

Representation of Thermal Energy in the Design Process

by

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Bachelor of Arts in Architectural Studies

University of Washington, 1990

Submitted to the Department of Architecture
in Partial Fulfillment of the Requirements for the Degree of
Master of Architecture

at the

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ABSTRACT

The goal of thermal design is to go beyond the comfort zone. In spatial design architects don't just look up square footage requirements and then draw a rectangle that satisfies the givens. There must be an interpretation. The requirements will be met, but there will be many other layers added. What is needed is a positive statement of thermal conditions that will support the architecture. An attempt must be made to actively design thermal delight rather than just hope that it happens.

This thesis proposes a method in which thermal qualities are presented as opportunities to strengthen and enrich architectural meaning and experience. Representation of the variables of human comfort and pleasure can establish a thermal order that can be communicated just as conventional methods represent structural and spatial qualities. This method of generating and recording a thermal order consists of a qualitative and project specific set of thermal intentions that can be added to ASHRAE laboratory derived standards. Once established, this thermal order in conjunction with standard energy analysis tools becomes a part of form synthesis. To do this, the thesis will develop a general method and explore its use in a design project.

In the present situation architects have the most advanced, efficient, low-impact technologies and powerful precise analytical tools ever available to the profession. The employment of these technologies requires a balanced attitude that values a human spirit as well as cost and efficiency. The use of energy-efficient technology needs to be considered phenomenologically. Good architecture respects mind, body, and all the senses. The material mass of a concrete environment at 68°F has a greater capacity to draw heat from a person than a 68°F environment of wood. The experience of the space becomes more than just visual or tactile. It is capable of changing the physical condition of the human body. This physical interaction with the environment is an essential part of architecture.

The hypothesis is that through representation during the design process, an integral link between quantitative energy requirements and qualitative aspects of architectural meaning can be attained by the making of a thermal order. The objective is to find ways in which thermal energy issues and qualitative aspects of the design process can inform and support one another. The project is a Public Pool for the city of Boston. The Public Pool is a building type that requires an extreme range of thermal conditions, a cultural presence, and a strong attitude about the interaction of the human body in architectural space.

Thesis Supervisor: John Myer
Title: Professor of Architecture

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Committee

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Photography and Illustrations

All photography and illustrations are by the author unless otherwise noted. Only illustrations directly cited in the text are given figure numbers.

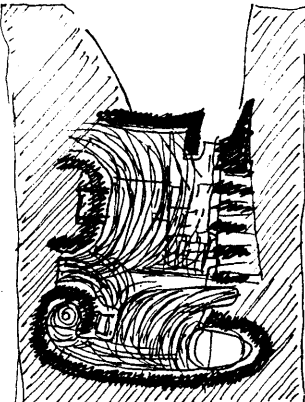
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Note: At content review, the committee for this thesis determined that color was required to fully communicate the ideas presented. Labeled black and white versions of all color plates have been included to assist the reading of microfiche copies.

Introduction

This study has its beginnings with a general interest in the integration of energy technology in design. One of the primary purposes of a building is to affect the climate in and around it. Particular thermal qualities are seldom presented as design intentions. Consideration of thermal issues often stops once means are found to maintain a constant 68°F. Factors such as structure, cultural significance, site, and program enter into every level of the design process from concept to construction documents; likewise, energy should also reveal itself as an indispensable part of a whole design. Decisions about the thermal environment cannot be solely based on the technical aspects of achieving optimal comfort in the most efficient way. Energy in building design needs to combine legal code requirements, economic decisions, and the need for resource conservation with the poetic realm of architecture.



NOW THAT I'VE BEEN INSIDE FOR 20 MIN. OR SO. THE MUSIC HAS TURNED TO FAR OFF CORAL, VERY SOFT. THE CHAPEL IS COLD, MY BACK AGAINST THE BACK WALL IS COLD. DAMP. IN THE CORNER, THE HIGH CORNER LIGHT PIERCES IN, WARM LIGHT HOT LIGHT IN THE CHAPELS IN BACK THE LIGHT IS LOW AND DIFFUSE BUT STILL WARMER THAN THE MAIN SPACE. THE ROOF HANGS LOW AND COLD. THE MIND IS DRAWN UP AND OUT.

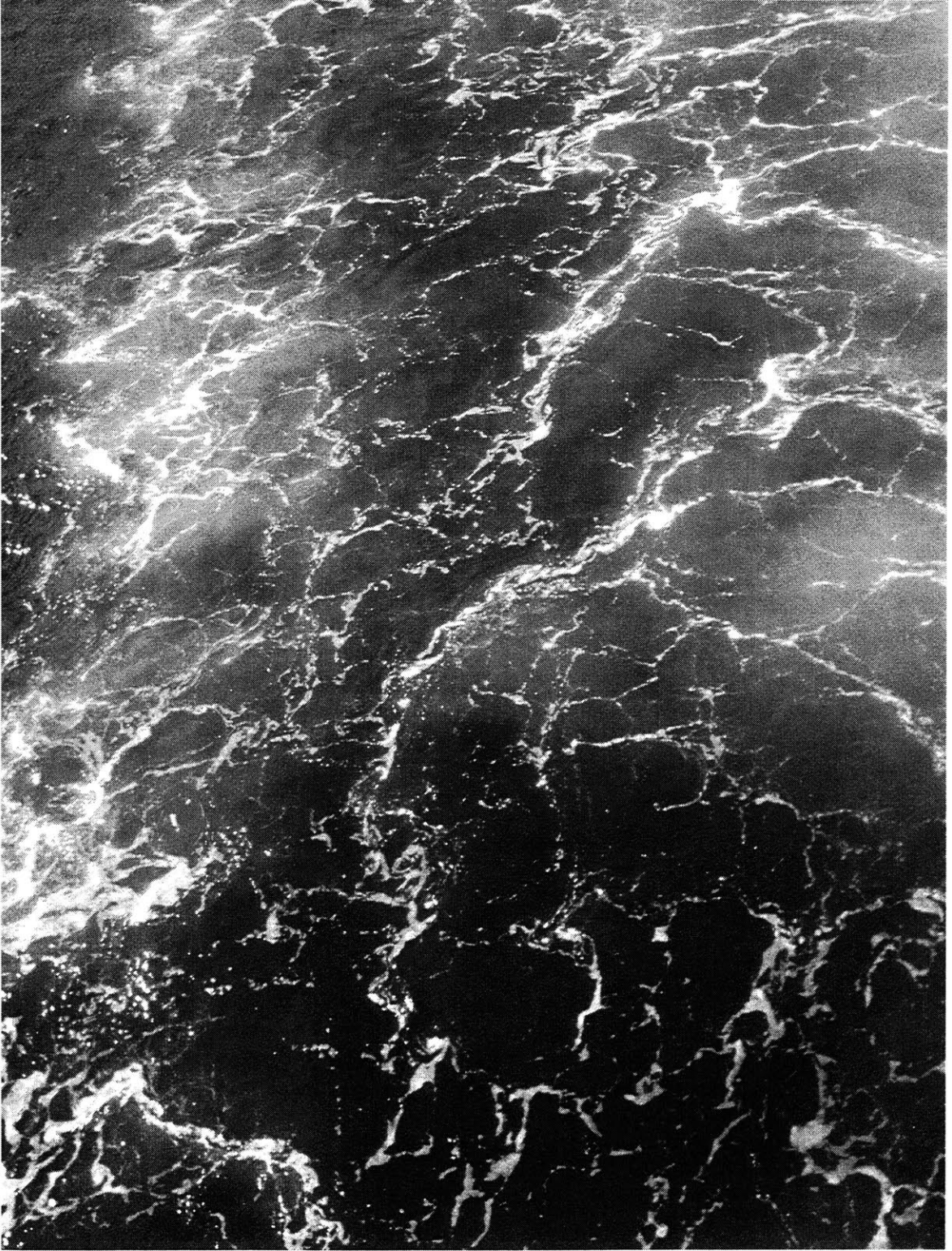
6/9/94
RONCHAMP, AGAINST THE BACK WALL OF NOTRE DAME DE HAUT
11:30 am 60.3/63°F 67% RH

An exploration of this type has many starting points. It seems that routes focusing on the technical development and implementation of energy-efficient technology are well worn. The 'how' question of thermal design has led to fantastic advances in efficiency and control of the thermal environment. It is in the 'why' question that the well worn path becomes a thicket. Lisa Heschong's book Thermal Delight in Architecture is one of a few sources of direction in this area. However, she does not make a design proposal. The next step in this highly qualitative ground is an attempt at implementation and finding a connection to the well trodden course of ASHRAE standards.

The work is presented in a linear manner as required by books. However, it was generated using a very cyclical method. The design project, representational studies, and the study of thermal design parameters all proceeded simultaneously, developing from one another.



Medical Lake, Washington State

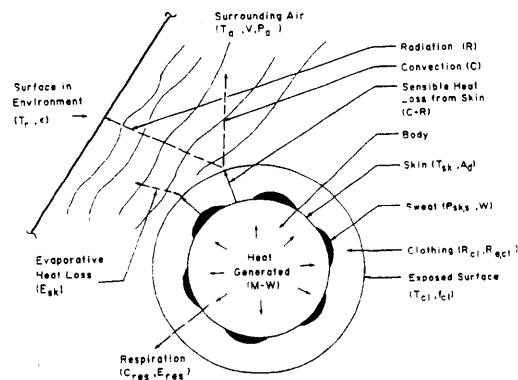


The Aegean Sea

I Argument for thermal order

"People used to make good value judgments with less quantitative information. We must reassert the importance of the qualitative and consider all the factors involved rather than only those that are most easily quantifiable."
- Bill Lam 1986

"Many design solutions were formerly limited by technical means. There were more stringent limits to dimensions of clear window openings, sizes of glass, sizes of economically attainable mirrored surfaces, trellis members, and so forth. The limits now are those of trade-off decisions rather than of technical feasibility. It is important to make these decisions on the basis of value (cost and benefit) rather than cost alone."
- Bill Lam 1986



Cylindrical Model of the Thermal Interaction of the Human Body and the Environment.
-From ASHRAE Fundamentals²

In the present situation architects have the most advanced, efficient, low-impact technologies and powerful precise analytical tools ever available to the profession. The employment of these technologies requires a balanced attitude that values a human spirit as well as cost and efficiency.

The approach which Bill Lam¹ has proposed for lighting can also be applied to the thermal environment. A design method should be based on the perceptual, cultural, and physiological needs of the occupants. Variation, surprise, and relief are all necessary. It is a phenomenological approach in that it is based on a full range of sensual experience, not limited to the visual.

ASHRAE standards² tend to slant towards a view of people as heat machines that must be kept in balance. Thermal success is a situation where 80% of these engines are in neutral, don't complain, and just work productively. The body of quantifiable knowledge which ASHRAE and others have amassed should not be in any way devalued. It must be supplemented with qualitative knowledge that can make a more direct link to Architecture.

A recent study conducted by the Center for Environmental Design Research³ for ASHRAE shows that standards set by laboratory tests don't hold up in the field. Two most important findings are that: 1) Satisfaction with thermal conditions is lower than

¹Lam, William M. C., Sunlighting as formgiver for architecture, Van Nostrand Reinhold Co., New York, 1986

²1989 ASHRAE Handbook, FUNDAMENTALS, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1989

³Stubbs, M. Stephanie, "Study Assesses Thermal Comfort In existing Office Environments", Architecture, March 1989

with non thermal aspects of the work environment; and 2) Satisfaction with work-area temperature is higher when the degree of individual control increases. These findings indicate that while efficiency and capabilities of HVAC systems have been improving, consideration of the thermal environment is stuck at an even 68°F.

In Amory Lovins October '84 lecture at MIT, he talked of a synergistic approach to energy issues in buildings. He acknowledged, however, that issues of human comfort are a big (?). A holistic and synergistic approach requires an understanding of the qualitative aspects of the thermal environment.

We may be able to evenly heat a place at optimal efficiency, but is that what we really need?

Clark and Edholm⁴ cite numerous studies of human comfort. The summation of these studies reveals the complexity of thermal comfort. Thermal comfort defined as the absence of discomfort may be quantified, as by Fanger⁵ and others. The positive alternative to thermal discomfort, thermal delight, eludes quantitation. The impossibility of expressing thermal delight numerically requires that we attempt verbal and formal communication.

Is it necessary to show evidence of the existence of thermal pleasure? Clark and Edholm have conducted experiments that would support a concept of thermal delight. The best evidence, however, is in individual empirical experience. Finding a sheltered

"The concept of comfort is an abstract one which does not coincide with any specific physiological sensation. Thermal comfort may be better described as the absence of sensation or discomfort."

-Clark and Edholm 1985

⁴Clark, R.P. and Edholm, O.G., Man and His Thermal Environment, Edward Arnold Ltd, London, 1985

⁵Fanger, P.O., Thermal Comfort, Analysis and applications in environmental engineering, McGraw-Hill, 1972

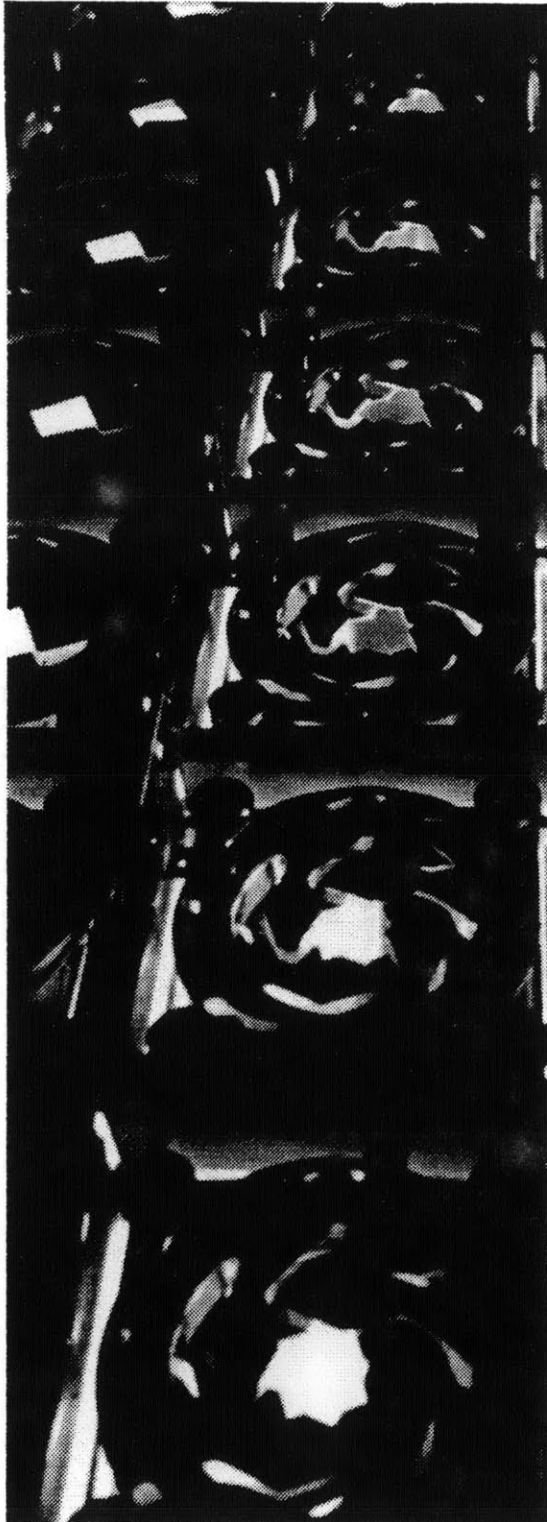
“The thermal environment has the potential for such sensuality, cultural roles, and symbolism that need not, indeed should not, be designed out of existence in the name of a thermally neutral world.”

- Lisa Heschong 1979

patch of sunlight on a windy winter day. Coming in from the cold to a warm cozy house. Running through a sprinkler on a hot day. Even the knowledge that differences are playing against each other can produce delight. Sitting by a fire watching a storm rage outside one may be in thermal balance, but feel warmed by the fact that they are not out in the cold. All these go beyond providing a steady state core body temperature. It is the intense presence of sensation that connects our living bodies to the physical world around us and makes life worth living.

In Lisa Heschong’s (MIT M.Arch ’79) work Thermal Delight in Architecture⁵ she begins “with the hypothesis that the thermal function of a building could be used as an effective element of design.” She elegantly presents an extensive set of references, offering “some background information, and a bit of musing, which are the first stages of any design work.” The next step, after absorbing this richly qualitative information about the necessity, delight, affection, and sacredness of the thermal environment, is to apply it to a design project. One must move from an analytical, researching, reflective mode to a synthetic form generating mode.

⁵Heschong, Lisa, Thermal Delight in Architecture, MIT Press, 1979



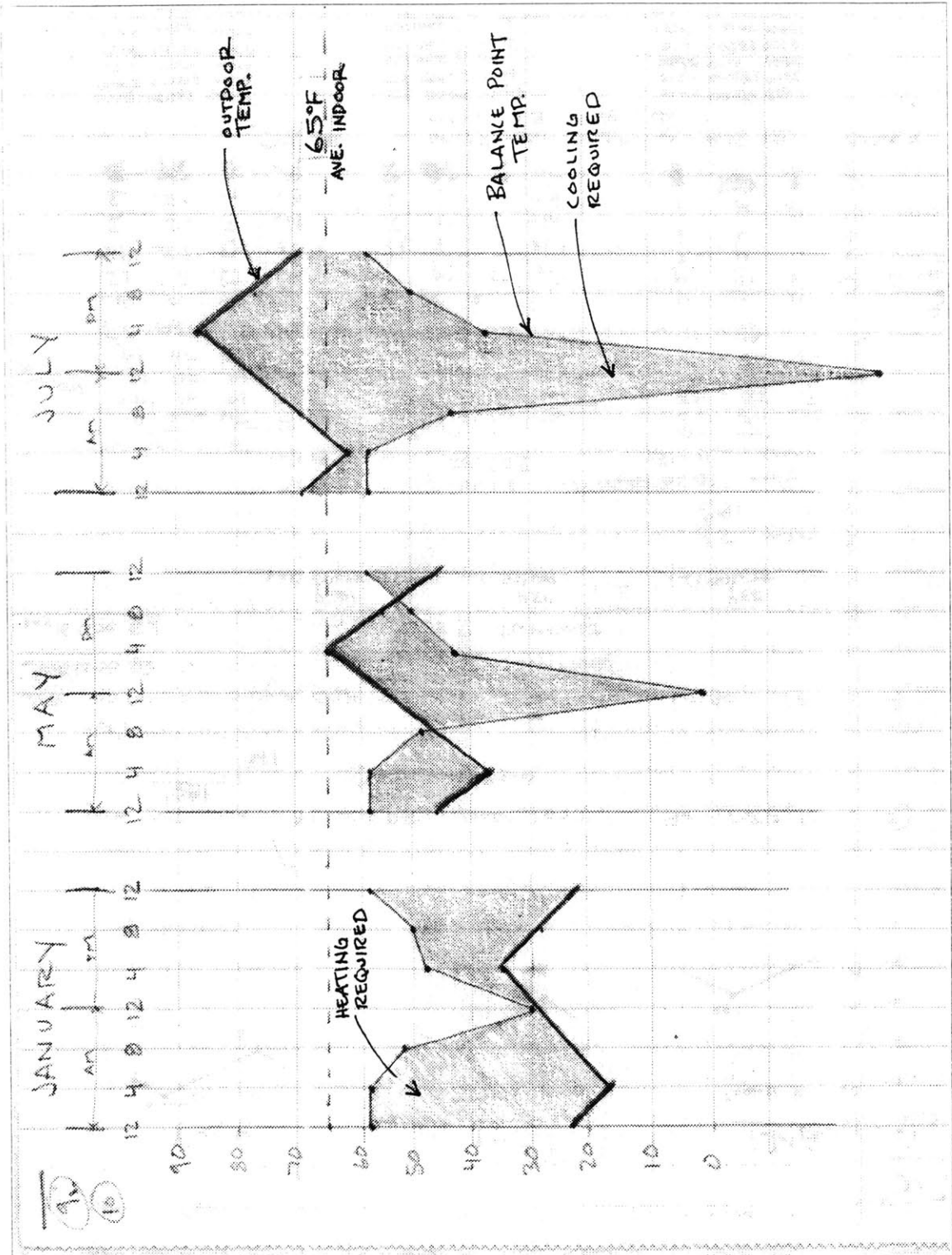
Institut Du Monde Arabe, Paris, France
Jean Nouvel, Gilbert Lezènes, Pierre Soria
- Photography, Shaun Roth

The oculi on the south facade are a good example of over-applied technology that doesn't work. 1) motors break down 2) shading is between glazing. Shading of the courtyard is more effective. Screens are exterior to the double glazing less complicated, but with just as interesting patterns of light.

Hypothesis:

Through representation during the design process, an integral link between quantitative energy requirements and qualitative aspects of architectural meaning can be attained by the making of a thermal order.

This thesis proposes a method in which thermal qualities are presented as opportunities to strengthen and enrich architectural meaning and experience. Representation of the variables of human comfort can establish a thermal order that can be communicated just as conventional methods represent structural and spatial qualities. This method of generating and recording a thermal order consists of a qualitative and project specific set of thermal intentions that can be added to ASHRAE laboratory derived standards. Once established, this thermal order in conjunction with standard energy analysis tools, becomes a part of form synthesis.



Notes on Heating and Cooling Patterns for a generic pool building.
 Developed from G.Z. Brown, Sun, Wind, and Light.

II Analysis and Synthesis

Analysis 1: separation of a whole into its component parts 2 a: an examination of a complex, its elements, and their relations b: a statement of such an analysis 3: the use of function words instead of inflectional forms as a characteristic device of a language 4 a: the identification or separation of ingredients of a substance b: a statement of the constituents of a mixture 5 a: proof of a mathematical proposition by assuming the result and deducing a valid statement by a series of reversible steps b: a branch of mathematics concerned mainly with functions and limits 6 a: a method in philosophy of resolving complex expressions into simpler or more basic ones b: clarification of an expression by an elucidation of its use in discourse

*Synthesis: 1 a: the composition or combination of parts or elements so as to form a whole b: the production of a substance by the union of chemical elements, groups, or simpler compounds or by the degradation of a complex compound c: the combining of often diverse conceptions into a coherent whole; also : the complex so formed 2 a: deductive reasoning b: the dialectic combination of thesis and antithesis into a higher stage of truth 3: the frequent and systematic use of inflected forms as a characteristic device of a language.
-Webster's Ninth New Collegiate Dictionary, Merriam-Webster Inc.*

We have to be very careful to distinguish and properly define analysis and synthesis, two vital components of design process. Analysis is always characterized by movement from a whole to an understanding of parts. It is an examination of something that already exists. Synthesis is always characterized by movement from many parts to an understandable whole. The two processes are moving in opposite directions. An optimal design process is not a exclusive linear application of analysis or synthesis, but a cyclical process involving both. Form cannot be generated by analysis. Yet the generation of form depends on analyzed parts for its ingredients. A complete but unanalyzed form will be lacking in rigor. The generation of architectural form is a dominantly synthetic process. A large number of tangible and intangible factors must be weighed and combined to form a coherent whole. Synthetic processes are less demonstrable than their analytic counterparts. As soon as one starts describing and illustrating, the shift to analysis has already been made. A design process must fully acknowledge synthetic and analytic tools.

