IN SEARCH OF THE ELUSIVE GIZMO: OR, HAVE YOU SEEN MY ULTIMATE MECHANICAL GOODY LATELY?

by

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ABSTRACT

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Architecture has been recognized as a shelter provision, but its relative abilities to support habitability and to display efficiency have been questioned. Habitability is discussed as a determinant of physical form, based on the physiological, psychological, and social aspects of man's activities, particularly with reference to architecture as an activity support. A system-environment analog is suggested as an abstraction for the man-bioclimate interaction, and the nature of the interface is described.

The physiology of man has been discussed in terms of the five basic requirements for life continuance -- maintenance of body temperature, provision for food, oxygen-carbon dioxide regulation, water balance, and waste removal. The bioclimate -- both natural and man-determined -- has been described. A comparison of the physiological requirements of human life and the relative ability of the bioclimate to provide for human life has indicated the need for an artificial, mechanistic support. Criteria for innovative, mechanistic designs were established.

A specific bioclimate was chosen and was described relative to an individual's support requirements. A series of mechanisms appropriate for support purposes were then proposed consistent with the basic premises of habitability and efficiency. These models were suggested as the cooperative bases of a new architecture.

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I. INTRODUCTION

A. Overcoming a Deficient Architecture

Architecture is essentially the development of a habitable shelter for man, providing comfort and recognizing the great variability of man's activities. But, disregarding this basis, it is often perceived as a formal and intellectual pursuit in which the prime issue is understood to be the creation of physical space. The questions of how buildings are sited or formally organized or structurally detailed are commonly discussed and publicized.

Alternatively, though, the architecture of the twentieth century might better be comprehended in terms of its mechanistic support: a recognition of the difference between the cave and the tract house. The cave, known to our earliest forbears as shelter from a hostile environment, has been a symbol throughout human experience. The gothic cathedral and the Madison Square Garden are simply more elegant extensions of this symbol. On the other hand, the tract house is perhaps the beginning of modern architecture. It is manifested as a superficial, membranous shell which responds to its hostile environment by utilizing a powerful mechanical core. This core heats in the winters, cools in the summers;

it provides light and water and music. In short, the mechanical core of the tract house does everything but grow food and take out the garbage.

But, at the risk of being pedantic and inflammatory, we must recognize that the tract house is also inefficient, that it provides only for limited needs, and that it is a constant source of pollution in the manner that it is used. The dwelling does not provide food. It emits furnace gases and dirt to the atmosphere, and the waste disposal which does take out the trash, nevertheless, pollutes the nearby river.

It is the author's contention that these inadequacies caused by lack of concern and understanding are correctable within our present technology. This thesis is an attempt to explore bases for the development of a more efficient and cooperative architecture, a concept which could perhaps be called a "new architecture." The thesis approach is organized around a description of man and his bioclimate and the development of a set of mechanistic interfaces provided to supplement the individual where his capacities are deficient. These interfaces are seen as the initial product of a new architecture which is more responsive to the requirements for a habitable shelter. Such a shelter technique must also be highly efficient and render no harm to its environment. Its efficiency is founded upon the cooperation of man and mechanism, and the partnership is capable of being self-sustaining within the environment.

B. Habitability as the Basic Premise of Architecture

An architecture based upon the requirements of habitability finds that the formal development of enclosure is no longer the central problem. Rather, such architecture follows naturally from understandings gathered from investigations into the physiological, psychological, and social issues determining shelter provision. These basic criteria delineate the design of shelter space.

Habitability might well be described as a relative quality of the living space which is dependent upon the purpose of man's presence, the type of performance he expects to achieve, and the time he will spend in the living space. As such, the success or failure with which habitability is developed is comparative, determined by the interaction of man and his living space (enclosure). A further characterization of habitability can be indicated by how well provisions are created for conditions requiring the following: human survival, support for specific activities, psychological integrity and group development, comfort, and adaptive tenant/habitat relationships. The degree and intensity of the provisions are, of course, variable coincident with the severity of the environment, physical or mental. Additionally, adaptability is reflected in how well the individual is able to respond to a changing life situation. If accustomed practices have left the individual inflexible to adaptive opportunities, then his ability to survive or find comfort or develop group consciousnesses might be impaired. Therefore, the development of habitability may require a reconsideration of the use of both mental and physical resources. Seemingly, the adaptive relationship should be predicated upon the following descriptors: the individual or group activity, the duration and difficulty of the task, and the user's prior attitudes. The inherent differences between individuals require the maximum opportunities for encouraging adaptability for each unique tenant/habitat involvement. Architecture based on these criteria must be so developed to provide for both flexibility and comprehensiveness.

