to be needed. It does not give the sophisticated diagnostics that the operators of direct digital control systems (at other campuses) claim their systems give. For example, the Johnson system will not detect a belt slipping on a motor.

In the dormitories, hot water pumps in the heat exchanger respond to the outdoor air temperature. This alters the temperature of the water. Once the outside temperature
rises to 55° the system stops. They try to control the zones so that the coldest known point in a zone is between 72° and 74°. That way the whole building will hopefully be reasonably warm. There is one sensor per zone and two or three zones per building. One of the buildings, Lewis Hall, with electric heat is operated in much the same way as the other dormitories. A few of the buildings are run slightly hotter because the sensors are not in the coldest places. Whenever there are problems in the system the operator has the choice of overriding the automatic system or opting for fully manual control. Academic buildings are heated to 78° and set back to 60° at night and at other unscheduled times. They set the temperature so high because they are worried that the system would back up (with condensate I presume) at lower temperatures.\footnote{28}

Only the operator can make changes in times and temperatures. Other people can request printouts of alarms, but they do not have direct access and cannot extract other data.

C. OPERATIONAL ISSUES

One of the biggest problems they have with maintenance of consistent temperatures in a zone is that people like different standards. There are ongoing battles to satisfy the users of each zone in a building. For staff-occupied zones, if there are constant complaints, they give them access to controls (presumably thermostats and valves). However, they don't like conferring these privileges on students. They are concerned with the safety of both the students and the valves. Notwithstanding, the principal operating algorithms for the computer; temperatures and ventilation rates and the like, appear to have been set by the supplier and not changed since.
In the mornings the shop supervisors obtain copies of the previous day’s system alarms to see if any systems have gone out of range, if any fans or pumps have stopped, or whatever. They hope to get to problems before people ring in. Similarly, the Campus Police have a printer attached to the system. If there is an alarm at night, such as a boiler going down, they can call up the shop supervisors, at home, to rectify the problems.

D. OTHER SYSTEMS

New buildings get (Johnson DSC 8500) direct digital control systems which work alongside the supervisory system, but which can be used with future full direct digital control systems. As well as providing much more versatile control, they provide good diagnostics. Wherever it is infeasible to attach a building to the central system, simple (non-digital) local controls are used. This gives some modicum of control on all the buildings.
VII. HOUSING

A. GENERAL ISSUES

Every dormitory has a resident manager responsible for student comfort and safety. This includes functions like management of keys, mail, controlling who comes in and out, and management of facilities. They act as counsellors, stimuli for student activities and disciplinarians. They deal with the other offices of the university, including all interaction with the Physical Plant Department (which takes about half an hour weekly).

A student who finds something wrong reports it to the resident manager, who in turn reports it to the Housing Office, (or the campus police after hours) which submits a request to the Physical Plant Department. Until 1986, the resident managers would approach the Physical Plant Department directly. Since the work was given inappropriate priorities requests now go via the Housing Office. While this means that there has been a transfer of workload from the Physical Plant Department to the Housing Office, which the housing people appear to resent, this has the additional advantage of creating a paper trail through the Housing Office.

The Housing Office has different priorities to the Physical Plant Department. While the Physical Plant Department tends to emphasize the academic buildings, the Housing Office believes that the dormitories should be accorded more priority. Because students cannot escape, and there is overcrowding, the Housing Office believes the facilities managers should do everything to make students as comfortable as possible. Similarly, it is interested in planned maintenance while the resident managers only appear to be able to elicit fire fighting from the Physical Plant Department. All these problems are, of course, compounded by the fact that the students are generally not terribly responsible.
B. HODGDON HALL

Hodgdon Hall was built in 1954 for 155 students (but sleeps 180). The manager says she has had fairly good interactions with the Physical Plant Department and that most calls take about a day to be fixed. Some (like a broken shower) will take a week. Anything complicated, like poor heat in one part of the dormitory, will often take several calls and several visits by the Physical Plant Department. She was surprised that the mechanic generally will not come more quickly for subsequent calls than for the first.

The electrical systems in the dormitory are poor. When it was first built, there was only one socket per room and no light fittings. It has been rewired to give two sockets. Students bring their own lamps and light bulbs. Circuits pop regularly (about forty circuit breaks per floor per day). However, the Physical Plant Department will not re-wire the building. To overcome this problem in many dormitories, the university has limited students to small ‘bar’ refrigerators. Heat is generally fairly well controlled. One or two rooms adjacent boilers are too hot. Neither she nor the students have any control over the rooms’ temperatures. There are knobs on the student’s radiators, but they seem to make little difference. The Housing Office has applied (successfully) for a grant to renovate the structure, and intends to upgrade the walls, windows, and electrical systems.

The building is generally considered poorly designed. It is a split-level construction of bricks and plastic and wood which the residents find very ugly. The partitions between the rooms are plywood, the doors are steel. Low frequency sounds, like doors slamming, pass right through the building. I interviewed an architect who worked at Tufts. She explained that the dormitories had been financed by the federal government which had put ceiling on the amount of money, per bed, that the university
could add to the initial appropriation. Consequently, they had been forced into very low
cost construction.

Not surprisingly, students are very frustrated with the building and it is one of
the least desirable on campus. However, it does have the advantages of having a
cafeteria in the basement that they can use as a study area, and of being a very social
dormitory. The long straight carpeted corridors make it very easy to get close to people.

The manager does not believe many of the single pane windows (without storm
windows) open in Winter, but does not check studiously. She does not check to see if
lights are left on. The dormitory is closed for a month at Christmas and over the
Summer to save on operating costs.

C. LATIN WAY

Latin Way was built in 1980 to accommodate 211 students. In 1987/88 it housed
210. The dormitory comprises two classes of living situations. Some students, generally
seniors, live in co-op units. These self enclosed co-operative apartments house four to
six students. The other half of the dormitory comprises suites of ten beds, a living
room, and occasionally a kitchen. Generally, these are occupied by sophomores.

The resident manager considers the construction to be pretty shoddy, though
better than Hodgdon. There are no problems with the electrical system, and minor
problems with overuse of the plumbing. As with Hodgdon, there are problems with low
frequency sound; particularly metal doors slamming. There are no complaints about heat
since each three or four rooms has separate temperature control.

The manager is concerned by ongoing problems with facilities in the dorms. She
originally solicited problems from students but received no response. In her experience,
the Physical Plant Department will only respond to crises, and is only able to solve
simple problems. For example, they are very good at unplugging toilets, but when the dormitory buzzer system broke they did not fix it for quite a time. This resulted in several broken windows as students threw stones to attract friends' attention.

D. BUSH HALL

The manager at Latin Way had also been resident manager of Bush Hall, built in 1960 to accommodate 115 students, for a few years. Compared to Latin Way, she was unenthusiastic about Bush Hall.

The heat control was very centralized, and the rooms uninsulated, so it was fairly uncomfortable throughout. This was compounded by the fact that the rooms were very draughty, especially through the gaps in the window frames. The lighting was all fluorescent in public spaces and never went off. Students turned off their own lights. However, since general illumination was so poor, students had to bring supplementary lamps.

To try to alleviate these problems, she would have the students fill out condition cards between September and Halloween. She would then go from suite to suite discussing facilities problems with the students and assembling a list for submission to the Physical Plant Department. At the end of the year she would re-check the rooms to look for damage.