Analysis tools:

- calculate and quantify
- understand connections
- test intentions

Synthesis tools:

- aggregate and qualify
- create connections
- state intentions

II - Analysis and Synthesis

Synergism : interaction of discrete agencies such that the total effect is greater than the sum of the individual effects.

A balanced utilization of synthetic and analytic tools will cultivate synergism. Synergistic design provides many advantages. Because it requires a coherent conception of the whole, architectural meaning and cultural significance are strengthened. The whole sums to more than the parts, therefore, it is more energy efficient and costs less.¹ For example, a pantry which needs to be kept cool might be placed on the north side of a house thereby keeping itself cool and acting as insulation to the house. When enough elements are put in the right place, the house can passively heat itself. The furnace can be eliminated.

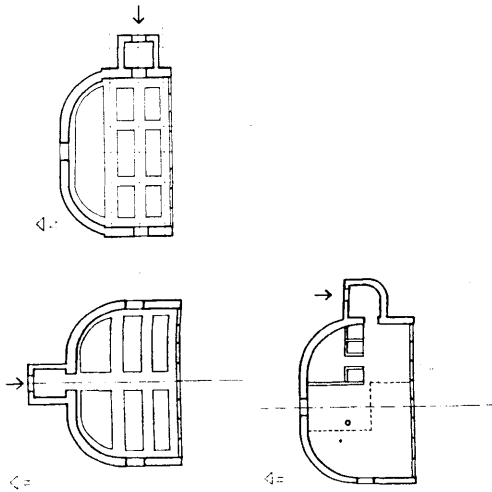
Synergistic design means thinking about the connections between many layers of design. Sun angle analysis may help determine a shading overhang. It is critical that sun angle is not the only factor considered. Effects of wind, strength and type of material to be used, obstruction of views, interaction with natural vegetation, composition of facade, relation to context, cost, the overall conception of the building, among others must be considered.

In 1963 Victor Olgyay² wrote Design with Climate. It is a fairly comprehensive text that gives equal weight to the qualitative and quantitative. Many concepts, charts, and figures from the newer texts are based on Olgyay. Thirty years later some of the text is outdated but most is not. Olgyay's argument for a passive approach and his definitions of comfort parameters are still valid and useful

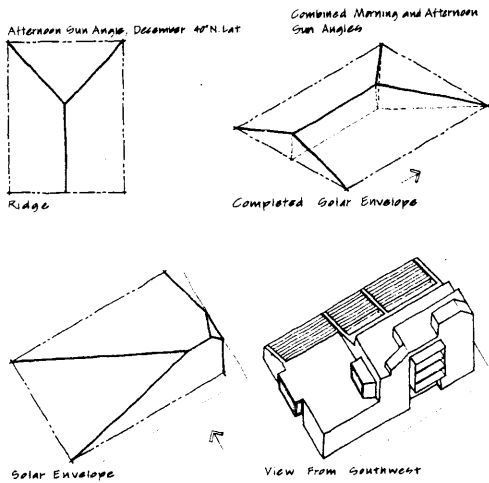
¹ Lovins, Amory, "If it's not efficient, it's not beautiful", *Fine Homebuilding*, no. 66 Spring '91, p.4

² Olgyay, Victor, with Aladar Olgyay, Design with Climate: Bioclimatic Approach to Architectural Regionalism, Princeton University Press, 1963

II - Analysis and Synthesis



Diagrams illustrating spatial and solar layering in two examples.
-From "Formal speculations on thermal diagrams"³



USC studio solar envelope exercise
-From G.Z. Brown, Sun, Wind, and Light⁴

today. It is part 3 of Olgyay's text, application, that needs a major updating and expanding to include synthetic tools.

Harrison Fraker³ begins to explore the formal implications of solar strategies. In his article 'formal' is used in the sense of relating to axis, symmetries, and entry facades. Fraker defines formal, luminous, and thermal diagrams. He then shows how these diagrams are overlaid with varying degrees of success in examples of solar architecture. This line of thinking has considerable potential for contributing to a synthetic process. However, the restrictive and one dimensional idea of 'formal' needs to be more inclusive of other forms and priorities of organization.

G.Z. Brown⁴ appropriately divides his book Sun, Wind, and Light into parts dedicated to analysis techniques and design strategies. However, the role of analysis is not always kept clear. Brown's example of the use of solar envelope studies by Ralph Knowles USC studio is heading towards dangerous territory. The form is derived from a very one dimensional interpretation of the solar envelope analysis. There is not much synthesis (architecture) happening here. Brown's examples of existing architecture are much more useful. These show how a specific technique can find it's place in the multi-dimensional reality of the built environment.

³Fraker, Harrison Jr., "Formal speculations on thermal diagrams", Progressive Architecture, v65 n4 April 1984 p104-108

⁴Brown, G.Z., Sun, Wind and Light: architectural design strategies, Wiley, 1985

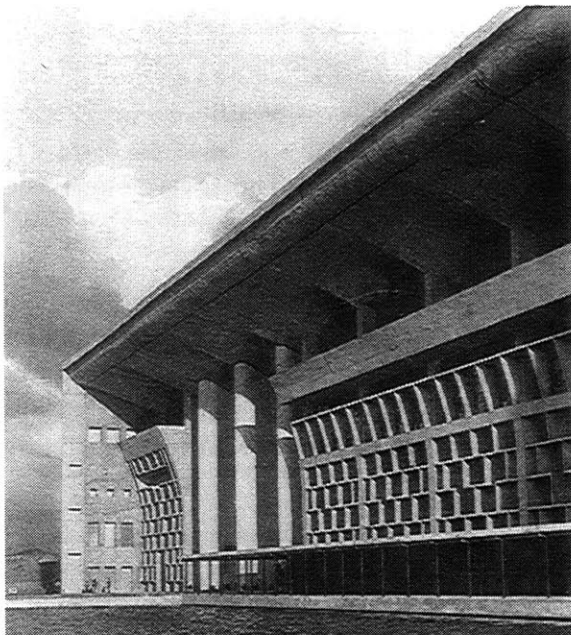
II - Analysis and Synthesis



Bridge, Querini Stampalia Foundation

-From Carlo Scarpa: Architecture in Details, Albertini, Bianca, MIT Press, 1988

-Photo by Sandro Bagnoli, Siena



Palace of Justice, Chandigarh, India, Le Corbusier

-Photography from "Le Corbusier in the sun", The Architectural Review, February 1993

G.Z.Brown uses Chandigarh as a design strategy example of window layering to reduce heat gain.

Norbert Lechner's⁵ 1991 text Heating Cooling Lighting provides basic information and guidelines. Nearly 30 years after Olgyay, this text is up to date on the latest advances in materials, lighting, and calculation methods. It provides a wide range of reference guidelines. However, a truly synthetic process is not offered.

A synthetic design process will consider thermal questions phenomenologically. Decisions at the scale of 'formal diagrams' will be supported by decisions at the scale of human interaction. The feeling of a hand on a railing and the railings formal orientation should be related. The design is a total experience of all the senses. Spatial aspects are supported by light, thermal, tactile, acoustic, even olfactory sensation. A physical interaction with the material quality of a space is a vital part of architecture.

⁵Norbert Lechner, Heating, Cooling, Lighting: Design Methods of Architects, John Wiley & Sons, 1991



Myyrmäki Church and Parish Center, Vantaa, Finland, Juha Leiviskä - Photography, Shaun Roth
Material differences and placement creates whites that range from very warm to very cool.

"The aim in designing a structure thermally is to establish an indoor environment which most nearly approaches comfort conditions in a given climatic setting. In Architectural terms this means that the planning and structure of a building should utilize natural possibilities to improve conditions without the aid of mechanical apparatus.

- V. Olgyay 1963

III Thermal Design

1. Present situation of thermal design

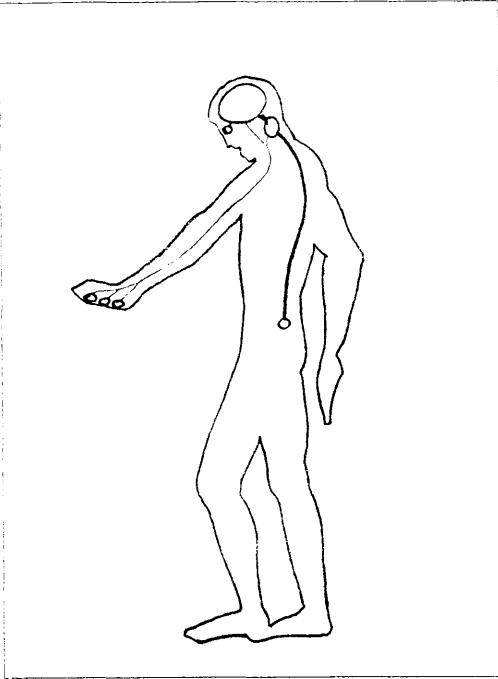
The state of thermal design has not come very far from Olgyay. Calculations are faster and more accurate. Materials available for manipulation are more diverse. Theory and process of application in form generation has not progressed much. The general conception of the thermal environment has changed only slightly. And unfortunately, the application of thermal issues in built examples has also changed only slightly. Olgyay was pushing passive design, just as Lechner and many others in between. The technology has been available for decades, so why isn't good passive design standard practice? Passive design has not been held back by costs. Generally it seems that the higher the budget gets for a project, the less passive it becomes. The thermal environment has been thought of as a neutral requirement not an architectural opportunity. The approach to the thermal environment has been dominated by technical rather than formal issues.

Harrison Fraker's writing on solar thermal and formal diagrams is a beginning. It is still not quite there. It does not provide a generative tool. G.Z. Brown's Design Strategies (many from Olgyay) are accessible to architects and near to being a generative tools. However, there is a step missing between diagram and a form which can be analyzed.

The attitude towards thermal design has consistently been limited to finding the optimal way of providing comfort zone (80% don't complain) conditions. There is no real design of the thermal environment, just of the technics needed to keep discomfort at bay. It is true that for many uses a neutral steady state comfort zone environment is desirable. It is also true that the spatial design equivalent to a thermally neutral space, a requirement for a large open homogeneous space, does not limit the articulation of structure, materials, finish, and lighting which define the space. The thermal dimensions of design must be explored as freely as structure and lighting have been in recent years.

2. Thermal sensation

All thermal information must be communicated through our bodies. Our skin, eyes, brains, etc. are all part of the same interconnected organism. In his Oct.'94 lecture at MIT Amory Lovins described three views of the brain and body relationship. The scientific model sees people as bodies without brains. The economic model sees people as brains without bodies. The third and most accurate view is of the whole person with brain, body, society and culture. These are the people who go out for ice cream on a cold snowy evening.



A simplified interpretation of the thermal nervous system.

Suddenly I feel chilled. As I read, the sun slipped away; the warmth silently trickled out. Now even my bones are cold. I'll put on the light and get a sweater.

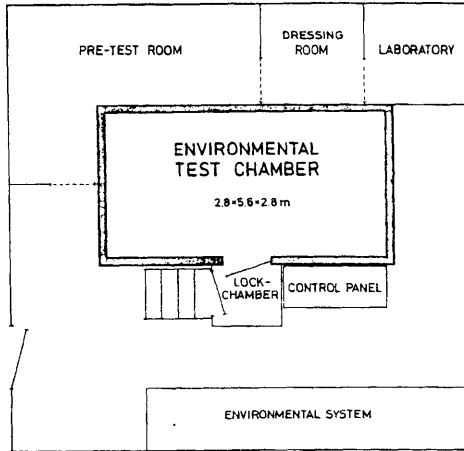
-S. Roth

There are three paths of thermal information to the brain. The most direct is from temperature receptors in the skin. Internal temperature sensors are linked directly to the hypothalamus. The third path is through associations of visual stimuli. Note: information on thermal sensation is coming primarily from Clark and Edholm¹.

The temperature sensitive nerve endings in the skin are stimulated by changes in the thermal environment. These nerve endings have a number of variations. There are hot and cold endings which fire respectively when their temperature is either rising or falling. Within the hot and cold groups there are subgroups which discharge through a certain range of temperatures. One ending may begin to discharge as the temperature drops from 25C to 24C, reach its peak firing rate at 20C, and then drop off to a lower firing rate. Our perception of heat and cold is coincident with temperature change. Temperature sensors rapidly stop discharging if there is no change. In the state corresponding to the definition of thermal comfort we are not conscious of any temperature sensation. Skin temperature sensors are not very precise in absolute terms. These sensors are indicators of change, flow of heat. They are not thermometers.

Sensation of internal body temperature is largely subconscious. When it does manifest itself it is often a general feeling of discomfort characterized by lethargy or irritableness. Core body temperature does not and cannot vary widely. Thus, a substantial change in core body temperature is usually a sign of severe stress on the body.

¹ Clark, R.P. and Edholm, O.G., Man and His Thermal Environment, Edward Arnold Ltd, London, 1985



Floor plan of the environmental facilities at Techn. Univ. of Denmark
 -From Thermal Comfort, Analysis and applications in environmental engineering²

$$M - W = Q_{sk} + Q_{res}$$

$$= (C + R + E_{sk}) + (C_{res} + E_{res})$$

- a. DuBois surface area
- b. mechanical efficiency
- c. metabolic rate
- d. clothing surface temperature
- e. water vapor pressure
- f. air temperature
- g. mean radiant temperature
- h. convective cooling coefficient

The visual field, including psychological associations and expectations, can affect judgment of thermal comfort. If it is hot outside people may desire a lower temperature than if it is cold outside. The climatic chamber, used by Fanger² and Nevins, attempts to neutralize these psychological variations by keeping subjects in for 2 1/2 hours. The subjects are completely separated from any context other than the chamber. Of course this is not how things work in real life. We can look out the window and be influenced by a blizzard of snow, or the heat waves rising off the pavement. It would seem that a climatic chamber is somewhat akin to measuring taste with a plugged nose. It's very controllable, but because of its detachment from reality must be taken with a grain of salt.

3. Environmental factors affecting human comfort

Fanger³ has combined eight factors which contribute to thermal comfort into a single equation. In this raw state, the equation is of little use to architects. However, understanding of its components can help explain some issues of thermal comfort. Future computational tools could make possible a situation specific comfort analysis. Fanger's eight factors are listed to the left.

The first four factors relate to the condition of a person in a space. The first two, surface area and efficiency, cannot be affected by architectural design. The DuBois surface area (total skin area) is different for every person, but does not change over short periods of time. Mechanical efficiency, work

²Fanger, P.O., Thermal Comfort, Analysis and applications in environmental engineering, McGraw-Hill, 1972

³ibid.

done by a person, is put in to balance the equation and can be assumed to be insignificant. Metabolic rate and clothing surface temperature (amount of clothing factored in) depend on activity. These two factors are affected by the program and conditions of a building. Because they are difficult to control precisely, metabolic rate and clothing are often given inadequate consideration. The last four factors, air and radiant temperature, water vapor, and convection, relate to a person's immediate surroundings. These are the most easily quantified and controlled by the designer.

4. Categories of thermal architectural definition

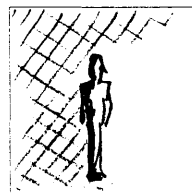
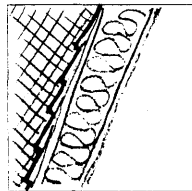
This thesis exploration has generated ten categories of architectural techniques which can be used to control the factors of thermal comfort.

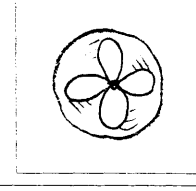
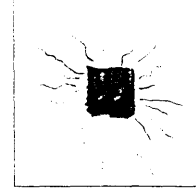
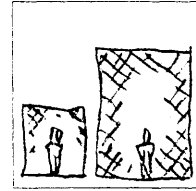
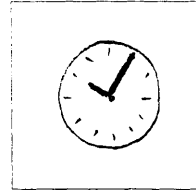
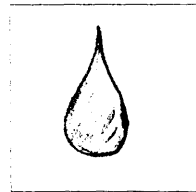
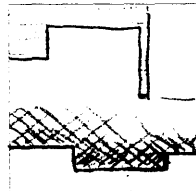
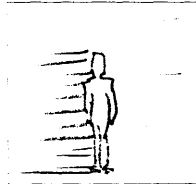
a. Material Separation

This is a wall or other physical separation of two spaces, and provides the most absolute definition. Often the separation works psychologically better than it does regarding actual heat flow. Transitions between spaces defined in this way can enhance or degrade the separation depending on how they are handled. Absolute separation is impossible of course.

b. Dynamic Flow

An example is a fireplace in a cold room or warm sun in what would otherwise be a cold space. The sensation of "motion of heat" adds a certain life to a place. It is not static. This type of situation has the potential of being a great energy drain, but can be used to recover otherwise unused energy/space.





c. Natural Air Movement

The degree to which the air is moving. Wind/no wind, affects evaporative cooling from the skin.

d. Section Quality

Variations in ceiling and floor heights makes use of the natural rising of warmer air.

e. Natural Humidity

Humidity affects the capabilities of evaporative cooling, as well as respiratory comfort.

f. Time.

True steady state can only happen theoretically. Unless they are imprisoned or bedridden people move. They may be in a particular situation for 1/2 second or 8 hours.

g. Volume to Heat Source Ratio

For example, small room with many people vs. a large room with many people. This is dependent on program and use patterns

h. Specific Heat Capacity of Materials

For example, a stone bench vs. a wood bench. This type of definition makes use of a smaller range of sensible changes. They are more subtle.

i. Color and Texture

These have psychological associations and physical effects. Different colors vary in absorbtivity. Texture affects convection.

j. Mechanical Manipulations

A/C, Heaters, Blowers, Etc.

5. Designing thermal delight

The goal of thermal design is to go beyond the comfort zone. In spatial design, architects don't just look up square footage requirements and then draw a rectangle that satisfies the givens. There must be an interpretation. The requirements will be met, but there will be many other layers added. What is needed is a positive statement of thermal conditions that will support the architecture. An attempt must be made to actively design thermal delight rather than just hope that it happens.

The well established definitions of thermal comfort should not be discarded and replaced with a thermal roller coaster. Many activities require a neutral thermal environment. There should be, however, opportunities to 'get a bit of fresh air'. Opportunities to activate the body's thermal sensors. Take a break, wake up, feel the whole body rather than just the tips of fingers on keyboard and eyes on screen. There are two areas in which thermal design is most important. The first is in thresholds and transitions that can be defined thermally as well as spatially. For example, a hallway between two offices may be kept cool. The second is in thermal intensifications within spaces that can provide people with choices and relief from neutrality. The most basic example is the operable window. If you are too hot (just ran up the stairs), but your colleagues are not (been reading for the last two hours), you stand by the window and everyone is happy.

A description of the Finnish sauna given by eighteenth century traveler Guiseppe Acerbi.

... In winter they often go out completely naked and roll themselves in the snow, while the temperature is 40 or 50 degrees below zero. If a traveler in search of help happens to arrive in a remote village at a time when all the inhabitants are in the sauna, they will leave the bathhouse in order to harness or unharness a horse, to fetch hay, or do anything else without ever thinking of putting any clothes on. Meanwhile the traveler, although enveloped in a fur coat, is stiff with cold, and does not dare to take off even his gloves....

Thus, the Finns move in less than a few seconds from a heat of 170 F to a cold of -50 F, which makes a difference of more than 220 degrees, and the effect is very much the same as if they jumped from boiling into freezing water. What astonishes the people of our climate most is that no ill effects ensue from this sudden change of temperature.

*- From Sauna: The Finnish Bath,
H.J.Viherjuuri, 1964*

A set of normative standards can be developed that would guide the design of thermal thresholds and intensifications. To a large degree these standards are encoded in something called 'common sense'. Our problem is that common sense is becoming less and less common. The intensity of thought which has gone into defining the neutral field of thermal comfort also needs to be applied to the edges and variations.

The eight factors of Fanger's thermal comfort equation combine to form a measure of Steady-State Energy Balance⁴. When the equation is in balance the body is in a state of thermal equilibrium, neutral, thus thermally comfortable by the ASHRAE definition. Gagge *et al*⁵ developed a Two Node Transient Energy Balance equation. This equation is similar to Fanger's but separates the skin and body core and accounts for the heat flow between them. The core varies only slightly and the skin can vary widely, this separation is conceptually important. Both equations are developed as steady state models. There is acknowledgment that even under steady state conditions a persons skin and core temperature will cycle through relatively small fluctuations.

The design of thermal thresholds and intensifications, the edges and variations, requires an examination of nonsteady state conditions. The ASHRAE standard⁶ allows five nonsteady state conditions. From

⁴ 1989 ASHRAE Handbook, FUNDAMENTALS, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1989, chapter 8.1

⁵ *ibid.*

⁶ ASHRAE Standard 55-1981 Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1981

ASHRAE's point of view these are acceptable variations not conditions to strive for.

a) Temperature Cycling- 4°F/h maximum rate for peaks of operative temperature variation over 2°F. No rate restriction on peak to peak variations within 2°F

b) Temperature Drifts or Ramps- 1°F/h is acceptable provided that it doesn't exceed the comfort zone by more than 1°F for more than an hour.

c) Nonuniformity- Vertical temperature difference up to 5°F. Radiant Asymmetry up to 9°F vertically, 18°F horizontally. Floor temperature between 65°F and 84°F

d) Sedentary-Nontypical Clothing- Lowering of temperature by 1°F per .1 Clo of increased clothing with minimum operative temperature of 65°F.

e) Active Persons- There are equations for reductions down to 59°F.

These alterations of standard comfort zone temperatures assume that people are in the space for more than an hour. The occupation of the space is in steady state as thermal conditions are changing. Thermal design will add to these five conditions thresholds and variations which entail nonsteady state occupation. In addition to ramps and drifts, there will be spikes, peaks, valleys, and plateaus indicating thermal and spatial transitions.

		Space Conditions	
		Steady	Changing
Occupancy	Steady	ASHRAE	ASHRAE
	Transitory	This Work	Future Work

Positioning of this work in comparison to ASHRAE studies and standards.