Kubis[1] in an essay for space vehicle habitability suggested that there are three primary levels of shelter acceptance: (1) survivability (especially with non-ordinary or hostile life situations); (2) a tolerable discomfort with possible, but acceptable, reduction in gross efficiency for individuals performing assigned work; and (3) a comfortable condition allowing reasonable efficiency in the work. Thus, life support and activity maintenance are intertwined, and the implementation of habitable enclosures depends upon the interrelationship.

C. The Mechanistic Supplementation of Man and Architecture

We have spoken of the mechanistic assistance which is the basis for the contemporary tract house. Similarly, we might consider the energy controlled by the mechanism. From the fire in front of the cave to the artificial fire emitting light, but no heat, in the tract house fireplace, the development of new technologies can be catalogued. The use of a simulated fire is hardly a sophisticated development. But the attitude that supports it is of interest: no longer must man depend on such primitive tools as fire for warmth and light. Now he has an assortment of mechanisms to provide for his needs and to extend his experience.

While we might express dismay with the fancies developed around these plastic toys, the more important lesson concerns the apparent disparity that exists between man's capabilities and nature's provisions. There is stark reality in experiencing the January snowstorm or the August draught. Without shelter and assistance, both could make survival difficult or even impossible. But with the construction of mechanistic aids and the expenditure of energy, the voids are filled. However, we are left with the questions: does the assistance help man to exist within his natural environment or does it separate him from nature? The latter question, if answered affirmatively, would suggest a counter-evolutionary situation requiring an entirely different set of attitudes; acceptance of so radical a change might provide very stimulating opportunities.

The common experience is based on man living within the environment and adapting to contrary to depletive conditions by the generally simple application of an assistance mechanism.

For current work in more bizarre environments like hydrospace or aerospace, man is not well-equipped, and unless a discrete evolutionary process occurs (like the development of a liquid breathing capability), comprehensive support is a necessity. Numerous models, real or imagined, abound in the literature providing designs for such artificial techniques as are required to supplement or to sustain the life process: (1) the Archigram cushicle[2]; (2) the Banham-Dallegret bubble environment[3]; (3) the stillsuit from Dune[4]; and (4) the Apollo capsule. Each of these models offers a habitability, supporting activities and suggesting comforts, and each is developed as a shelter mechanism simulating and extending a static, formal architecture.

The architect, recognizing that buildings are indeed "frameworks around man's activities"[5] must develop more rigorous understandings of the scientific bases characterizing man's habitability requirements. Providing for habitability requires mechanical supplementation of any enclosure so that the architect, regarded as a "creative anthropologist"[6] should also be able to describe himself as a "creative mechanist."

In Chapter II, man and bioclimate have been characterized as system and environment, respectively. This abstraction is intended to support comparisons more easily delineated in systems theory. The various concepts, however, can be deduced by substitution of terms which might then reveal juxtapositions that will be discussed in the following chapters.

II. THE SYSTEM/ENVIRONMENT ANALOG

A. Definition of Terms

The term system is used to denote an internal organization or multivariable structure coordinating element groups linked by common factors. It has been simply defined by A. D. Hall as "a set of objects with relationships between the objects and their attributes or properties."[7] These relationships might be formalized, or they could be established by convenience or coincidence. They should be regarded as process descriptors indicating probable higher orders of arrangements.

The environment is a collection of objects which are related to those within the structured system and whose existence affects the nature of the relationships bonding the system elements together. Hall has similarly defined the environment as "a set of all objects outside the system: (1) a change in whose attributes affect the system; and

(2) whose attributes are changed by the behavior of the system."[8] The system and the environment form a universe of all objects within a specifically denoted context. The inclusiveness of the system, environment, and universe is determined only as a means of giving definition to a complex organization, requiring more definitive exposure.

Hall has suggested that a group of universal factors exist which describe the character of man-made systems, particularly those whose plexus -- raison d'etre -- is man.[9] These factors are (1) the state of the technology and the attitudes of the society toward it; (2) the natural bioclimate; (3) the relative complexity and the internal structuring of the organization; and (4) the cost/benefit conditions (especially for new systems). Growth opportunities might be fostered by innovative developments and increased demand. A similar, and perhaps the most influential, modificant is the advance of the individual's awareness and attitudes in being able to deal with specific innovative systems.