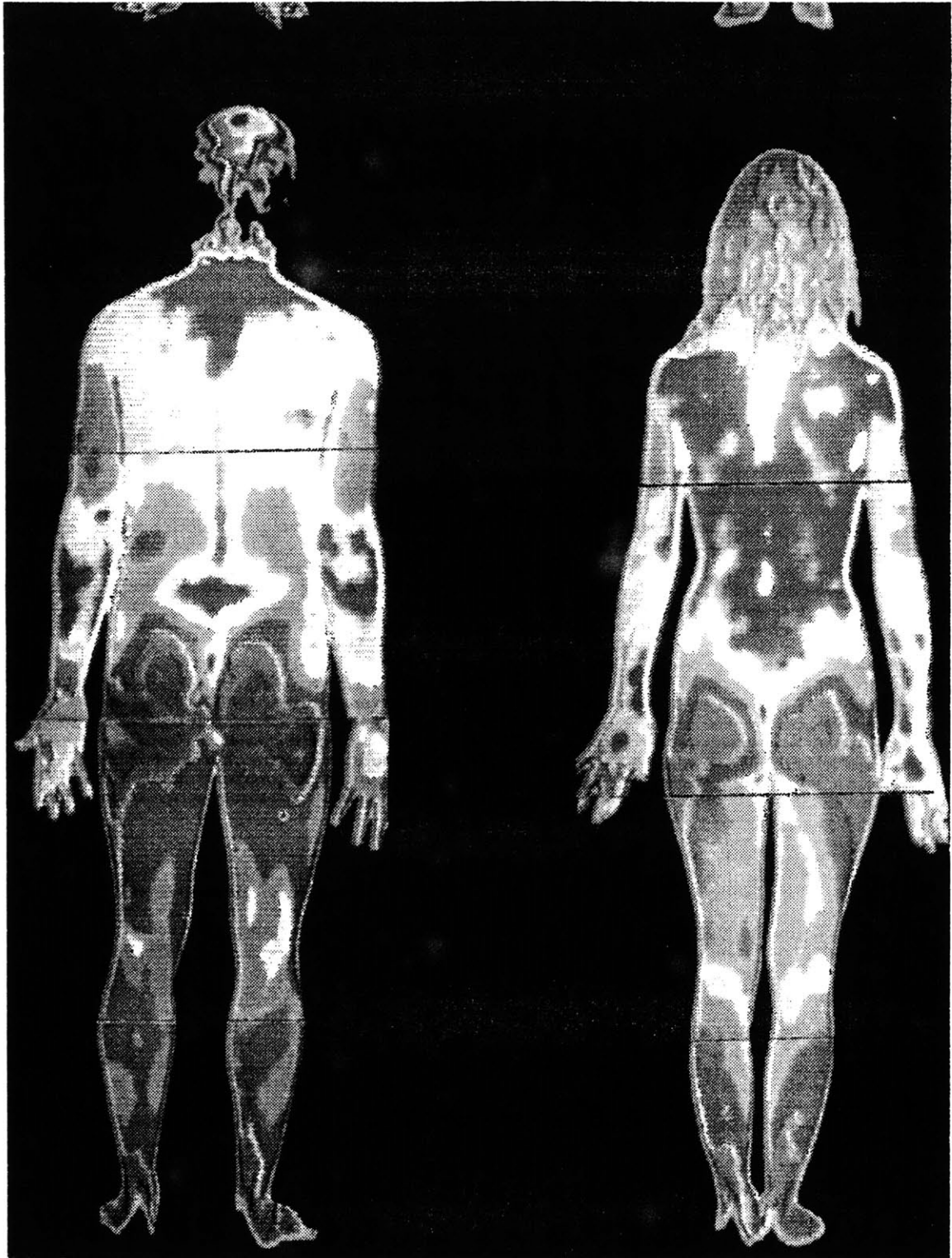


Fig.4.1 Thermograms of people. Black background is ambient. White is the warmest surface temperature. -From Man and His Thermal Environment

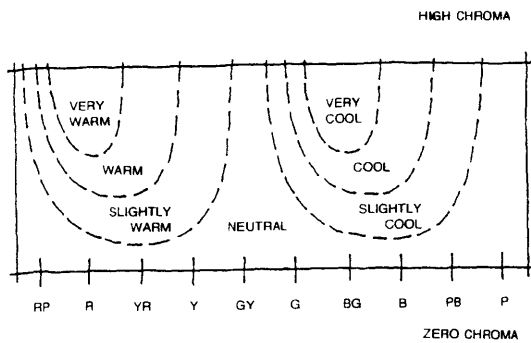
IV Representation

1. Evolution of representational studies

There are no architectural drawing conventions for the depiction of the thermal environment. We can show light, materials, volumes, but how do we describe heat or cold in a space? The thermal description needs to be intuitive, related to the variables of thermal comfort and sensation, and allow direct application to the process of design.

In spatially oriented sketching, architects often sketch existing buildings as a way of understanding them and improving their skill at depicting unbuilt design proposals. The rendering conventions of both types of sketching may be the same even though the source of one exists and the other is imagined. The analytical and generative processes of sketching have the same form of output. This idea was taken as the starting point for a set of representational studies.

Infrared thermography has been used to illustrate surface temperatures in studies of building efficiency. Thermography is also used extensively in medical research. The graphic result of a thermogram is an image with a color scale from black/blue/cold to white/red/hot. Fig.4.1. Thermography is a completely analytical tool. It measures what is there.



"Temperature Feeling" chart
-From Visual Awareness and Design²

The first representational studies for this thesis were experiments in what dimensions to represent and how to represent them. An attempt was made to use black and white. With a black and white scale there is a question of which is hot and cold. In grayscale thermograms¹, black is cold and white is hot. In color thermography blue is cold and red is hot. This does not translate into a grayscale. In this coding system yellow is cooler than red, but the grayscale value of yellow is higher than red.

There are strong perceptive associations of color and temperature. These associations make the use of color representations a more accessible vehicle to the design process. Basic color theory classifies warm, cool, and neutral colors². A carefully chosen color scale can translate to grayscale. For example, one can create a scale that ranges from hot light yellow to cold dark blue. Any grayscale, however, is only capable of depicting the range of one variable.

Representational studies based on the thermogram have numerous limitations. The thermogram measures surface temperature. In a design sketch one wants to also see air temperature and 'thermal mood'. These initial studies Figs.4.2-4.4 were very one dimensional, representing just mood, or just temperature. They were lacking any rigorous definition. They were not providing useful design clues. The first studies were attempting an absolute representation of conditions. This approach was too close to the analytical model of the thermogram to be of much use as a synthetic tool.

¹Pettersson, Bertil and Axén, Bengt, Thermography, Swedish Council for Building Research, Stockholm, 1980

²Thiel, Philip, Visual Awareness and Design, University of Washington Press, 1981

IV - Representation

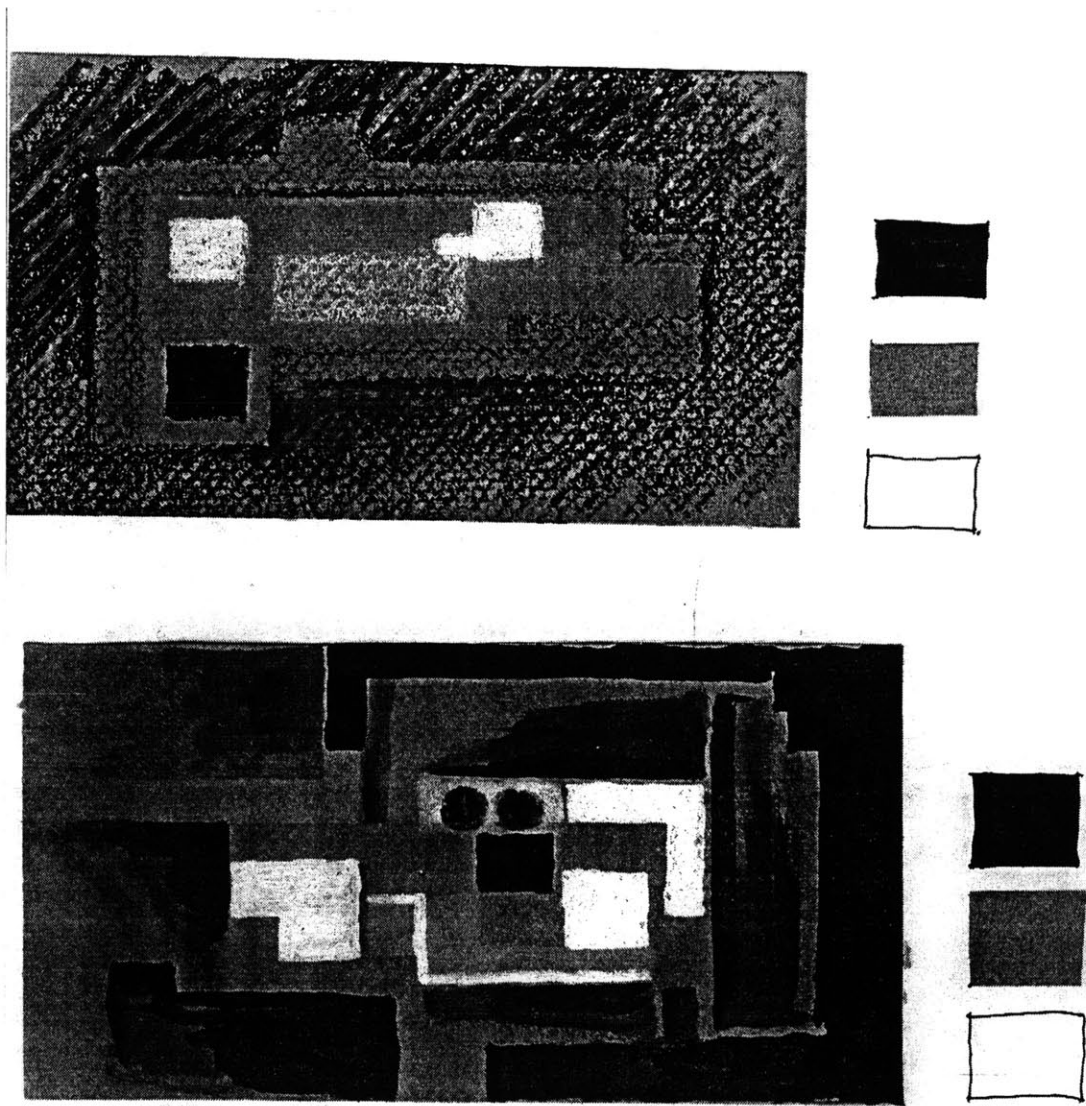


Fig.4.2 Test of thermal grayscale.

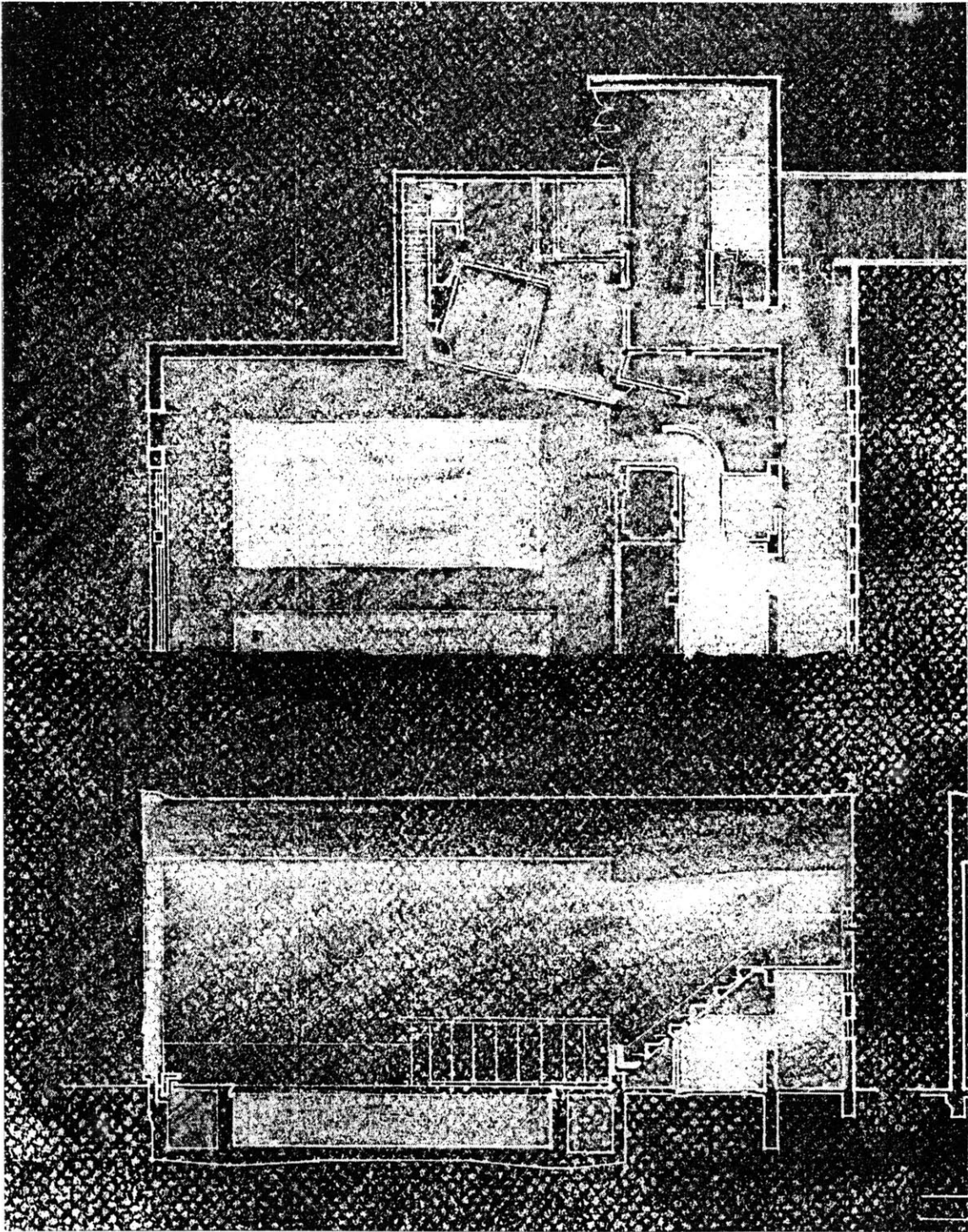


Fig.4.3 Study of M.I.T. Alumni Pool. Winter Morning

IV - Representation

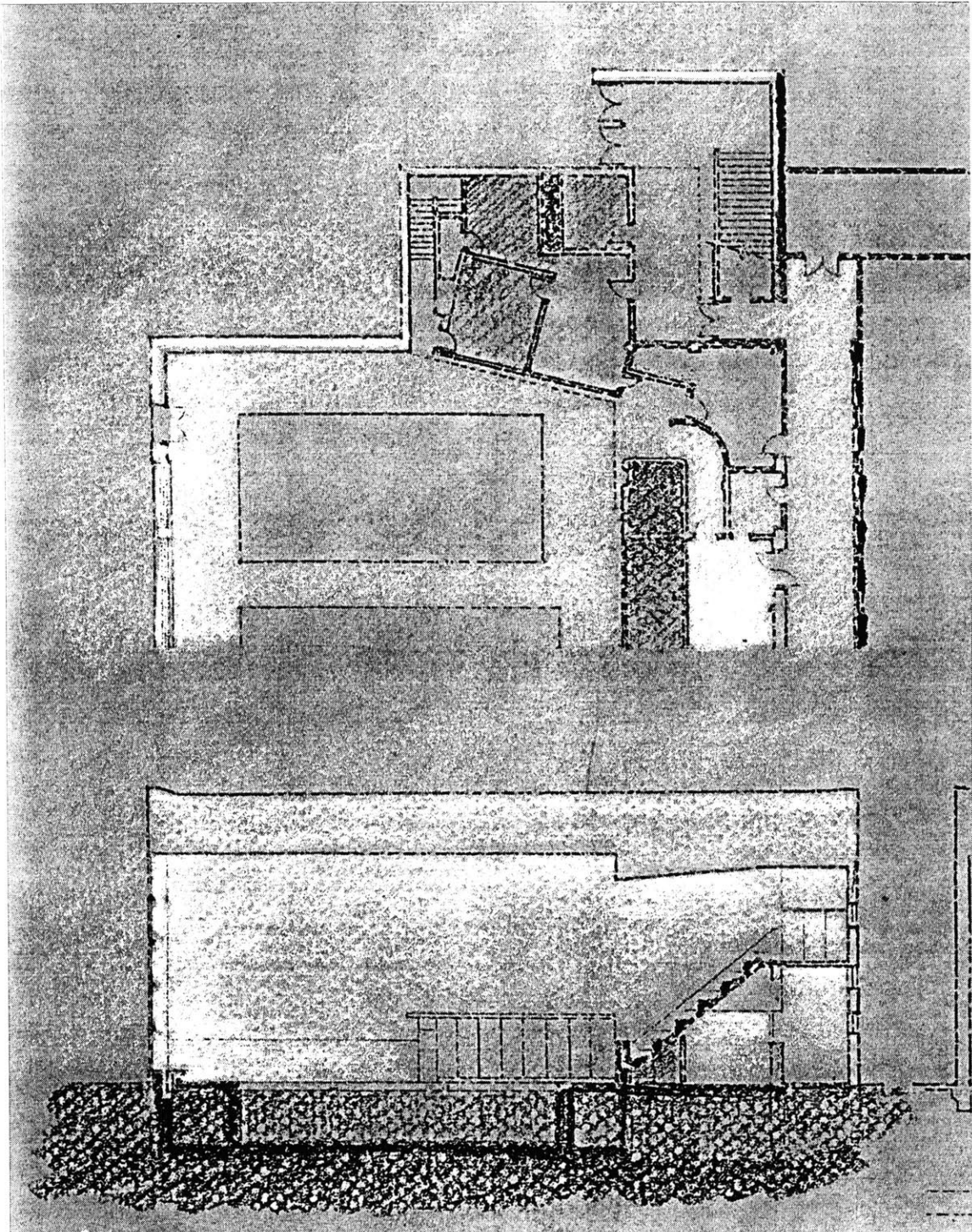


Fig.4.4 Study of M.I.T. Alumni Pool. Fall Morning

IV - Representation

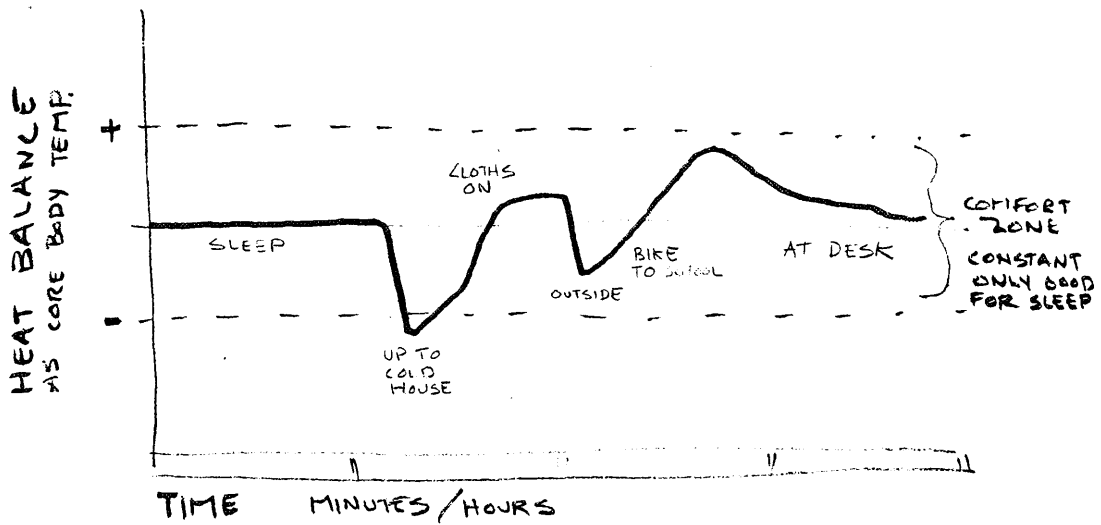


Fig.4.5 Energy flow from sleeping to being at work. This is a qualitative graph, as a sketch of what a quantitative graph might look like.

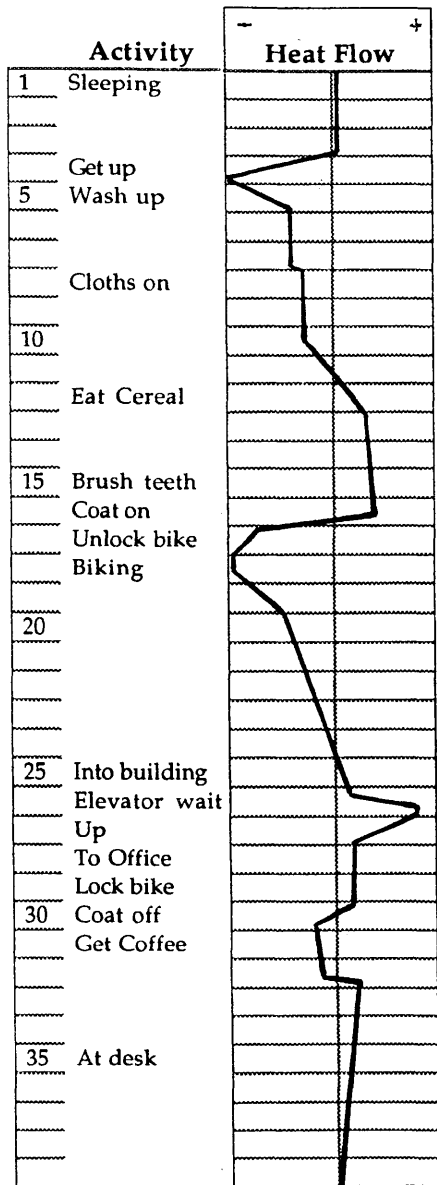


Fig.4.6 Thermal Design Sequence for a Commuter in Winter.

It is the thermal thresholds and intensifications that need to be represented. It is the changing of temperature that is critical to thermal delight. Both steady state and nonsteady state conditions need to be represented so that the interaction between them is clear. ASHRAE defined³ nonsteady state guidelines assume that people are in the space for more than an hour. The occupation of the space is in steady state as thermal conditions are changing. Good thermal design will add thresholds and variations which entail nonsteady state occupation. In addition to ramps, drifts and other non-uniformities, there will be spikes, peaks, valleys, and plateaus indicating thermal and spatial transitions.

Transient Energy Flow: will be defined as that part of the thermal order which represents an accumulation of the factors of thermal comfort using a transient model (Section 3) and emphasizing thermal sensation at the skin.

The first representation of transient energy flow was generated in the process of documenting the thermal experience of waking and biking to work. Fig.4.5. The graph is of variation of energy flow over time. The slope of the graph indicates the rate of thermal change. There is a range of comfort that can accommodate a wide variety of activity. Extreme conditions can be tolerated, and even enjoyed, for short periods of time. Fig.4.6 is a cleaned up version of the first graph.

³ASHRAE Standard 55-1981 Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1981

Thermal Design Sequence for Spectators in Winter.

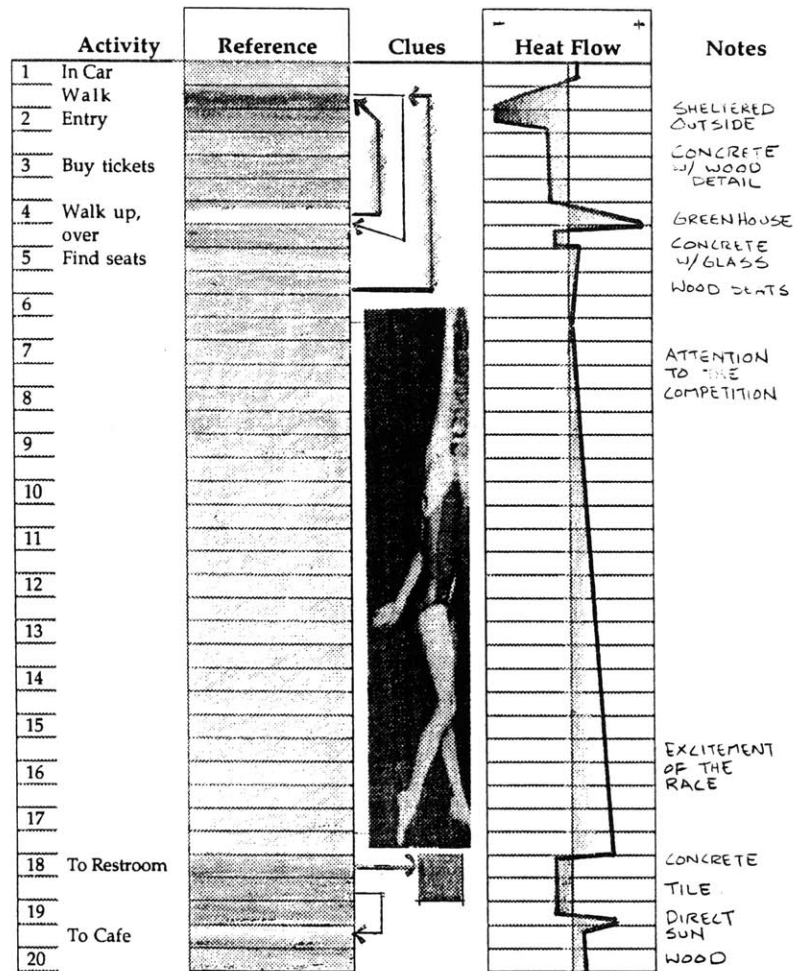


Fig.4.7 Black and White version of heat flow graph. See color plate page 75. -Photo from The New Science of Swimming, Counsilman & Counsilman, Prentice Hall, 1994

The need for a transient energy flow concept was brought out of the development of a thermal program for the design project. (Section 5) The thermal program gradually came to include most of the variables of thermal comfort. (metabolic rate, clothing, humidity, wind, air and radiant temperature) These variables then needed to be combined and given spatial positioning qualities rather than just square footage. The result is a representational system where fields of color rendered in plan, section, or perspective correspond to various slopes and positions of a transient energy flow graph. This system must acknowledge changing time and activity in a drawing/sketch format.

Changing conditions, slope on the graph, are represented with a color scale ranging from yellow/heating/slope up to blue/cooling/slope down. Between these shades of yellow-green, green, and blue-green represent slopes returning to neutral balance. Relatively steady conditions, near horizontal on the graph, are represented with a color scale ranging from orange/position warm to gray/position neutral to purple/position cool. All of these are intended to be within the comfort zone when time is respected.

Fig.4.7 and Fig.4.8

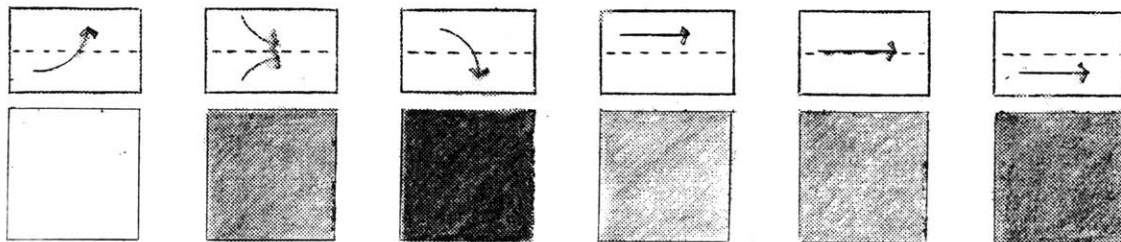
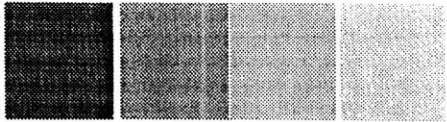
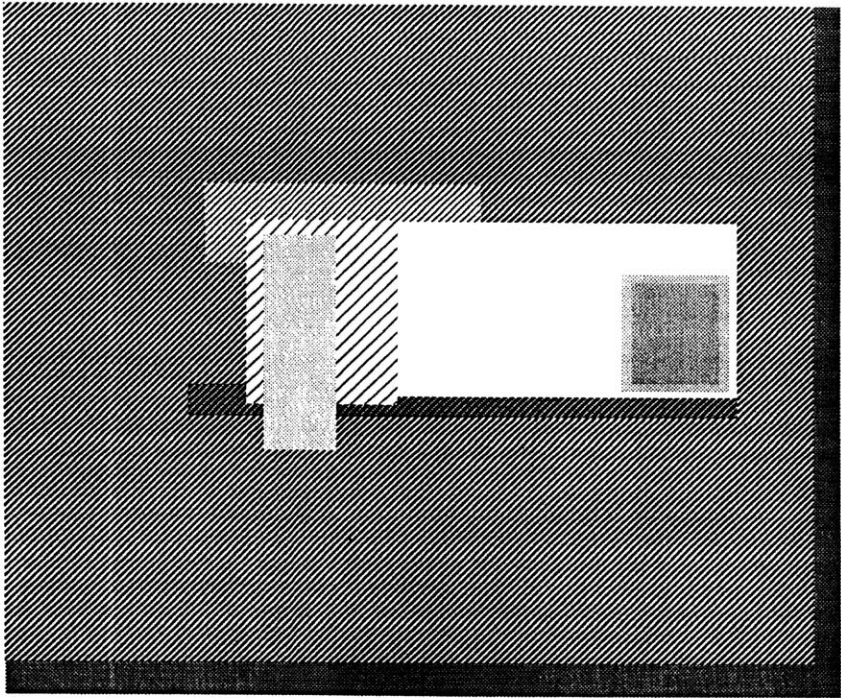


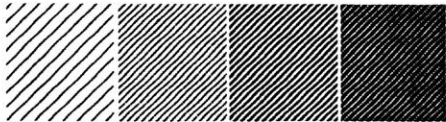
Fig.4.8 Black and White version of Transient energy flow scales. See color plate page 67.

IV - Representation

7/30/14



HOT



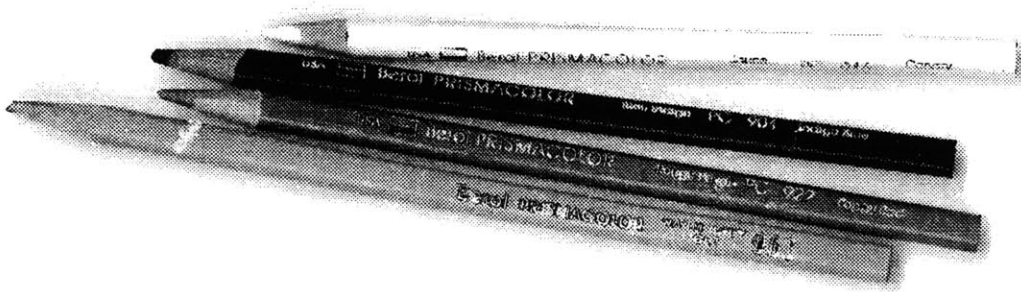
COLD

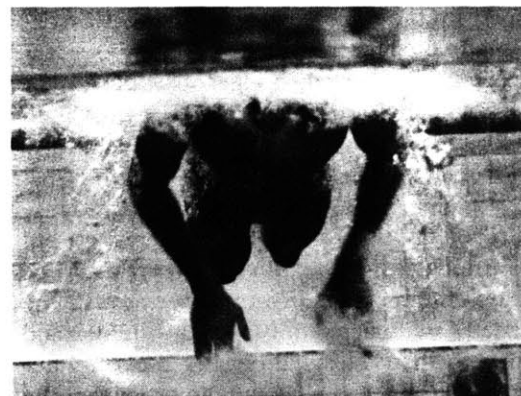
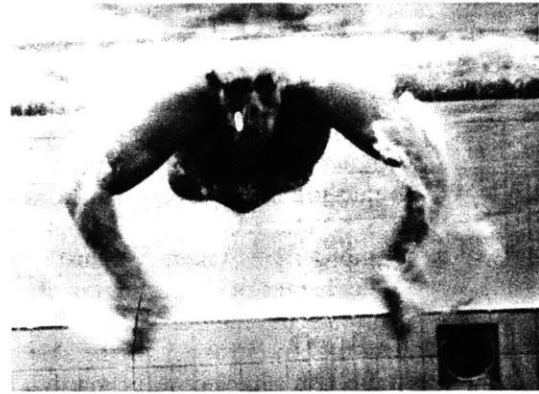
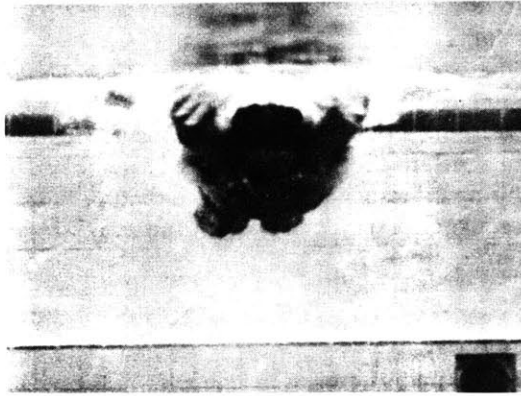
Fig.4.9 One of many failed black and white studies. Neutral is white, extremes toward hot or cold are darker value. Overlapping of hot/dots and cold/hatches was meant to show changing conditions.

Berol PRISMACOLOR
916 Canary Yellow
901 Indigo Blue
922 Poppy Red
963 Warm Gray Light

The combination of two scales, one dynamic and one steady state, excludes the possibility of effectively translating this method to a grayscale. Attempts were made at using hatch patterns to differentiate the two gray scales. Fig.4.9 These studies were not successful in application. The method of employing the color scales using pencil was very effective for a number of reasons. In both scales the colors were chosen such that blending would have an intuitively correct result. When hot/yellow comes up against cold/blue you naturally get neutral/balancing/green. Dark orange laid over yellow or blue changes them to their steady state companions orange and purple. The sketch is done with four pencils.

Transient energy flow is the part of thermal order that this thesis has focused on. This method of transient energy flow proved to be the most useful and influential in application to the design project.





-Photography from *The New Science of Swimming*, Counsilman & Counsilman, Prentice Hall, 1994

V Testing the Hypothesis

1. Choice of site and program

The project is a Public Pool for the city of Boston. The Public Pool is a building type that requires an extreme range of thermal conditions and a cultural presence. The Public Pool demands an intensified relationship between the body and the built environment. The Pool provides a good vehicle for thermal exploration.

The Metropolitan District Commission (MDC) currently operates two seasonal outdoor pools in Boston. An indoor pool complex will supplement the MDC racquet and skating facilities providing a wide range of year round fitness and recreation opportunities. A year round pool would also be capable of hosting large competitive events and provide competitive training facilities, making it an attractive addition to the city's public sphere.

*He learnt to swim and to row, and entered
into the joy of running water; and with his
ear to the reedstems he caught, at intervals,
something of what the wind went whispering
so constantly among them.*

*-Kenneth Grahame in
"The Wind in the Willows"*

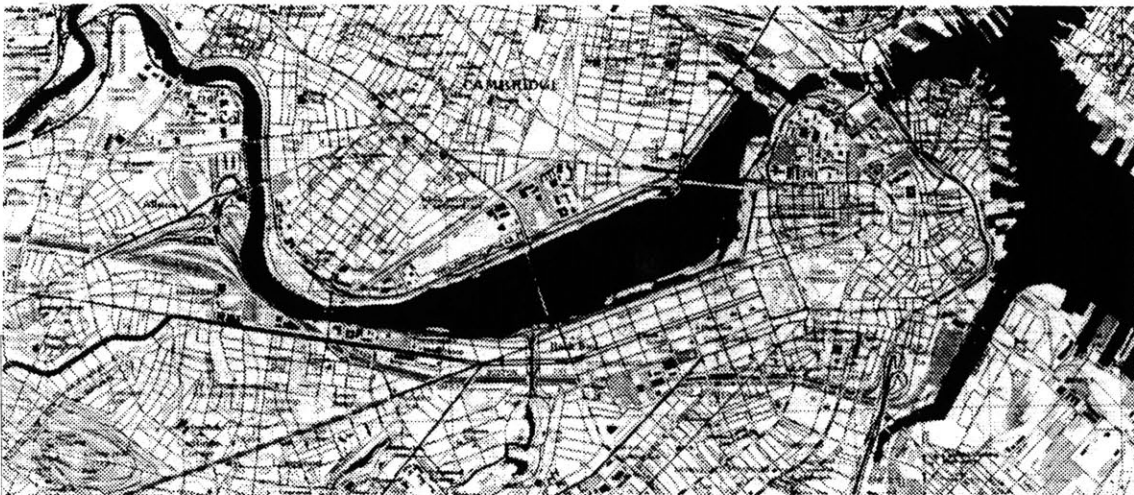
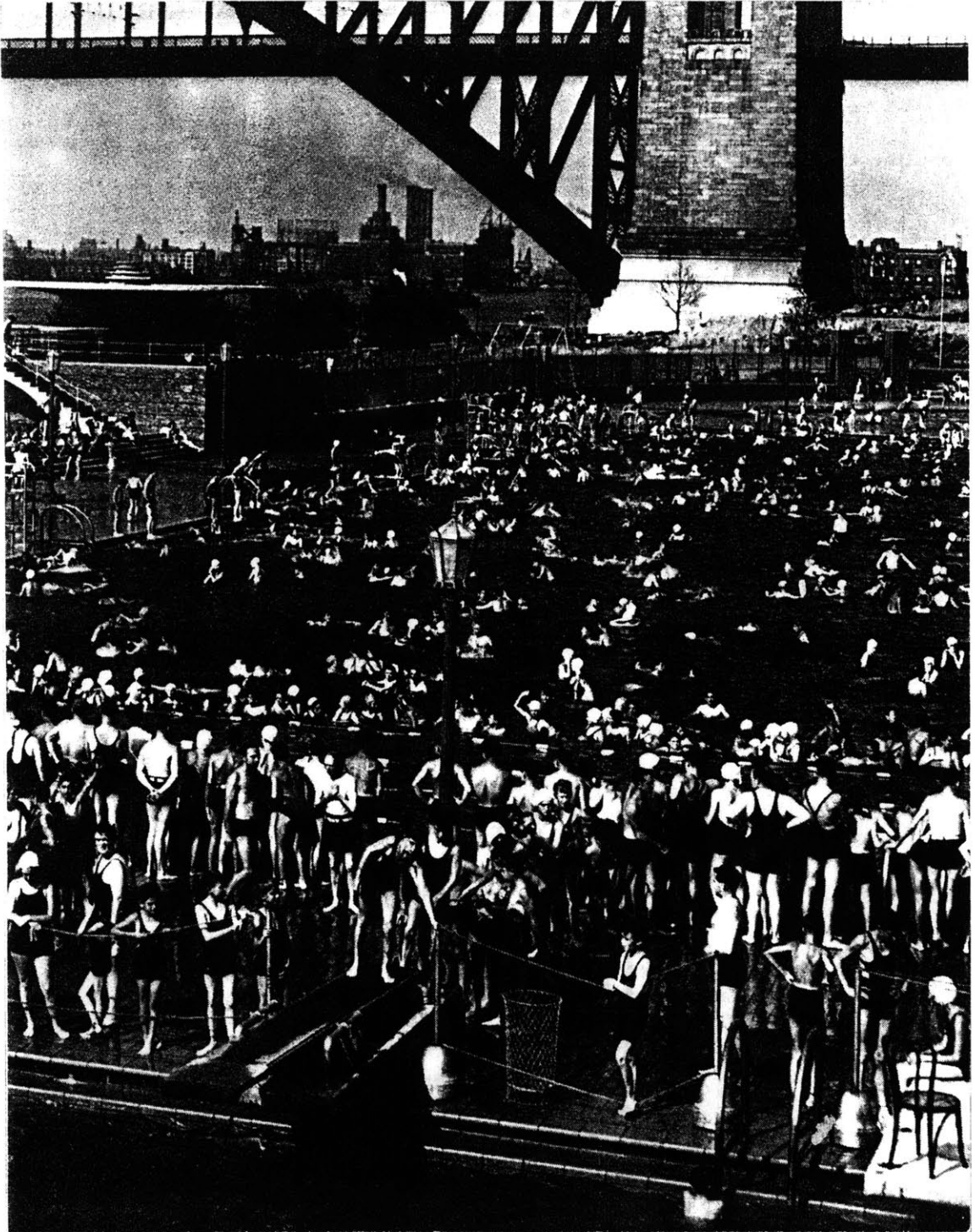


Fig.5.1 Boston, Cambridge, and The Charles. Map illustrating the new channel cut between Storrow Drive and the Charlesbank play fields.

V - Testing the Hypothesis



Astoria Pool, New York City
- Photography, Max Ulrich, "New era of public works", Metropolis, v13 n1 July-Aug.1993, p17

The role of the Public Pool as a component in the life and identity of a city is a separate thesis that cannot be completely explored here. Many issues of the public pool in society today also relate to the search for a qualitative relationship of the human body to its thermal and spatial surroundings. Starting in the 1930's with the WPA projects¹ and continuing into the 1950's many cities in the U.S. built impressive public pool facilities. These projects presented a positive attitude toward the relationship of people to their city. In a pool facility there is a very intimate relationship between the body and public space. In recent decades this type of facility has been largely privatized in the form of health clubs, or restricted to educational institutions. This shift follows a more general decline in civic involvement and responsibility.

The new Asphalt Green Swim and Sports Center is Manhattan's first built to competition standards and the only public pool built in the last 20 years.^{2&3}

¹"Visible City: WPA Pools", Metropolis, v7 n1
July-Aug.1987 p66

²"New era of public works", Metropolis, v13 n1
July-Aug.1993 p17

³MacDonald, Effie C., "Manhattan Oasis",
Architecture Review, v194 n1170 Aug.1994

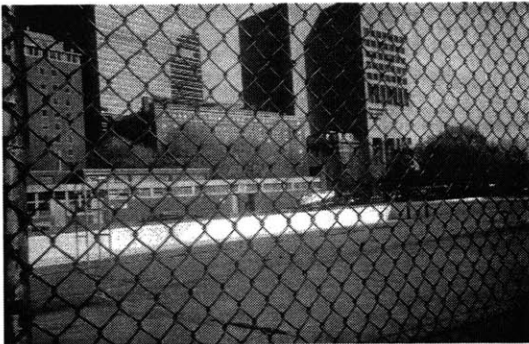


Charlesbank Playfields from Longfellow Bridge.



Charlesbank Playfields as they meet Storrow Drive.

The existing MDC Lee Pool is located on the east bank of the Charles River between the Museum of Science and the Longfellow bridge. During all but the summer months the pool is an unsightly fenced off area. There are no real connections to the city or the river. The pool's river frontage takes the form of a parking lot. The site is easily accessible from the red and green MBTA lines, and by car via Storrow Drive. The Charlesbank play field area is currently a weak petering out of the Esplanade. The site's central location and opportunities to better link river edge recreation through to new central artery parks make it ideal for a public recreation project. The project is a redesign of the Lee Pool site to include year round swimming facilities, connections to the city and river, and of course, thermal delight.



View of the existing pool.



Charlesbank Playfields as they meet the river. The Longfellow bridge is in the background.



Fig.5.2 Charlesbank Playfield Site - From Boston Redevelopment Authority documents.

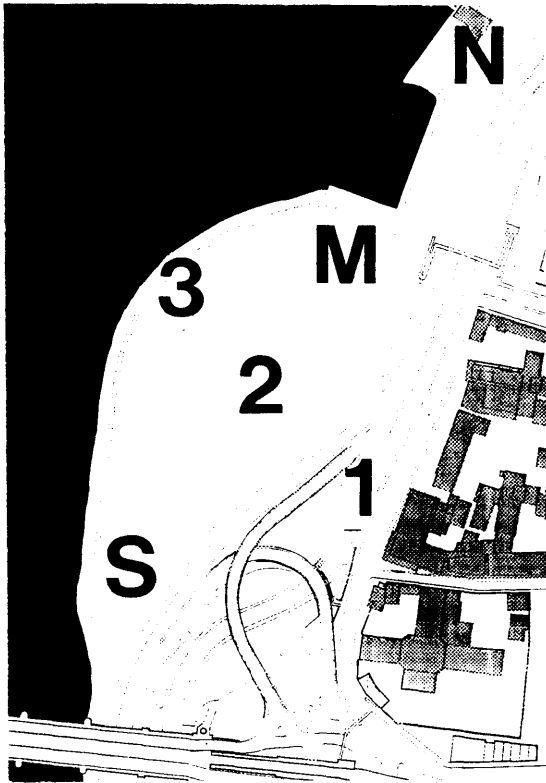


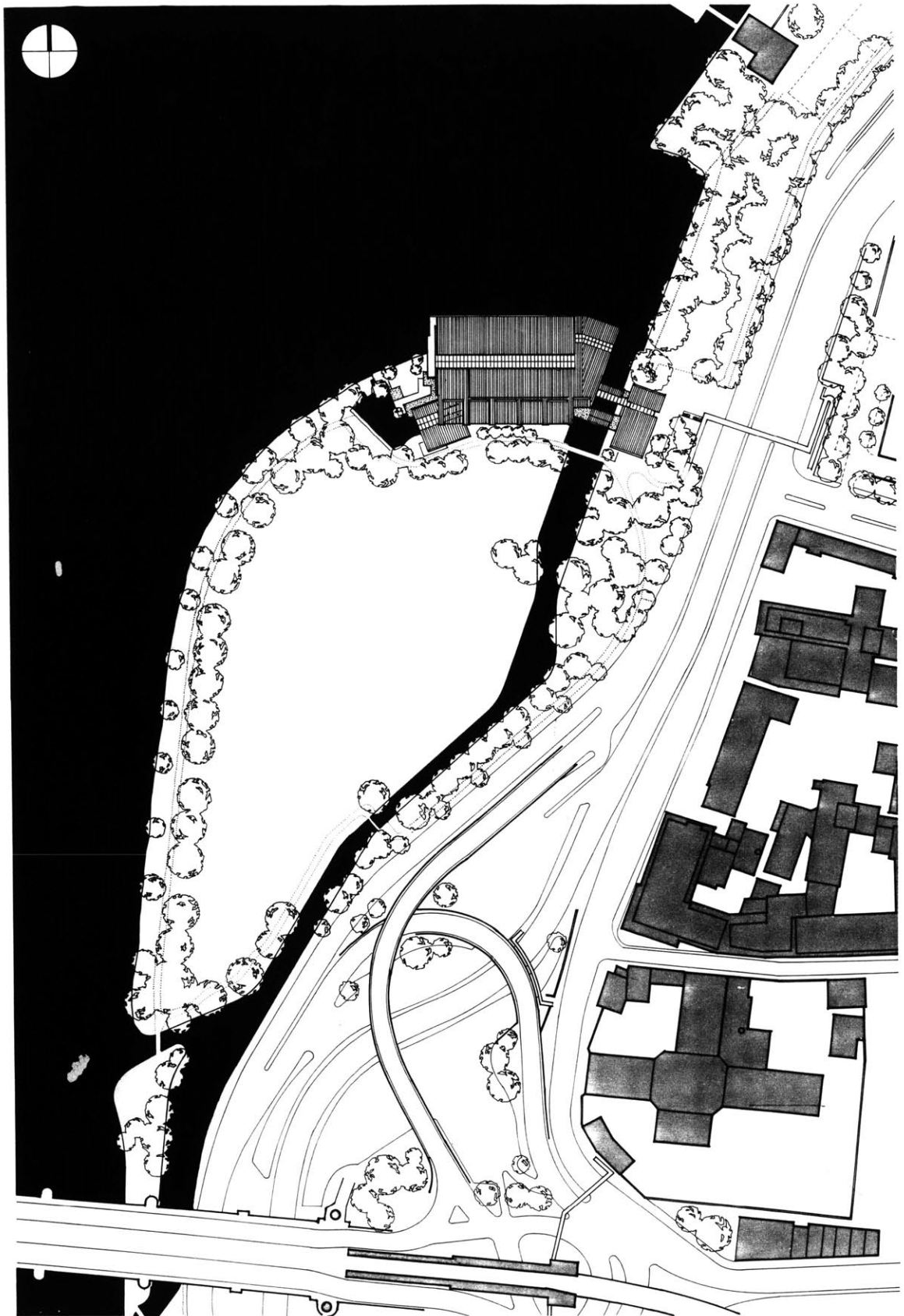
Fig.5.3 Existing Site Plan

2. Process of design

a. Site issues

Three aspects of the existing site were taken as requirements. Fig.5.2

1) The project would not change the operation of Storrow Drive. 2) The number of play fields would not be decreased. 3) The biking and walking trails would continue through the site. There are three buildable zones on the site, north (N), middle(M), and south(S) Fig.5.3. The size of the north location is limited by the Museum of Science and ship canal. It was determined that the area required for an Olympic sized pool could not be accommodated in this zone. The south zone is also limited in size, is crowded by the Longfellow bridge, has noise conflicts with the MBTA, and problems of access. The middle zone offers the best relationship to the play fields and the river, good access and solar orientation.