B. The Analog as a Structured Framework

The term system has been introduced as an indication of a mechanical structure, representing man and his life needs. His search for life continuance, habitability, growth, and comfort are also understood as principal attributes. The natural world surrounding man and providing an immediate environment is characterized by man's ability to respond to it and his effect upon the bioclimate. The pursuit of the life activities of the human being defines the consequent interaction of system and environment. The presence of the system as a continuing entity is thus integrally related to the immediate environment. The system does not exist *merely within* the environment, but also *by means of* the environment, and the development of those relationships is a requisite for responsive, common growth.

The closeness of fit between the system and its environment is generally reflected in how the system has been introduced into the environment (i.e., whether the system, already developed was discretely placed in the environment, or whether the system was aggregated from within the environment and was, therefore, initiated and determined by the environment). Growth opportunities, dependencies, and flexibilities are then more easily operable. The interface established in either instance may be discrete or amorphous (the latter condition would be best delineated as a highly diffusive membrane). Additionally, the interface is characterized as an active and complementary presence allowing exchange of material and helping to establish equilibria or stabilities.

If the capabilities of the system are deficient and assistance is required for the system to exist within its environment in a stable manner, the interface will have to provide the required supplies. The results of such provisions may be separation, independence, symbiosis, or dependence, each a consequence of efficiencies or linkages generated between system and boundary or system and environment. The probable extension of the system amy or may not be developed at a cost to the initial system/environment fit.

In the technological, or mechanistic, sense, the interface can be viewed (1) in terms of the opportunities afforded by new technologies, and (2) from the premise of new applications and exploitations for the system in the previous (unaided) system/environment analog. The interface, once established and functioning, will provide for growth and adaptability, enabling the system to develop new capabilities.

C. The Interactive Analog as Architecture

The viability of a system/environment interaction is predicated upon a series of linkages between attributes of both organizations. A range of activities is established and goals are initiated. The interactive mode follows a set of tolerance extremes and seeks higher orders of cooperation. The result, hopefully, supports a mutual development of both system and environment. If, contrarily, non-involvement of the attributes is the result of common mixing, efficiency and flexibility will be negated.

If we recognize that the system/environment analog as described is in fact an abstraction of the man/bioclimatic experience, the interface introduced for the former analog is evidently the basis for architecture. The understanding that the bioclimate may be harsh or that it may not fully support the range of life activities characterizing the individual's existence represents an introduction for developing shelter as a life-supporting or sustaining medium. This transition unit is implicitly artificial and man-centered: a humanistic creation developed by ingenuity for the purpose of extending life. The interface is organized at a scale that fosters linkage development between individual attributes of both man and the bioclimate. Therefore, an architecture so based should result from mutual benefits established within the linkages. An expanding range of activities is indicated and cooperation can be provided. An additional requirement is the allowance for change suggesting adaptation and growth. The architecture structured within this interactive mode is to be supported by a highly efficient, mechanistic interface.

III. MAN

A. Man as a System

A systematic exploration of man will reveal a complexity of interrelationships and hierarchic functions in which the life activities are regulated by a number of subsystems (*e.g.*, circulation, respiration, elimination, sight, *etc*.). Each subsystem is in turn characterized by its ability to control its segment of the life process and to influence other segments. The subsystem relies upon a highly ordered framework which coordinates the activities and determines the response to external stimuli. The presence of a number of subsystems shows a community whose members are highly interdependent and exist within a complex and non-random behavior.

For further clarification of how a complex living system is structured, an extended reference to a paper by Iberall and McCulloch[10] seems appropriate. A life system is there defined as:

> Any compact system containing an order of and distribution of sustaining non-linear limit cycle oscillators and a related system of algorithmic guide mechanisms that can 1) regulate internal conditions with regard to the external environment so as to perpetuate itself; 2) perpetuate itself for a relatively long period of time consistent with the physical, mechanical and chemical mechanisms; 3) recreate its own internal systems or itself out of material at hand.

The life system demonstrates a marginal stability centered upon and suggesting an approximate equilibrium. In turn, the equilibrium is determined by the system's ability to respond to stimuli according to an optimal arrangement of subsystem capabilities. Iberall and McCulloch indicate that the key principle by which a living system is organized is "the dynamic regulation of its internal degrees of freedoms."[11]

The system follows a rhythmic process and is directed by perceived needs and a series of activities devoted to fulfilling these needs. The systematic needs and the system's response to them may follow a cyclic framework. Behavior can be modelled as a collection of replies to non-linearly induced deficiencies or "hungers." To close the system, formalizing the linkages between the various subsystems, an integration of these non-linear but rhythmic cycles must be accomplished, providing satisfaction for the hungers. Such integration demonstrates a model of the transfers of material and energy in the human body and suggests, as an analog, a well-ordered physico-chemical assistance mechanism developed to sustain life.[12]