V - Testing the Hypothesis



The Charlesbank Playfields and most of the existing trees are retained on the site.

At the largest thermal conception, the pool is a warm place in cold surroundings in winter and a cool place in hot surroundings in the summer. In both cases it acts as a place of refuge. An additional river channel is cut along Storrow Drive to form stronger connections to the whole of the Charles River basin recreational area and as a means of insulating the pool and play fields from traffic. Fig.5.1&5.4 The new channel creates an island as a place of retreat, recreation, and reflection. The channel provides for a new route of the bike and pedestrian path under Longfellow bridge. The path now goes under a different span than vehicle traffic. At the pool site, bridges over the channel form a transformative sequence from the city to the island.

Opposite page: Fig.5.4 Proposed site plan

V - Testing the Hypothesis

Natatorium	50m x 15.5m main pool	8,200ft ²
	40ft x 20ft learning pool	800ft ²
	45ft x 35ft diving pool	1,575ft ²
	Minimum platform area	4,544ft ²
	Total	15,119ft ²
	Occupancy per 30ft ² pool+deck = 504	
Spectator stands		
	Occupancy 1,000 @ 7ft ²	7,000ft ²
Restrooms	Men's	200ft ²
	Women's	200ft ²
Locker rooms	Men:	
	Dressing-locker room	1,000ft ²
	1 water closet	
	2 urinals	
	4 lavatories	
	12 shower heads	
	Women:	
	Dressing-locker room	1,000ft ²
	3 water closets	
	4 lavatories	
	12 shower heads	
Sauna		200ft ²
Steam room		200ft ²
Lobby		300ft ²
Lounge		400ft ²
Cafe		300ft ²
Exercise/Multi-Purpose		2,000ft ²
Classrooms	2 @ 400 ft ²	800ft ²
Lifeguard showers		250ft ²
Offices	2 @ 200 ft ²	400ft ²
Storage		1,000ft ²
Mechanical Equipment		1,500ft ²
Terrace		1,500ft ²
Outdoor Pools		4,000ft ²
Parking	50 cars	
	Total Roofed	35,869ft ²

b. Thermal program

A Conventional program for the Boston Public Pool was written as a starting point for explorations into a thermal program.

A series of thermal programs were developed as an exploration of how to begin stating thermal intentions. Figs.5.5-5.8

Locker rooms

Males:	Dressing-locker room	1,000ft ²
	3 water closets	
	2 urinals	
	4 lavatories	
	6 shower heads	
Females:	Dressing-locker room	1,000ft ²
	4 water closets	
	4 lavatories	
	6 shower heads	

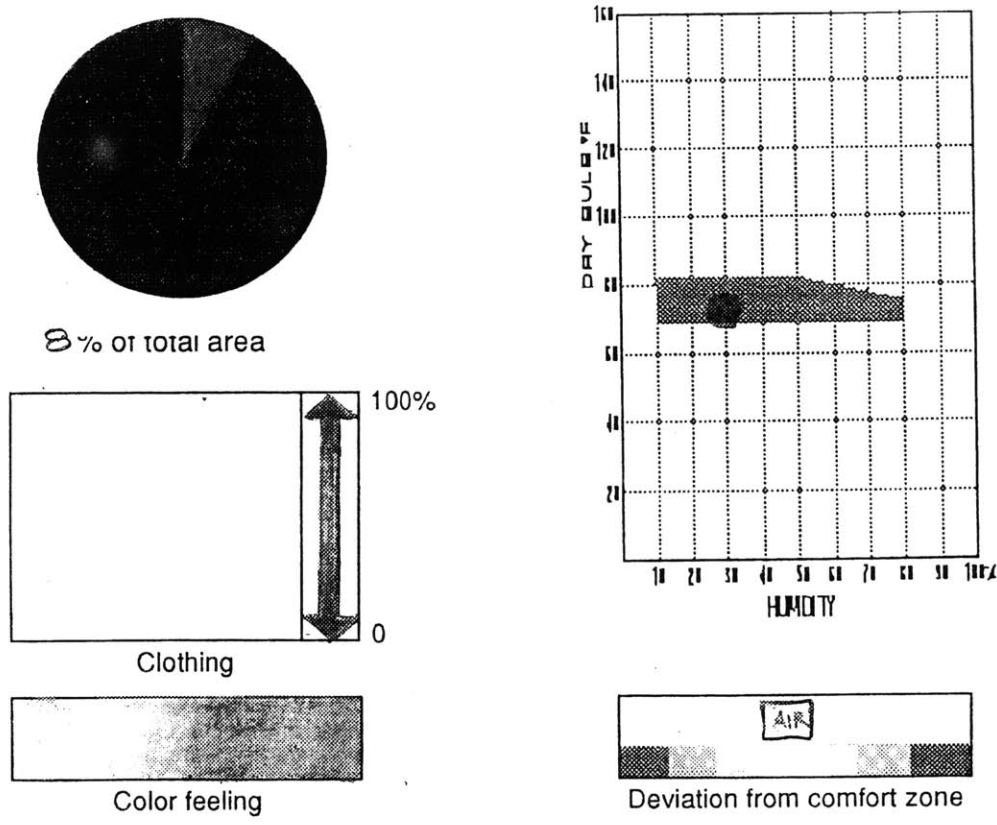


Fig.5.5 First thermal program study using a standard form for each space listed in the conventional program. 'Locker rooms' is one of eleven. The spot the bioclimatic chart is the temperature target for that space. The arrow in the clothing section indicates that clothing level ranges from nothing to fully dressed in this space.

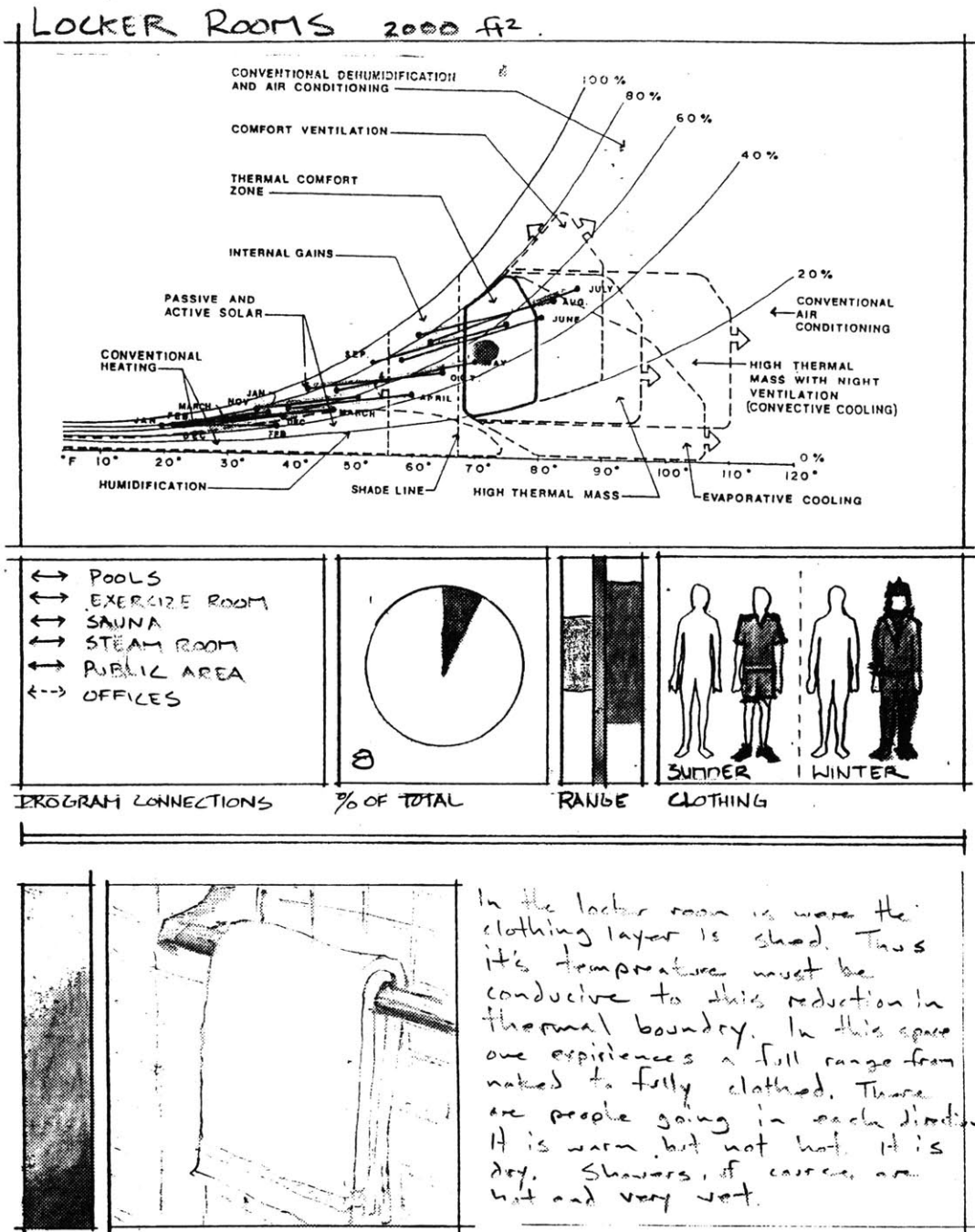


Fig.5.6 This is the same locker rooms in a revised format. Quantifiable and purely qualitative factors are separated. Attempts are made to make it more graphic. This study's biggest drawback is that the 'RANGE' information was given the least amount of space. In retrospect, this turns out to be one of the most important items.

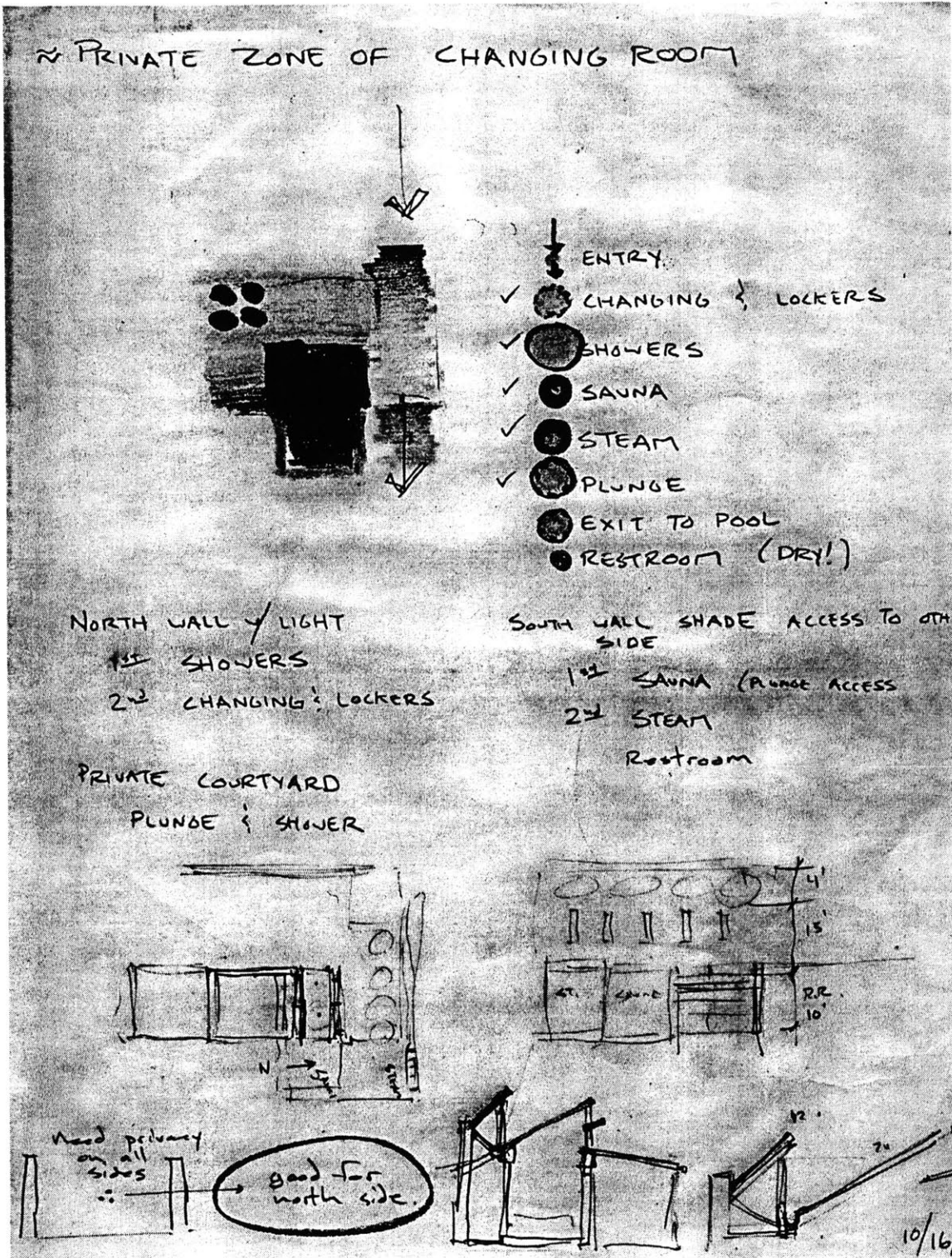


Fig.5.7 This page of notes is the first attempt to move the thermal program study towards a spatial understanding.

c. Thermodel

The Thermodel was an experiment in making a touchable thermal diagram. The various materials in the model draw heat from the hand at different rates and thus evoke various thermal moods. Fig.5.8 is such a diagram illustrating relationships between wet and dry areas in the pool complex.

d. Prioritizing Thermal/Other issues

Some form issues are in realms which are beyond or not influenced by specific thermal issues. An example is the orientation of the large pool. This is a decision at a scale the size of the Charles River; city scale. An attitude about the city and river have priority over efficiencies and programmatic specifics of a project such as this. To force in a thermal issue would cause problems. However, tweaking within set priorities is fine. An example in an early study model is the 20 degree shift from Storrow Drive to allow more sun to the interior and make better opportunities for solar hot water. Fig.5.9. Integration of thermal design means that it is a balanced part of the whole design not the one and only driving force in the project. If this method of thermal design is to have broader application, a balanced approach is necessary.

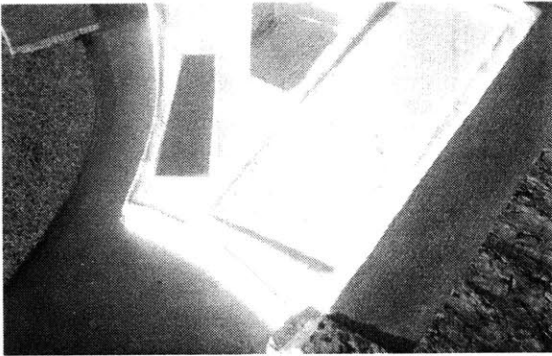


Fig.5.8 Thermodel

e. Thermal design of the pool

The first 'thermal mood' drawing of the pool had no form or spatial relationships, just mood and the beginning of an experiential sequence. Fig.5.10 pp61,63 The next stage of drawings began to have some diagrammatic relationships, but were still formless. Fig.5.10 At these early stages there also was very little rigor to the coloring scheme. The colors chosen just felt right.

Simultaneous to the thermal representational work, a series of site massing and organizational studies were developed. At first these studies proceeded in a very conventional fashion without a large amount of influence from the new thermal studies. The thermodel, Fig.5.8, and last site scale model, Page 77, began to have more dialog with the thermal studies.

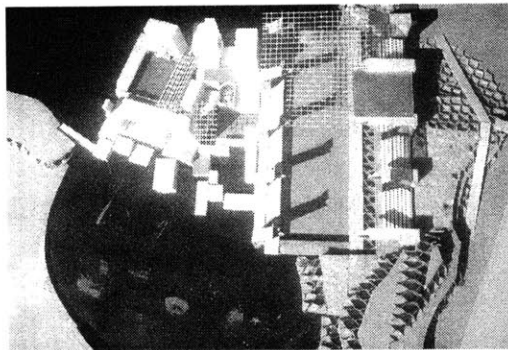
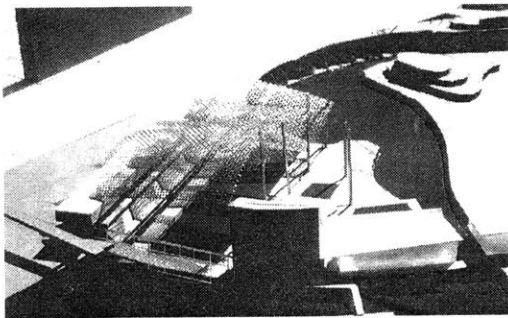
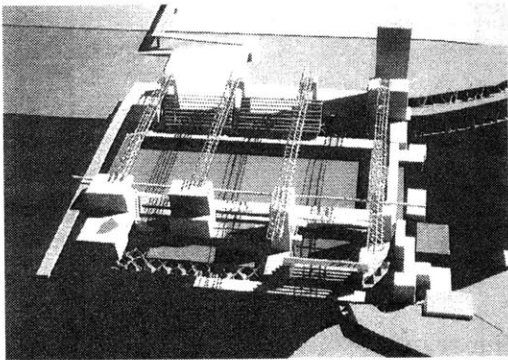


Fig.5.9 Three study models with different pool orientations and configurations. In chronological order from top to bottom.

Once the idea of transient heat flow representation was developed, a more rigorous pass at thermal design could be attempted. Fig.5.11 pp65,67. This first pass at heat flow representation includes summer and winter drawings of a complete slice through the building and adjacent site. These drawings in conjunction with other issues motivated a reworking of the model plans and sections in order to better respond to the thermal intentions. The bridge for spectator access was moved and rethought in terms of a transient heat flow experience. Then entry area was reorganized to put area which always wanted to be cool towards the north. The reorganization also strengthened the overall entry sequence. At this stage as well more of the smaller scale decisions regarding materials and construction were adjusted according to the thermal plan. The particular combination of steel, tile, concrete, and wood in the showers and locker rooms was defined according to the thermal design and use requirements.

The showers are tiled concrete receiving natural light through glass block. Night lighting is outside the block to insure privacy. A drying area is provided adjacent to the showers in order to keep the locker area from becoming to wet. The materials in the lockers, located on a steel bridge over the water, contrast the shower area. They are framed in wood and have clear, operable glazing. The materials and space feel warm and dry. There is connection to the outside.

The next round of thermal representations were summer and winter heat flow drawings which take a zoom lens approach rather than a whole building slice. Fig.5.12 pp69,71

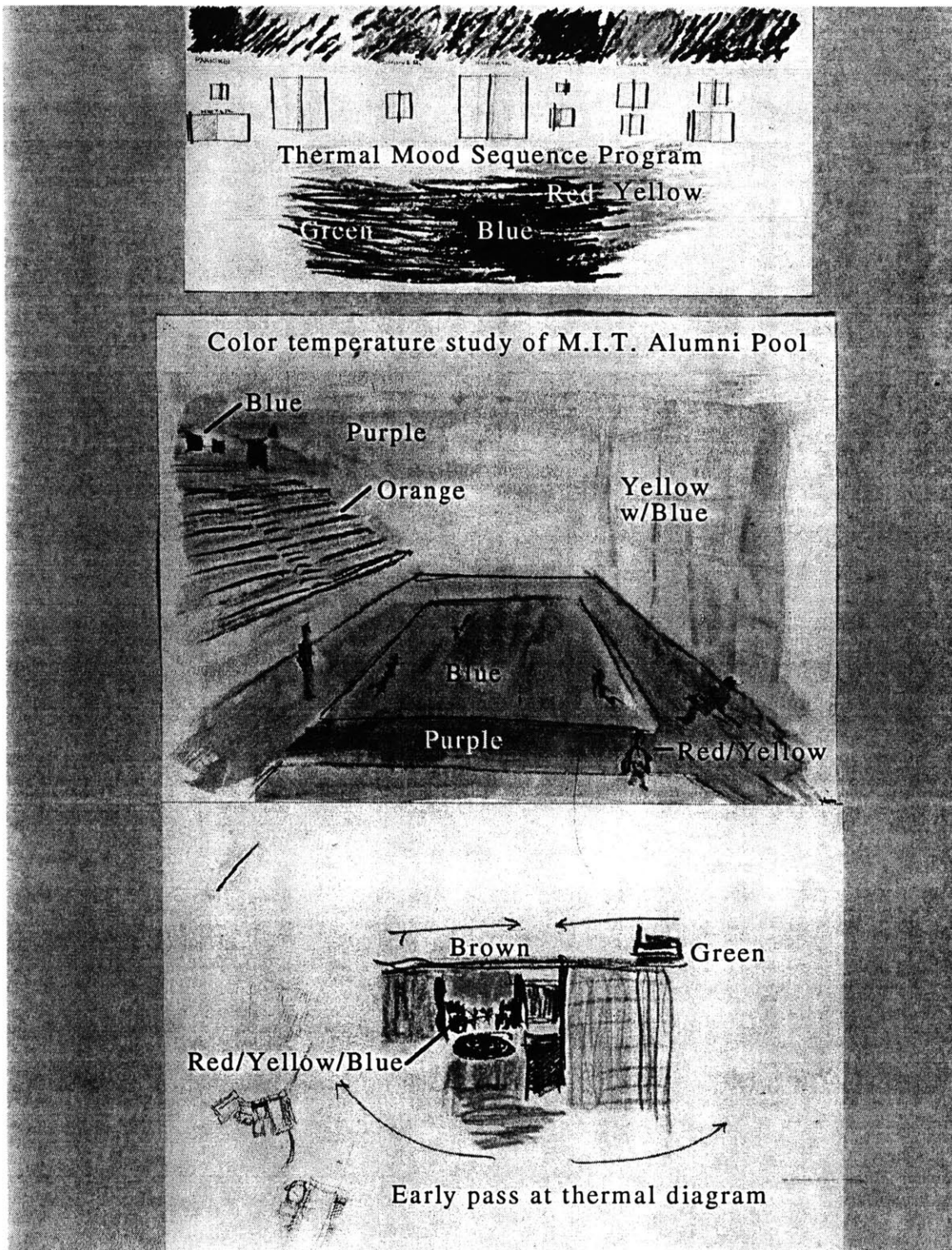


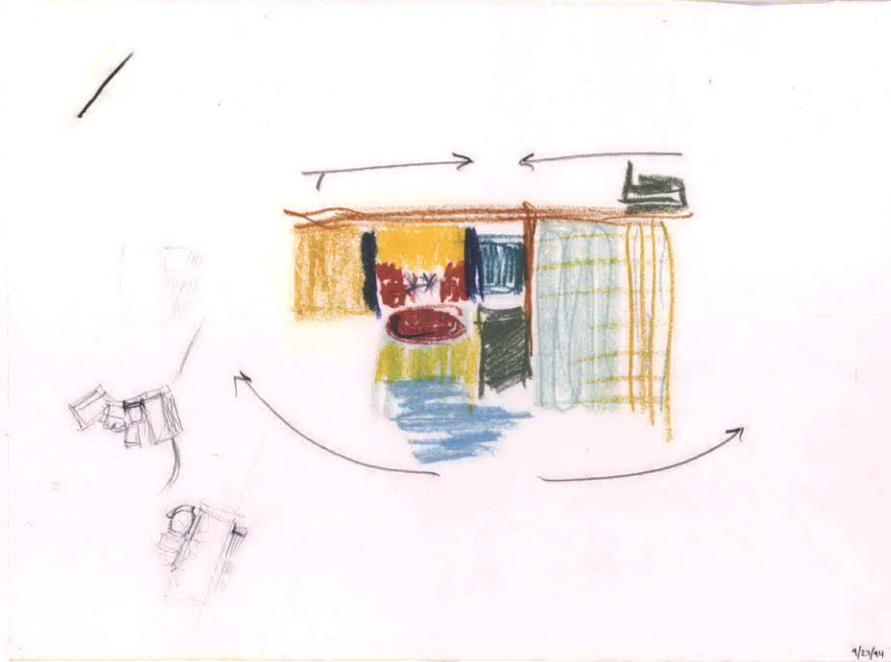
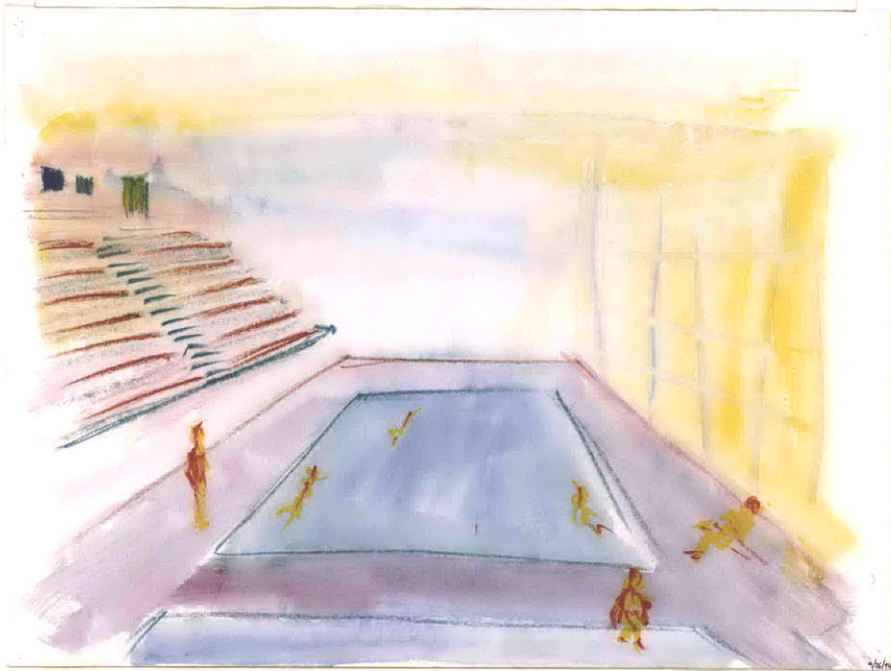
Fig. 5.10 Early color studies
Top: Thermal Mood Program
Middle: Study of M.I.T. Alumni Pool, first stages of a relative heat flow method of representation.
Bottom: Thermal diagram with non-specific coloring.

Opposite Page: Fig.5.10 Early color studies

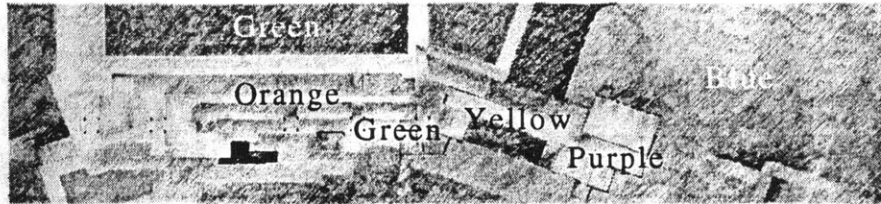
Top: Thermal Mood Program

Middle: Study of M.I.T. Alumni Pool, first stages of a relative heat flow method of representation.

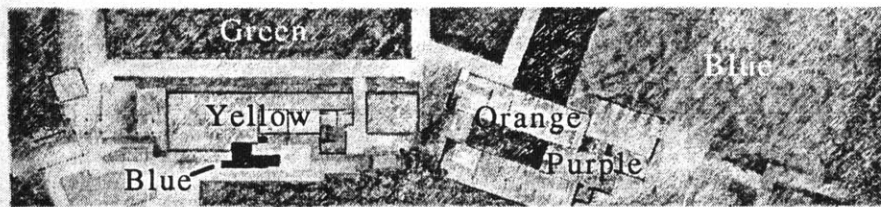
Bottom: Thermal diagram with non-specific coloring.



Spectator Areas - Winter



Key to scales
 yellow-green-blue-orange-grey-purple

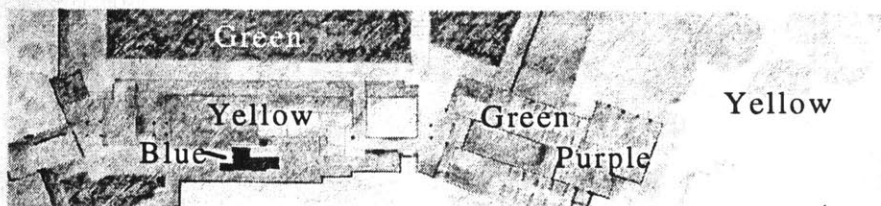


Swimmer Areas - Winter

Spectator Areas - Summer



Key to scales
 yellow-green-blue-orange-grey-purple

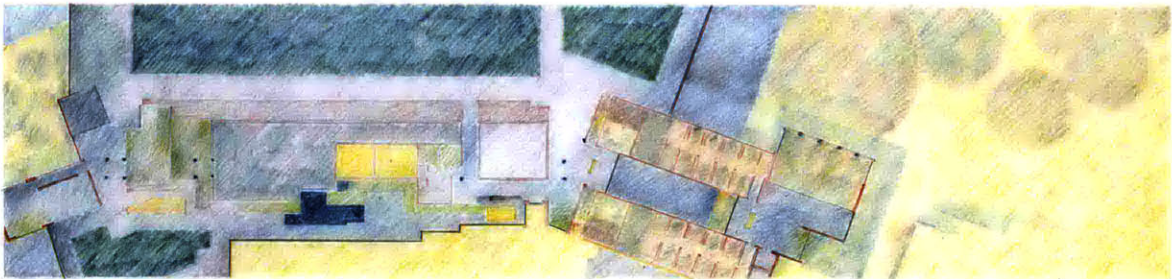
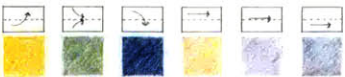
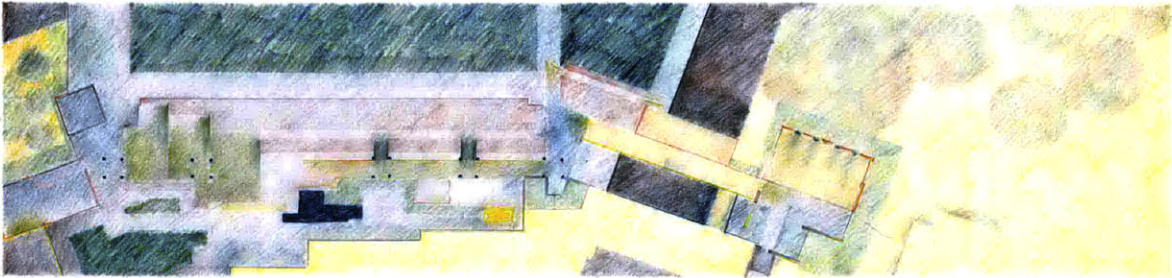
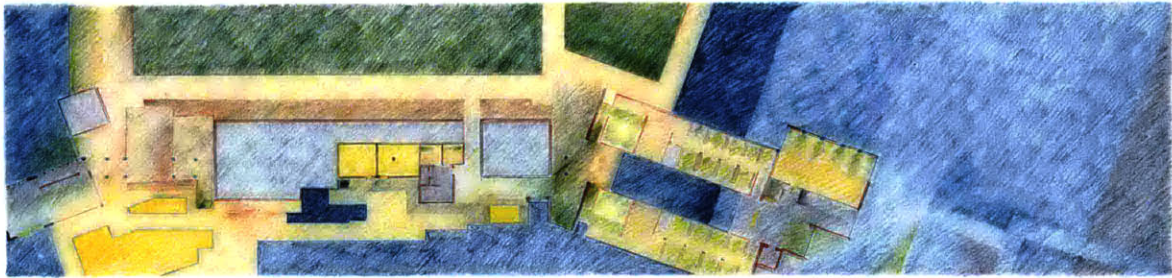
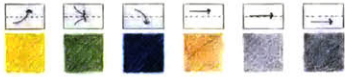
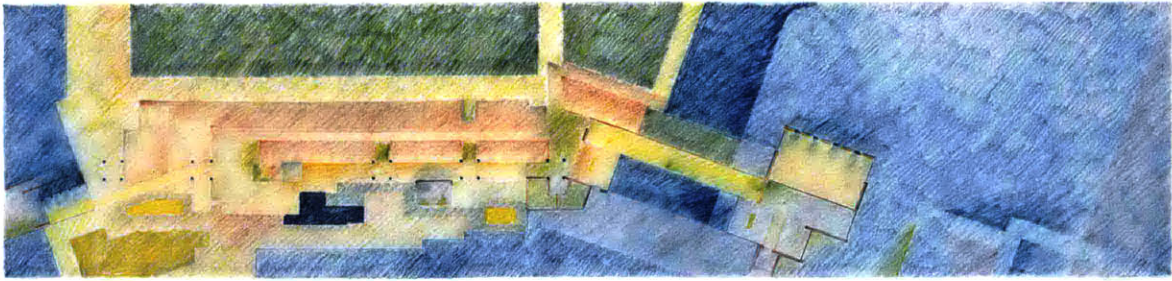


Swimmer Areas - Winter

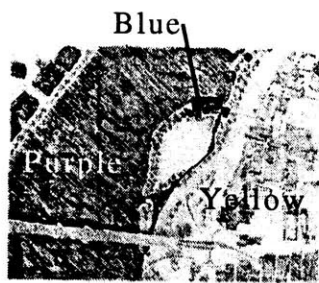
Color Pencil Rendering using two scales
 yellow-green-blue dynamic transient energy flow
 orange-grey-purple steady state energy flow

Fig.5.11 First spatial and transient flow representation.

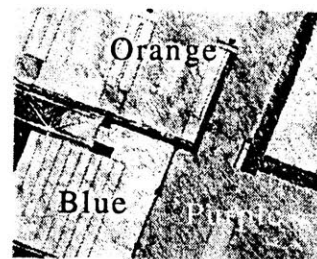
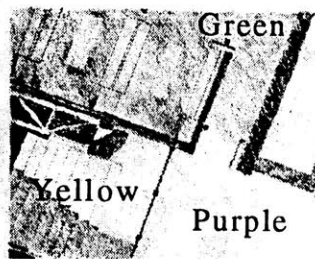
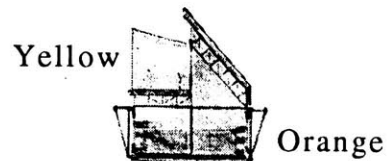
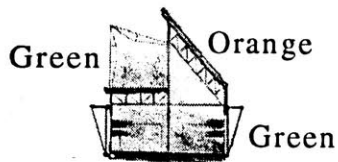
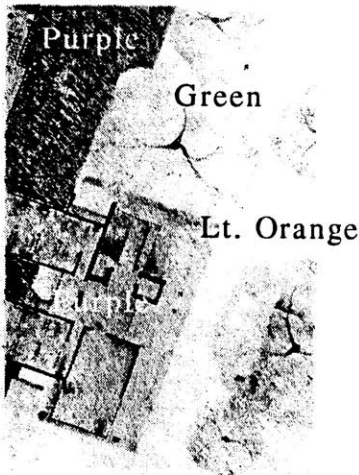
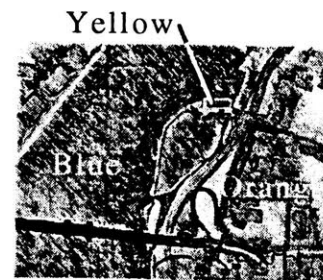
Opposite Page: Fig.5.11 First spatial and transient flow representation.



Summer



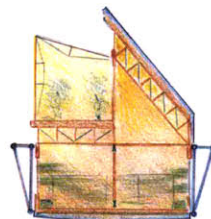
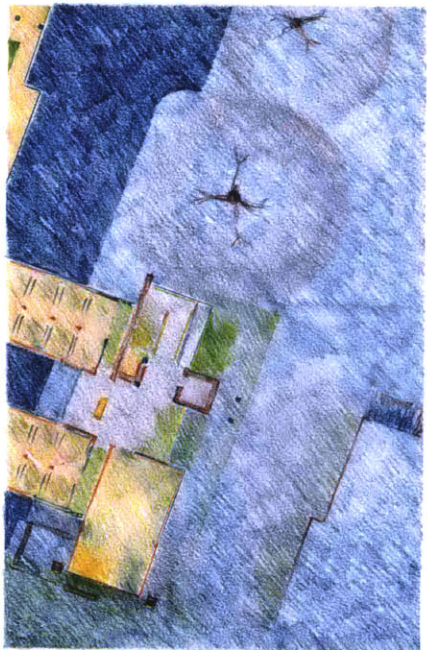
Winter



Color Pencil Rendering using two scales
yellow-green-blue dynamic transient energy flow
orange-grey-purple steady state energy flow

Fig.5.12 Transient energy flow representations at four scales in summer and winter.

Opposite Page: Fig.5.12 Transient energy flow representations at four scales in summer and winter.



Thermal Design Sequence for Spectators in Winter.

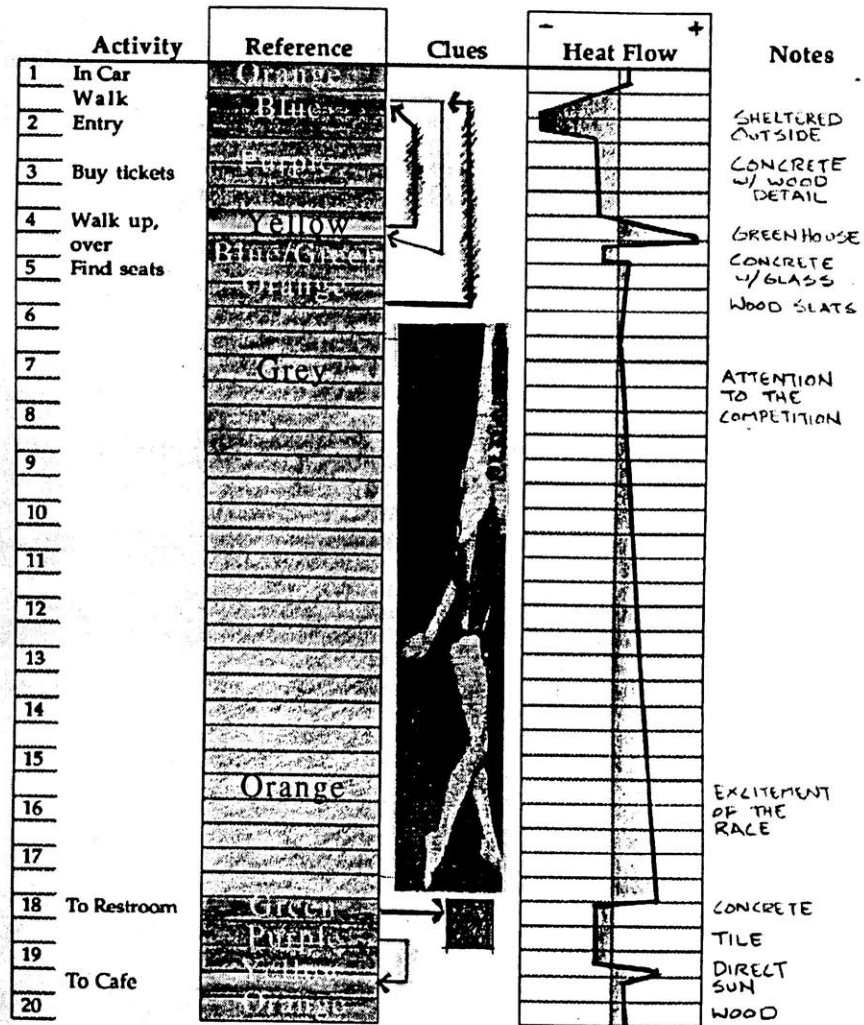
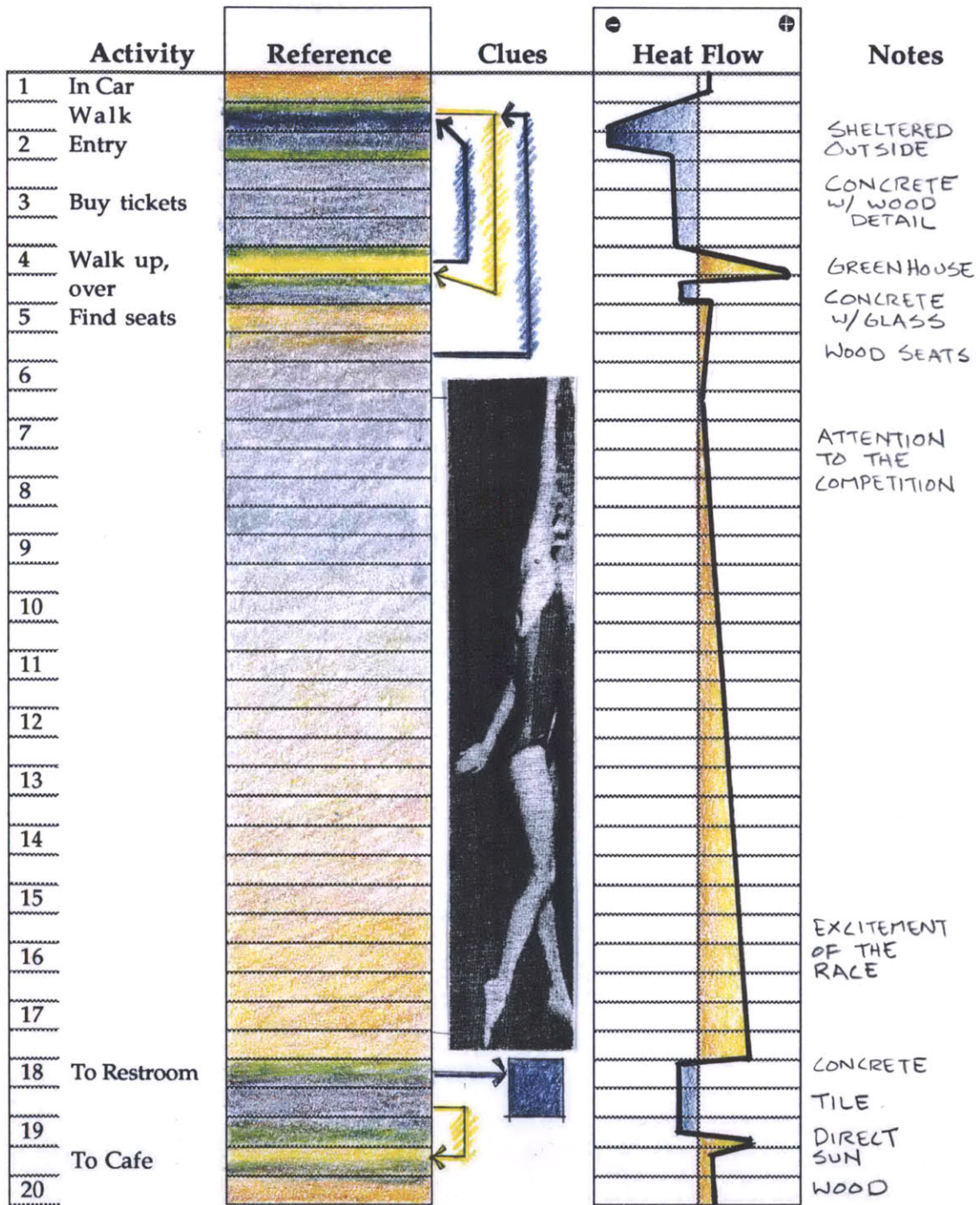


Fig.5.13 Thermal Design Sequence
 -Photo from The New Science of Swimming, Counsilman & Counsilman, Prentice Hall, 1994

Opposite Page: Fig.5.13 Thermal Design Sequence
-Photo from The New Science of Swimming, Counsilman & Counsilman, Prentice Hall, 1994

Thermal Design Sequence for Spectators in Winter.