Man can, therefore, be appreciated as a system possessing intellect and being sustained through the satisfaction of the "hungers" or life requirements. Fulfillment of the various hungers creates the fundamental basis for man's interaction with the bioclimate. As such, the systematic man is a goal-directed organism. Beyond the interaction of man and bioclimate directed at satisfying primary life needs, man attempts to manipulate his surroundings to create greater comfort. In an essay by Proshansky et al.[13] the response to the environment is seen as an attempt to organize the attributes characterizing man's immediate environment, thus maximizing his flexibility and freedom of choice. The organization and mastery are formulated around a search for artificially-induced processes developed for growth within and control over activity, behavior, and enclosure, culminating in a possession of "territoriality."[14]

B. Man as Biosystem

The discussion of the issues within this section is based upon the understanding that man is a closed system requiring certain supports to assure continuity. The relative "closedness" is determined not by an internalized cyclic process, but rather by a structural form consisting of subsystems, each working in a cyclic framework (e.g., the circulation of blood or the tactile response associated with the nervous system and the brain). The cycle established between the man and the bioclimate in which man's life requirements are fulfilled is closed only if we recognize that needs are satisfied and the life activities proceed until the needs require new satisfaction.

The principal attributes of the system are not specifically separable, although general models of each of these characteristics are possible. Similarly, models exist which will at least approximate an individual's life process during the performance of a particular task. The general life process can be described in terms of a "functional analysis model" in which the life descriptors and their components are delineated:

1. Physiological necessities
    - a) The furnishing of oxygen, the removal of carbon dioxide, and the presence of atmospheric pressure.
    - b) Suitable nutritional intake, characterized by food sufficient to satisfy the metabolic body rate, and the supply of appropriate nutritional requirements such as vitamins, minerals, fatty acids and/or the appropriate amino acids.
    - c) Provision of water for intake and removal of water by elimination, perspiration and respiration.
    - d) The maintenance of body temperature throughout a range of activities and for a variety of bioclimates; the relationship between deep body and skin temperatures and metabolic rate.
    - e) The removal of eliminated or waste products -- organic or inorganic.
2. Biological Activities
    - a) Reproduction and care for the young
    - b) Mobility to assist in food gathering and activity support (work or play) and to provide for changing the environment which man inhabits
    - c) Physical exercise -- prevention of muscular atrophy
    - d) Cleansing of the immediate surroundings, including the air and the body
    - e) Prevention of disease
    - f) Appropriate length of sleep or rest

3. Psychosocial Extensions
    a) Communication between individuals, close and distant
    b) Presence of stimulation -- prevention of mental atrophy
    c) Experience of light
    d) Separation from distressing noise sources; presence of enough noise to alleviate distressing quiet
4. Physical Extensions
    a) Presence of gravity
    b) Separation from hostile animals (and men)
    c) A discrete shell to maintain all of the above
    d) An energy source to support all of the above

Within the relatively closed system that characterizes man, needs exist which are exclusive of environmental support (e.g., mobility, physical exercise, or mental stimulation); needs also are occasioned by the lack of support from the environment (e.g., body temperature and the provisions of sufficient water and food). When man is removed from the more familiar environments, such as occurs during aerospace and hydrospace activities, the requirements for survival are even more comprehensive. Therefore, the provision of systems assistance is a general necessity -- whether it is a question of what are the inadequacies in the immediate environment or what kind of support is required to sustain man in his quest to extend his activities. In each of the three areas of need, the adaptability of man can be enhanced or established by creating innovative techniques or allow for activity support and development.

The reason for establishing a cooperation between the system and a mechanistic support is fundamentally indicated by D. G. Goddard's statement that "no organism lives without an environment; as all organisms are depletive, no organism can survive in an environment of its exclusive creation."[15]

This statement, while always true in nature, may be effectively minimized for man by the use of artificial mechanisms which control energy and matter flow and implement regenerative cycles. Such mechanisms will allow the lengthening of any lifetime by increasing efficiency and negating the ravages of wear and misuse. On the other hand, all matter and energy still experience the two most basic and common controls, birth and death. But to make it possible to extend the lifetime or to extend the lifetime's activities, is conceivable. The task of this thesis is to demonstrate a mechanism which will provide the latter by developing cooperative arrangements between man and mechanistic supports founded on efficient, regenerative cycles.

C. A Sketch of the Physiology of Man

We have indicated, through the work of Iberall and McCulloch in Section III-A and the display of the "functional analysis model" in Section III-B, that the human body is a framework of complex and interactive subsystems. The discussion that is to follow is a description of the elements of the "model" characterized as "the physiological necessities." While each of the five needs will be delineated individually, their general interdependency should be explicitly recognized.