SHELTERED
OUTSIDE

CONCRETE
W/ WOOD
DETAIL

GREENHOUSE

CONCRETE
W/GLASS
WOOD SEATS

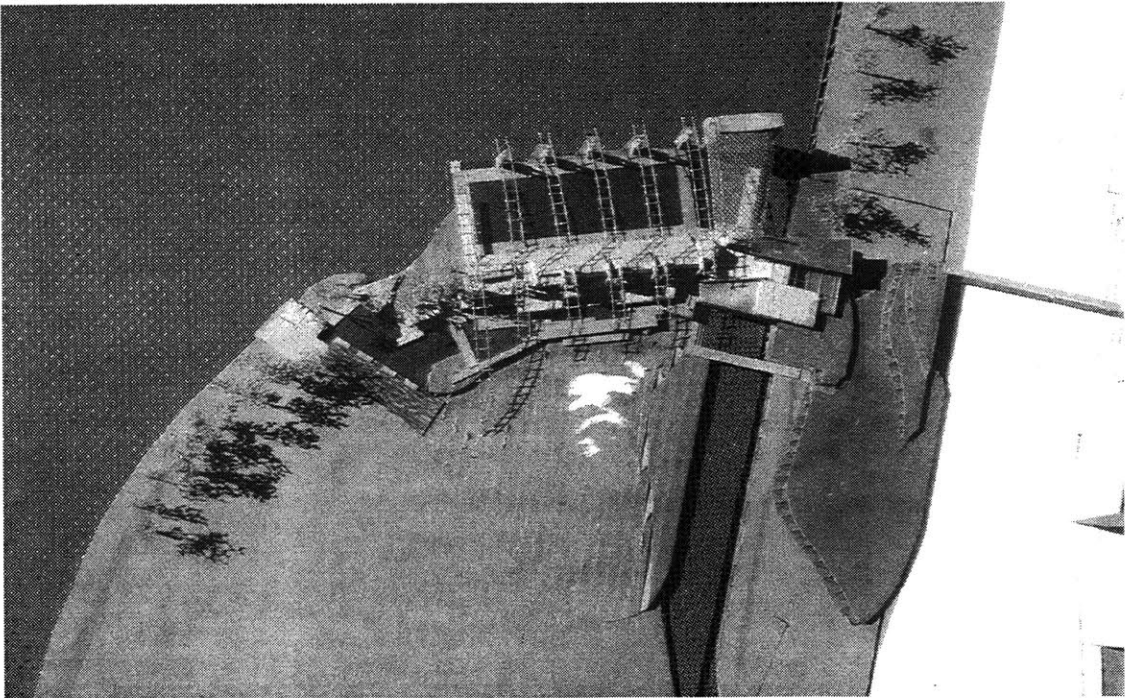
ATTENTION
TO THE
COMPETITION

EXCITEMENT
OF THE
RACE

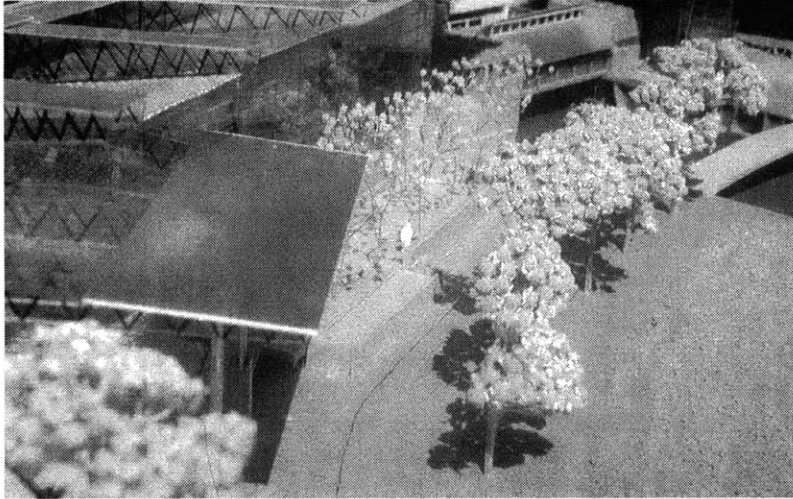
CONCRETE
TILE

DIRECT
SUN
WOOD

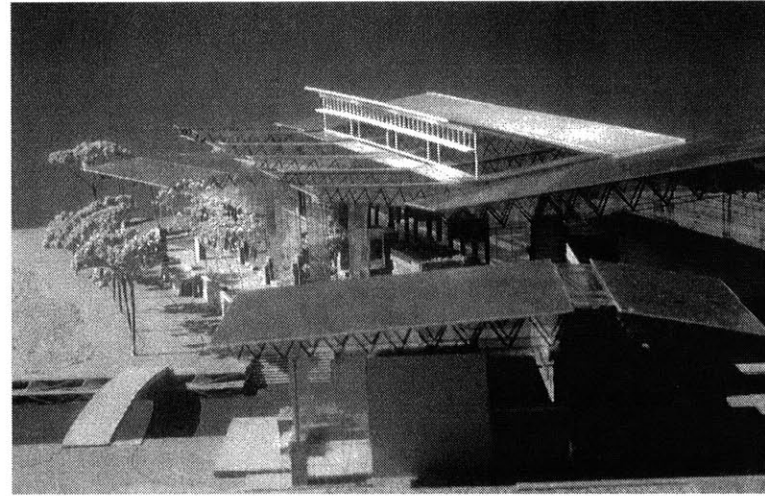
Following are the last round of design drawings and photos of the 1/16"=1'-0" study model.



Last site study model



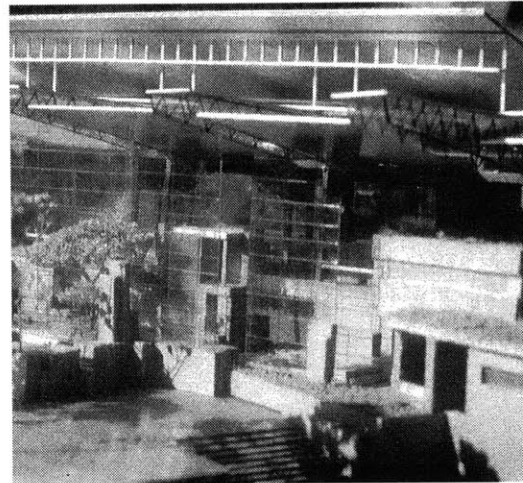
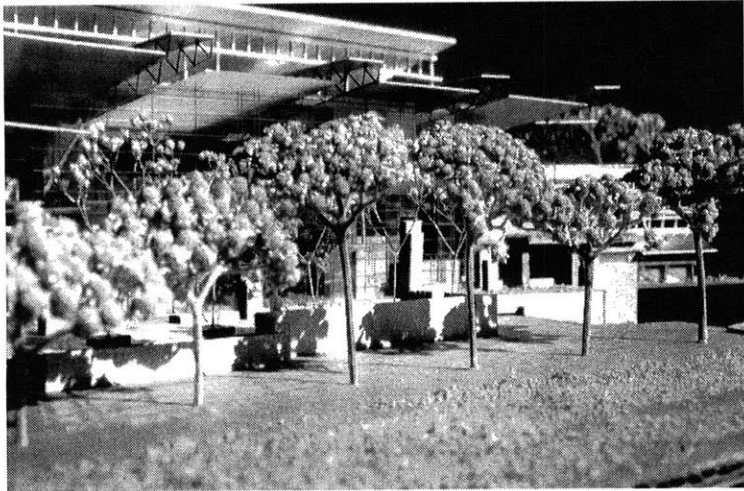
78 View looking east from above outdoor pool



View looking west from above Storow Drive

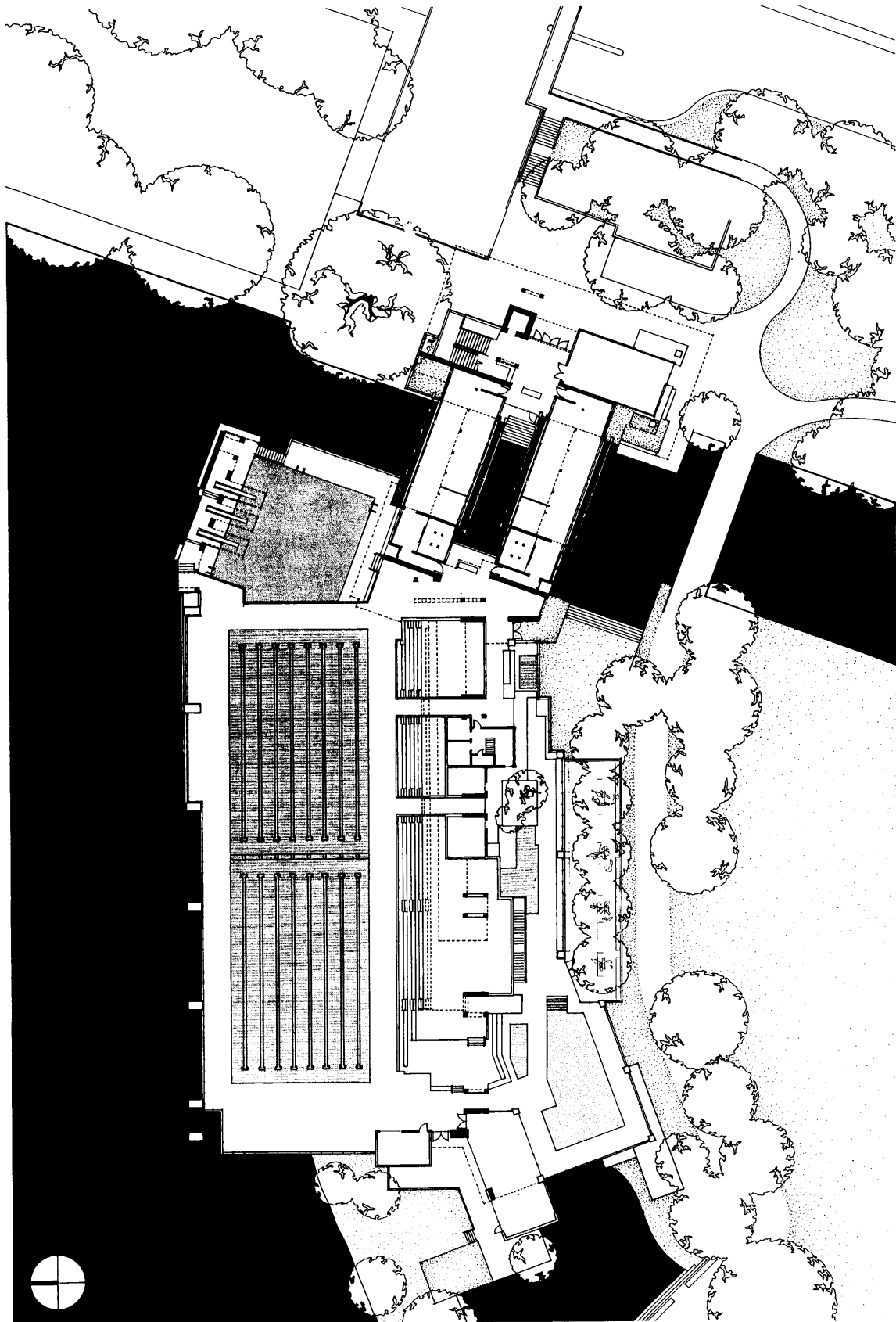


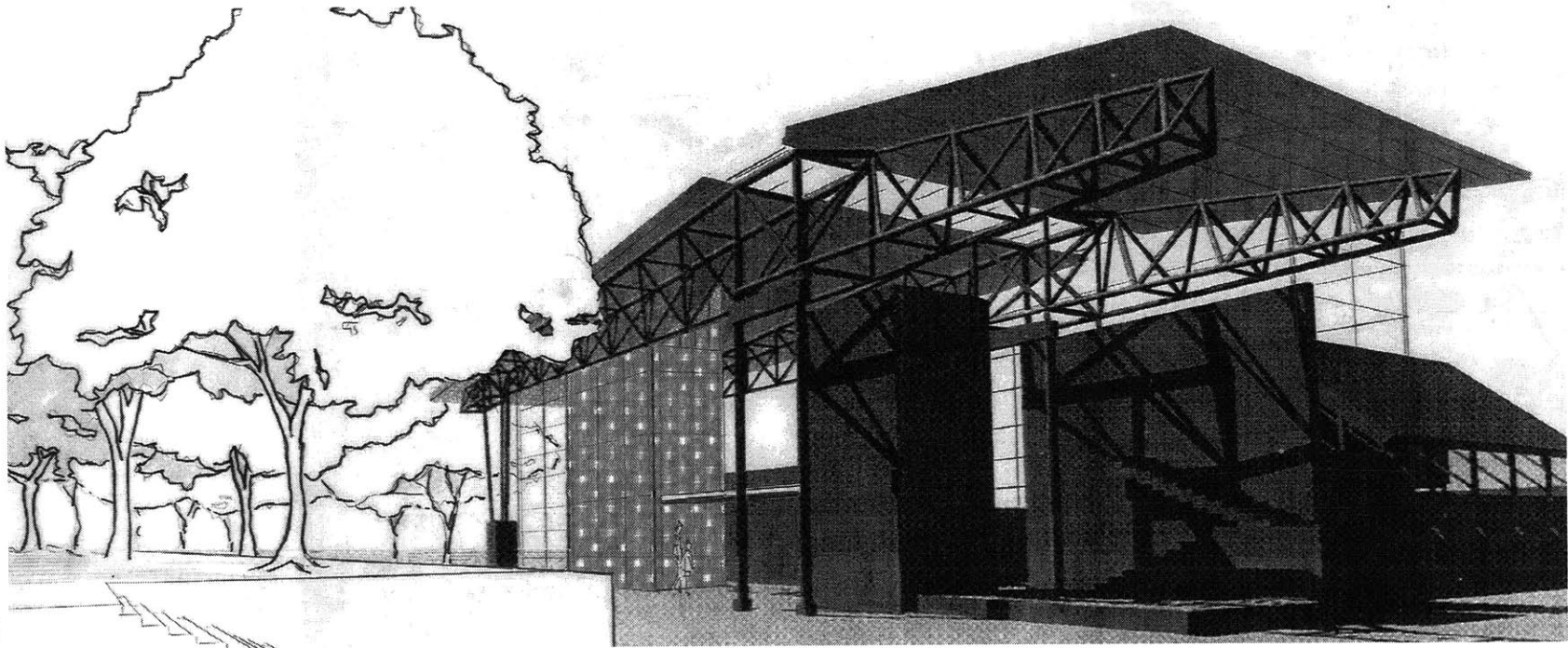
View of entry and changing room from the north



08 Two views of the south side
 The raised terrace is accessible only to swimmers from the recreational pools just inside. The massive forms moving up are of concrete. The south wall is a R8 glass curtain hung from the roof cantilever. Trees and overhang provide for summer shading and winter sun. The bikeway goes beneath the large trees.

Below: Ground Floor Plan and surrounding site. Parking is under the trees in the NE corner. The entry lobby, elevator, and exercise room are located on the east side of the new channel. Two locker rooms bridge the channel. These then open into a waiting area on the west side of the channel that also serves as a transition into either the large pools to the north or the recreational and health pools to the south. A sauna, steam room, and lifeguard facilities are tucked under the stands opening to the south. At the west end of the building are two classrooms and a storage area. Beyond these is an outdoor garden and pool that is accessible to the swimmers. The main pool provides eight 50m lanes that can be split in half with a moveable barrier. The floors of this pool are adjustable to accommodate different events.



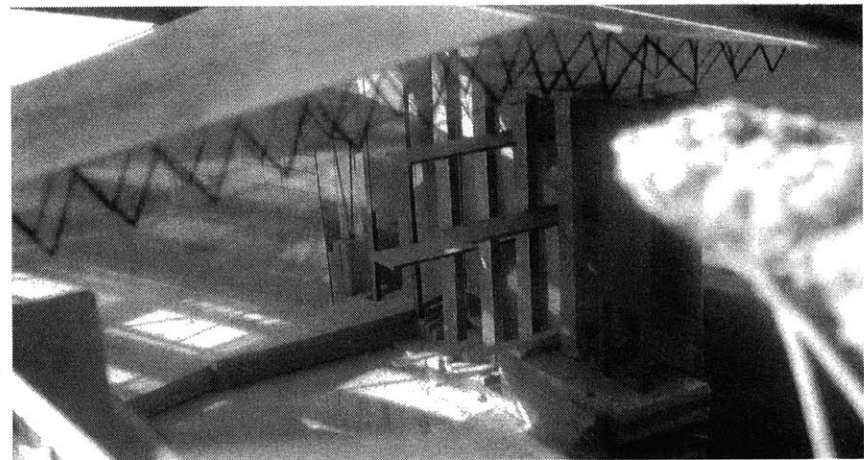


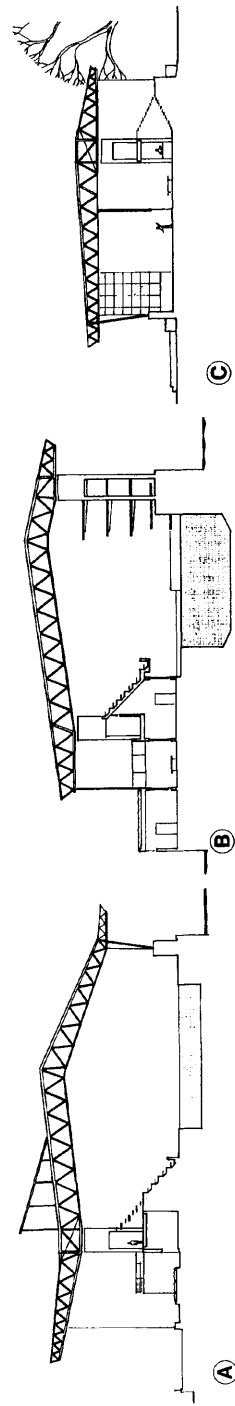
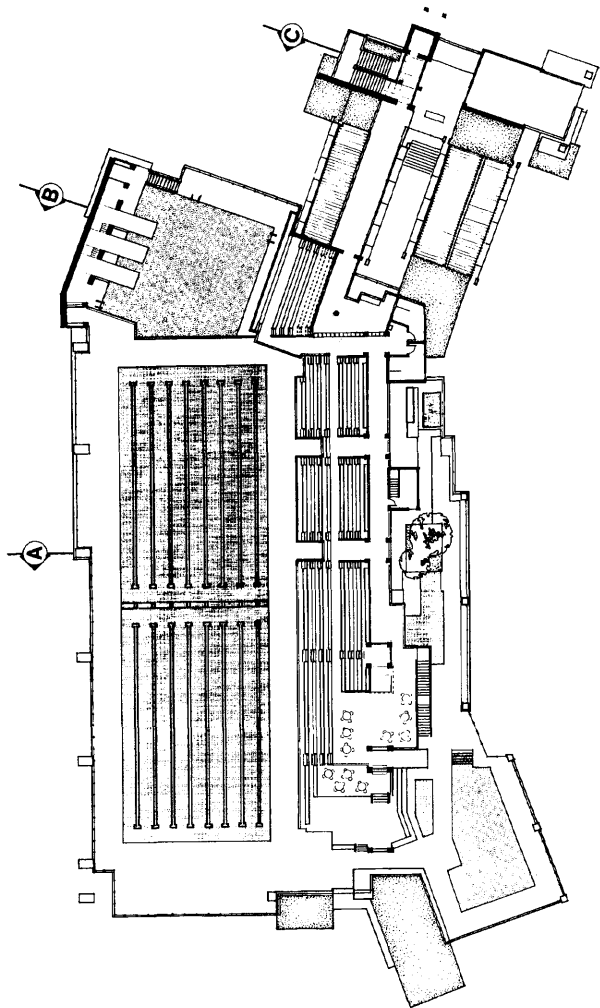
82

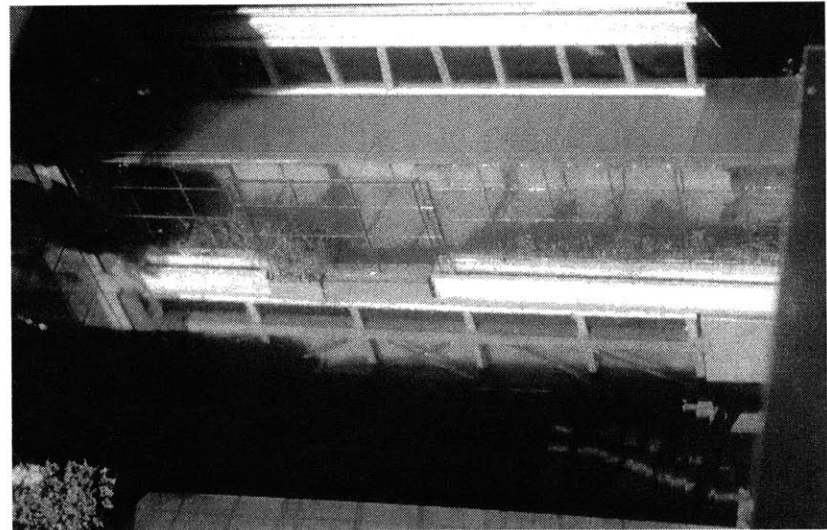
Above: Perspective of entry. Emphasizing the structural system of concrete groundforms rising up to meet the steel pavilion roof. The triangulated steel tube trusses transform from this basic version as one moves through the building.

Right: View into the diving pool. The diving facilities include a 3m and two 1m spring boards, as well as platforms at 5m, 7.5m, and 10m.

Below: Second Floor Plan and Sections. The second floor is the dry spectator area separated vertically from the wet areas below. The entrance is on the east side of the new channel. After entering one goes up stairs or elevator to the upper level. The bridge to the stands is a plant-filled greenhouse. At the far end of the stands is a cafe with views to all the pools.

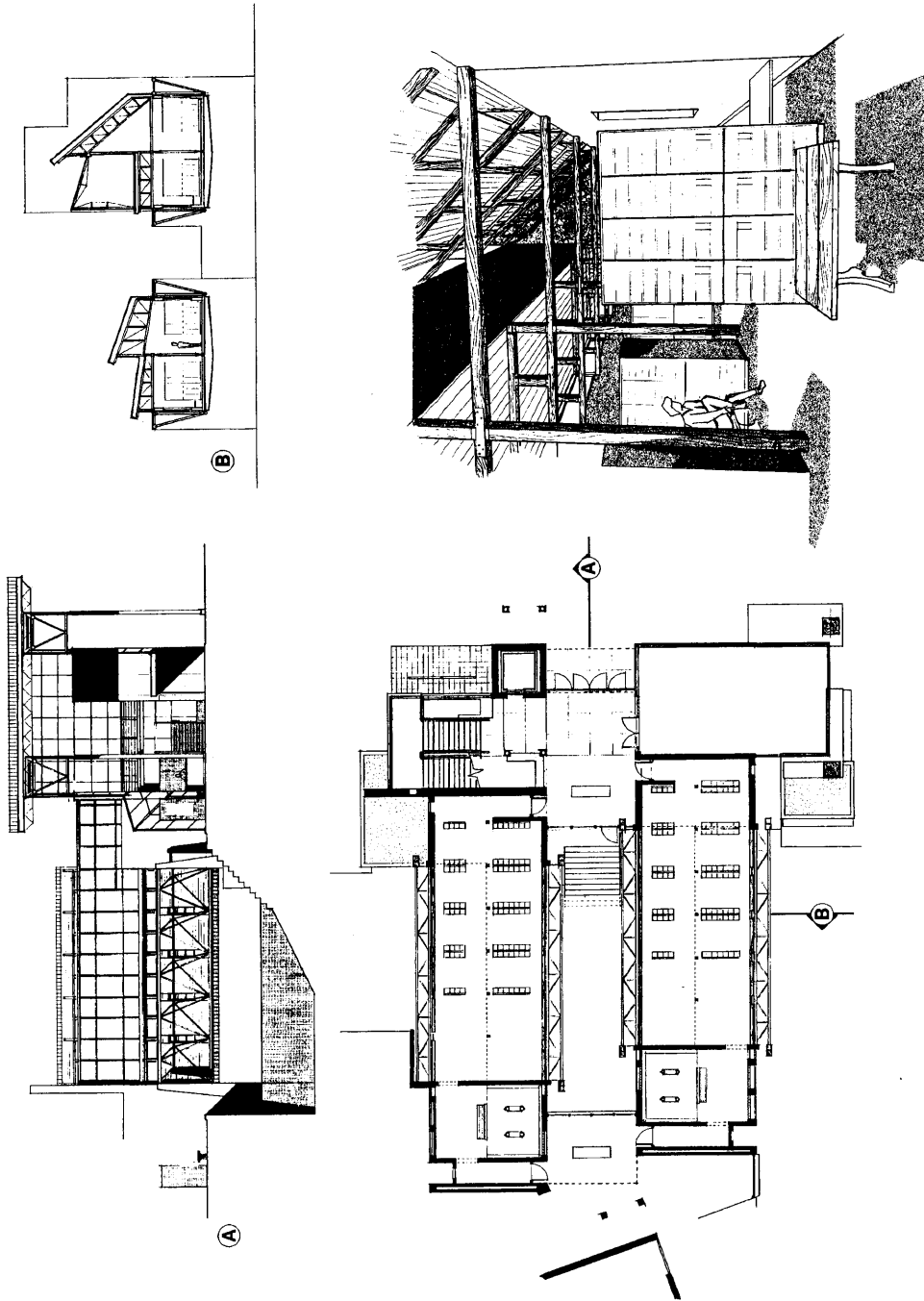


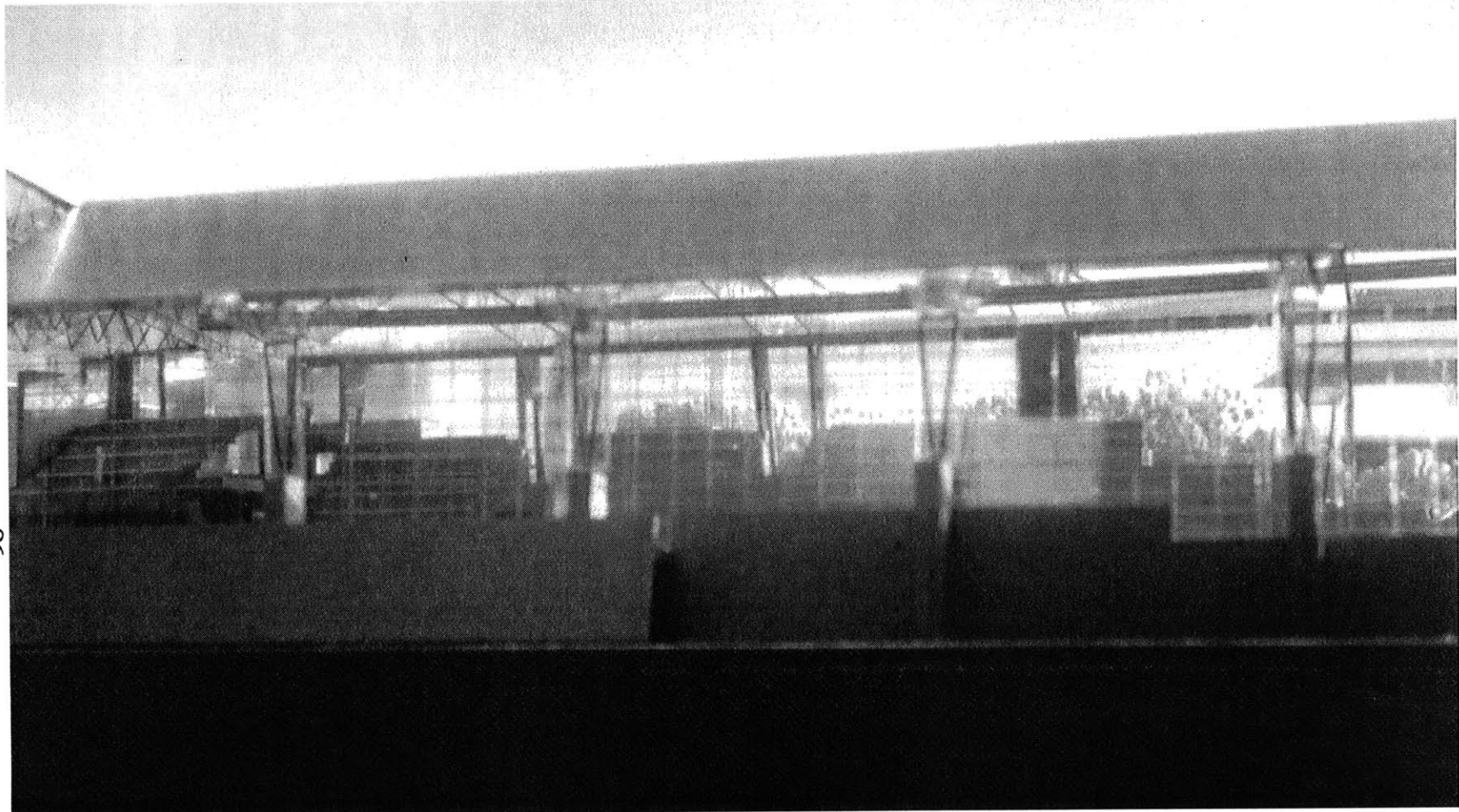




Overhead view of the spectators entrance bridge.

Below: Plans, Sections, Perspective of entry and locker rooms. The entry is concrete, tile, and masonry with wood handrails, doors and counter. The changing areas are framed in wood, with wood benches and floors. The shower areas are tiled with adjacent tile drying areas. The windows between the lockers and above are operable for natural ventilation. The perspective is from inside the north locker room looking west.

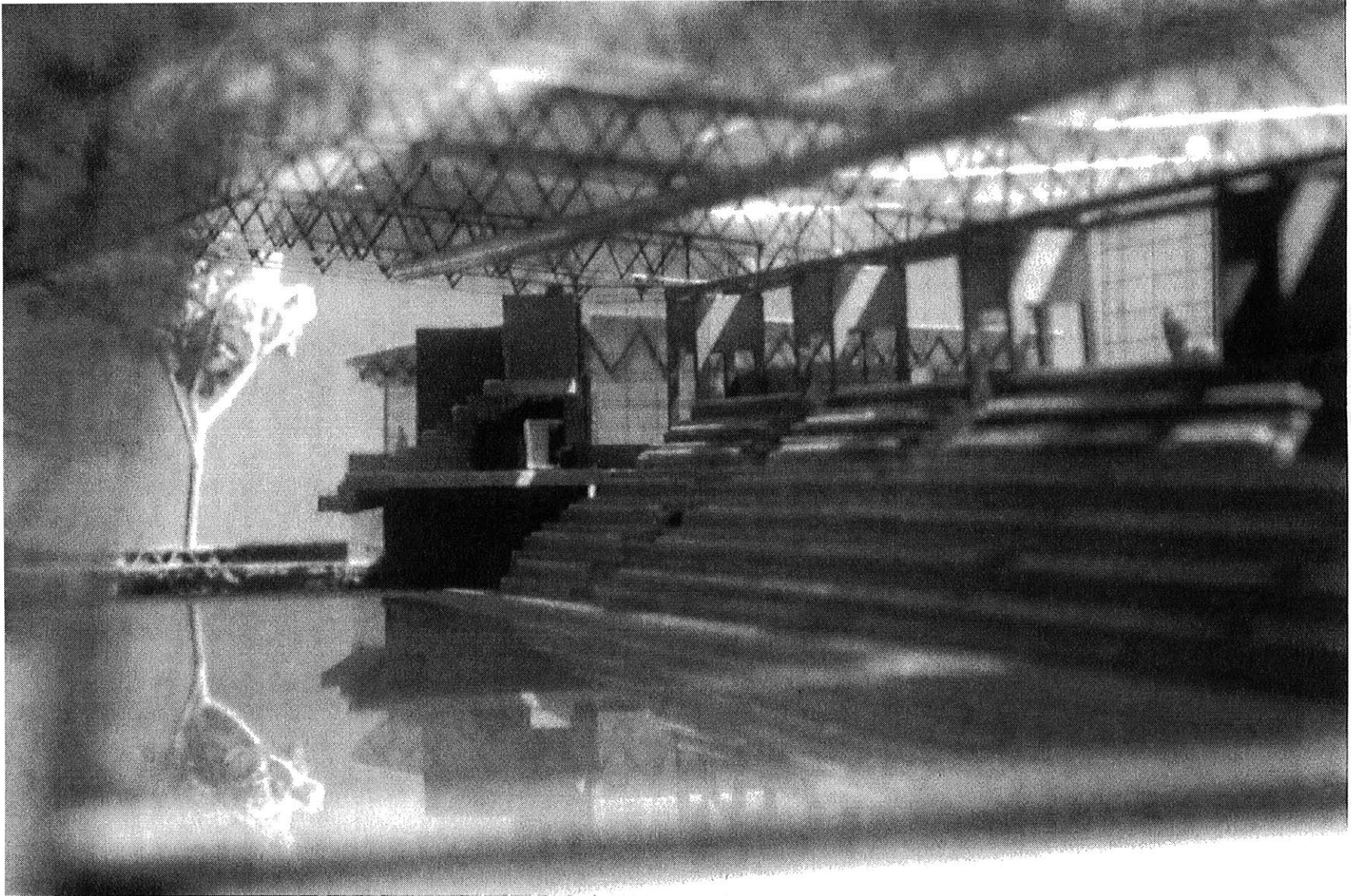




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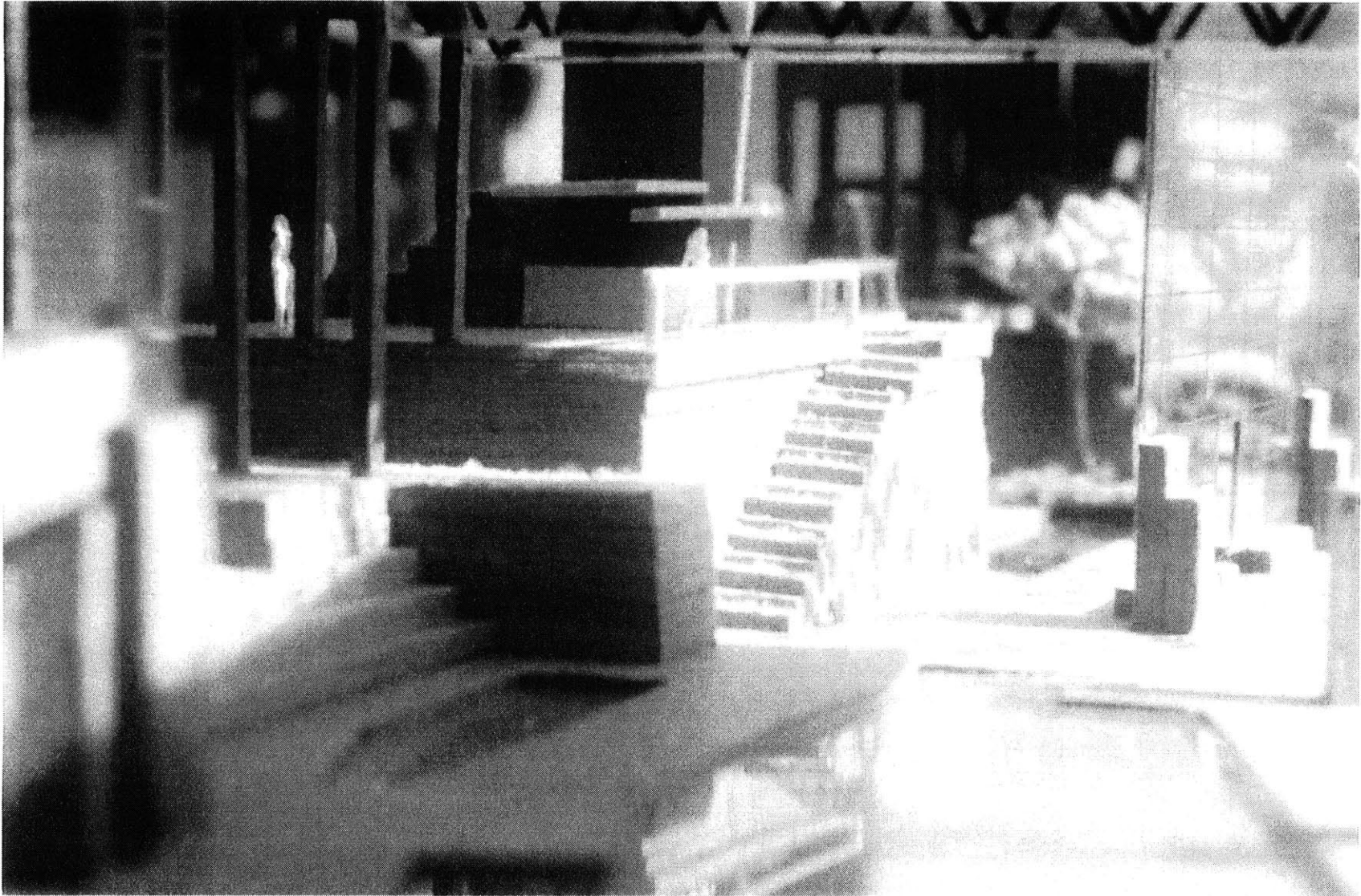
View of the pool from the north.

Below: Interior of Natatorium from the west side of the Olympic size pool. Spectators enter at the upper level from beneath the raised diving pool viewing stands. A large existing oak tree is framed by the glazed end wall. The lower portion of the main stands and the diving stands are in concrete. The upper portion of the main stands are steel. All seating is on wooden benches. The large duct overhead is an air supply. Air is taken out of the Natatorium from the overflows around the edge of the pool. This gets chlorinated air out as soon as possible and allows pool side to be conditioned without pool center.





A cafe is located at the end of the spectator stands. Tables in this area have views of the main pool to the north and the recreational pools on the south side.



View of the recreational pools looking east.

VI Intent to Evaluation

Intentions must be defined first. No code book or computer is ever going to be able to do that. One of the most elusive aspects of the design process is stating and then representing the goals. Then there is the issue of not just solving for this set, but creating an architecturally significant whole. So often we fall into the trap of just following a system, or making a system to follow, then we stop questioning. The questioning of goals and motives should never stop.

Once established, intentions must then be carried through to the wood, concrete, steel, glass, and other materials of a real building. Representations in drawings and models provide conceptual and practical stepping stones. The renderings of transient heat flow represent mid-design intentions. In an actual building process the last round of design drawings would be followed by an analysis to be checked against intentions. A process of construction drawings and further analysis would precede groundbreaking. The analytical comparison of a design to intentions needs to be quantitative and qualitative.

Evaluation of the qualitative quickly becomes subjective. This is what separates architects from technicians. There is no formula for good architecture. There are rules, guidelines, strategies, concepts, and precedents. But in architecture, two plus two should equal at least five, seven if your really good.

VII Conclusions

In any design process thesis, there is the problem of the lab rat examining itself. This thesis exploration would not stand up in any court of science. That was not the intention. The hypothesis was that through representation during the design process, an integral link between quantitative energy requirements and qualitative aspects of architectural meaning can be attained by the making of a thermal order. This thesis has answered 2 1/2 of 3 parts of that hypothesis.

1) It is possible to represent thermal qualities in a manner that is accessible to designers and informative during the design process. It is possible to communicate through a purely qualitative thermal sketch.

2) A thermal order can be designed and represented. Thermal design has normative standards just as structural, spatial, and programmatic elements of a design.

3) An integral link to energy requirements is a strong possibility. The proof of an integral link would require a study of multiple projects carried through construction and occupation. This singular, nine week design project, has not invalidated the possibility of an integral link.

The idea of rendering transient heat flow is just hatched, i.e. very fuzzy and immature at this point. This concept will need considerable refinement. Computational tools can help with some intermediate steps, but the true test can only be in a full scale built project. Virtual reality goggles won't do on this one. Thermal architecture must apply to live bodies interacting with the space around them.

Thermal delight will always elude definition and illustration. Just like a fine meal, it may be beautifully illustrated in writing, verbally or on film, but one can't completely experience it without actually being there.

References

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American Architectural Foundation, Alexander Shaw ed., Energy Design for Architects, The Fairmont Press Inc., 1989, NA2542.3.E47

The AIA Foundation provided the organization for this book, which is a major update of the AIA Energy Professional Development Program. It puts forth a specific Energy Design Process, explains energy fundamentals, design elements and design analysis. Very bureaucratic in its presentation.

ASHRAE Standard 55-1981 Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1981, TJ223.T4.T44

1989 ASHRAE Handbook, FUNDAMENTALS, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1989, TH7011.A51

Booz, Allen & Hamilton Inc., Energy Graphics: A new approach to energy-conscious design, Booz, Allen & Hamilton Inc., 1982, TJ163.5.B84.E554

This book proposes a New Graphic method. It seems too analytically based to make an effective bridge from energy to form generation.

Brown, G.Z., Sun, Wind and Light: architectural design strategies, Wiley, 1985, NA2542.3.B76

Basic reference. The introductions to the various sections are particularly interesting in Brown's reference to generative strategies, and rejection of energy elements as applied devices.

Clark, R.P. and Edholm, O.G., Man and His Thermal Environment, Edward Arnold Ltd, London, 1985

This text is a clear and comprehensive explanation of the physiological aspects of thermal comfort.

Commission of the European Communities, Building 2000 vol.II, Kluwer Academic Publishers, 1992, NA2542.S6.B85

A research and development project of the Commission. In volume II, Office buildings, Public buildings, and Hotels. They fairly thoroughly analyzed each of the projects presented. It is useful to see the variety and effectiveness of the editors attempts to communicate energy issues

Commission of the European Communities, Solar Architecture in Europe, Prism Press, 1991, NA2542.S6.S656

Thirty recent European projects. Same situation as Building 2000.

Cook, David Lionel, The New England SOLAR ENERGY ATLAS, University of Maine, 1986, QC911.82.U45.C66

Fanger, P.O., Thermal Comfort, Analysis and applications in environmental engineering, McGraw-Hill, 1972, TH7222.F211

Heschong, Lisa, Thermal Delight in Architecture, MIT Press, 1979, NA2541.H47

Hypothesizes that the thermal function of a building could be used as an effective element of design. Thermal qualities are an important part of our experience of a space. This text is my jumping off place. Lisa Heschong has set the stage for a design project.

Lam, William M. C., Sunlighting as formgiver for architecture, Van Nostrand Reinhold Co., New York, 1986, NA2542.S6.L35

Third in a developing series, this is an absolutely critical text presenting a humane method for lighting design. The thought process can be applied to many other architectural situations.

Norbert Lechner, Heating, Cooling, Lighting: Design Methods of Architects, John Wiley & Sons, 1991

Contains a brief overview of Heating, cooling, and lighting as form-givers in Architecture. Explains basic principles and thermal comfort. Gives climatic data for the U.S.. A good basic reference. This book does not advocate a specific method for getting from data and tools to form.

Olgay, Victor, with Aladar Olgay, Design with Climate: Bioclimatic Approach to Architectural Regionalism, Princeton University Press, 1963, NA2540.045.C5

Many concepts, charts, and figures from the newer texts are based on Olgay. Thirty years later some of the text is outdated but most is not.

Pettersson, Bertil and Axén, Bengt, Thermography, Swedish Council for Building Research, Stockholm, 1980, TH6025.P47

All about the uses of Thermography in analyzing building details.

Poole, Scott, The New Finnish Architecture, Rizzoli, 1992

Examples of contemporary Finnish architecture, which by necessity must be energy efficient. They look good too!

Stein/Reynolds/McGuinness, Mechanical and Electrical Equipment for Buildings, John Wiley and Sons, Inc., 1986.

This reference, generally viewed in the same category and with similar mechanical coldness as ASHRAE standards, has a surprisingly enlightened introduction, advocating natural over mechanical systems.

Swedish Council for Building Research, Building Stockholm, 1986, NA1290.B85

Presents an overview of Stockholm building in the early '80's. Gives a short history and description of energy design as well as case studies of six recent projects.

Thiel, Philip, Visual Awareness and Design, University of Washington Press, 1981

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Croutier, Alev Lytle, Taking the Waters, Abbeville Press, 1992, GT2845.C76

On the Spirit, Art, and Sensuality of water.

Gabrielsen, M. Alexander, Ed., Swimming Pools, a guide to their planning, design, and operation, Human Kinetics Publishers Inc., Champaign, IL, 1987, TH4763.S83

A complete guide to the design of pools. Includes everything from determining who will use the pool to which chemicals are best for water purification to solar energy opportunities. Competitive, safety, and accessibility standards are included.

Hall, Max, The Charles: The People's River, David R. Godine Publisher, 1986,
F72.C46.H34

History and life of the river.

Kauffmann, John M., Flow East: A Look at Our North Atlantic Rivers, McGraw-Hill Co., 1973, GB1216.K21

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NA1333.S625.A4

Swimming Pool, Leca da Palmeira, in the landscape.

Articles:

Coplan, Joseph, "Visible City: WPA Pools", *Metropolis*, v7 n1 July-Aug.1987, p66

Lovins, Amory, "If it's not efficient, it's not beautiful", *Fine Homebuilding*, n66 Spring 1991, p4

Fraker, Harrison Jr., "Formal speculations on thermal diagrams", *Progressive Architecture*, v65 n4 April 1984, p104-108

MacDonald, Effie C., "Manhattan Oasis", *Architecture Review*, v194 n1170 Aug.1994

"New era of public works", *Metropolis*, v13 n1 July-Aug.1993, p17

The *Architecture Review*, "Energy for Life", + 11 projects + article on Corbu, February 1993, pp. 19-74

The zeitgeist says energy issues are in vogue again.

Architecture, "Study Assesses Thermal Comfort In Existing Office Environments", March 1989, p44

Sites a current study whose findings indicate that static ASHRAE standard environments are not the most comfortable or enjoyable. This study will provide strong support for this thesis.

Lectures:

Julie Dorsey, Assistant Professor, M.I.T.

October 1994 M.I.T. Design Inquiry Series

The use of 'inverse method' in Julie Dorsey's continuing work was critical to forming an understanding of thermal issues that could be more generative.

Amory Lovins, Director, Rocky Mountain Institute

October 1994, M.I.T. Center for Real Estate

Lovins's study of energy and support of synergism underscores the need for designers to have a better understanding of thermal comfort issues.