1. The Maintenance of a Thermal Stability

The bioclimatic chart, developed by Olgyay,[16] has been much used in the recent past to determine thermal comfort for varying conditions. This work was based on thermal conditions in the body and how bioclimatic effects influenced them. While this work was established by observation, an understanding of energy transfer within and near the body will provide more direct understanding.

Energy expenditure in the human body and the maintenance of a thermal stability are both related to the bodily response to any set of activities. The human body resembles a machine receiving fuel and exhausting the byproducts of a combustion-like reaction, and in the interim, maintaining an almost constant core (deep internal) temperature (98.6° F or 37.0° C). A heat equation may be used to describe the balanced thermal conditions as it exchanges energy:

$$H_{SR} + H_M \equiv H_R + H_C + H_K + H_E + H_{RESP} + H_W \qquad (1)$$

where:

H_{SR} = Energy received from solar radiation (Kcal/hour)
H_M = Energy received from metabolism
H_R = Energy expended or received by radiation
H_C = Energy expended or received by convection
H_K = Energy expended or received by conduction
H_E = Energy expended by evaporation
H_{RESP} = Energy expended by respiration
H_W = Energy exchanged by work or activity efforts

With a knowledge of how much energy is being produced and expended relative to a work effort, how much is received from the sun, and exchanged with the immediate bioclimate, it is possible to predict the energy balance of the body at any moment. If the balance is being distorted, the utilization of equation (1) will indicate how compensation may occur.

The body's primary source of energy is the result of a series of metabolic reactions which depend upon activity. In Appendix I the energy costs for associated activities are summarized. Using this information, it is possible to determine the amount of metabolic energy required to perform activities for a given period. A small quantity of energy is used in mechanical work, and the rest is expended as heat.[17] The amount of energy expended as that required to do mechanical work is 20% (± 2-3% depending upon the physical condition of the individual) of the metabolic heat production. This measure is also an indication of the body's overall efficiency (i.e., its ability to translate energy into work). The remainder of the energy generated as metabolic heat is exchanged to the bioclimate. This exchange is strongly influenced by several environmental factors, including solar radiation, air temperature, atmospheric pressure, wind, and moisture in the atmosphere. Similarly, the individual may voluntarily control heat loss by donning or shedding clothing, entering or leaving buildings, or by acquiring or negating heat sources.

Energy expended to the immediate environment is usually dissipated by heat transferred through radiation and convection directly to the air, or by evaporation of water lost as sweat over the body's surface and as respired water vapor from the lungs. Small quantities of energy may be lost by conduction to other objects in contact with the body and by evaporation of water lost by diffusion through the skin. Naturally, these bodily mechanisms change perceptibly with varying clothing covers and environmental conditions. The flow of heat from the skin is determined by the internal transfer of energy from the body core to the skin by the circulation of blood. The human biothermal response to activity performance has been modelled by Brown[18] and includes a systematic description of heat transfer within the body and energy exchange to the environment. Additionally, he has developed a computer model simulating the homeostatic mechanisms which control the internal body temperature during activity periods. The general behavior of energy expenditure between the body and the environment with a clothed subject for radiation and convection and for evaporation may be predicted by the following equations:

$$H_{R+C} = 5.55A\ (1/\mathrm{Clo})\ (T_S - T_A)\ (^\circ\mathrm{C}) \qquad (2)$$

$$(H_E)_{MAX} = 5.55A\ \left(\frac{i_m}{\mathrm{Clo}} \right)\ (2.2)\ (P_S - P_A)\ (\mathrm{mm\ Hg}) \qquad (3)$$

where T_S and P_S are the temperature and partial pressure respectively of sweat on the skin, and T_A and P_A are the temperature and partial pressure of water for the surrounding air; A is the surface area of the body (normally taken as 1.8 square meters for the prototypical 70 kg, 5'9" tall, 25-year-old man); and the values (i_m) and Clo) indicate the evaporative impedance (or impermeability index) and the insulating value of the clothing worn by the subject.[19] Heat loss by evaporation is determined by the principle that each gram of sweat exchanged to the environment released 0.58 Kcal as the latent heat of vaporization.

The metabolic heat, produced by the oxidation of food assimilated by the body, is the energy used by the body for all muscle activity and assorted involuntary activities like blood circulation and assimilation of O_2. The rate of metabolism is proportional to the weight of the body and can be determined with reasonable accuracy by noting the quantity of oxygen inhaled during specific work levels. The reactions of oxygen with the primary nutritional components -- protein, fat, and carbohydrates -- proceed with different energy releases: a gram of protein oxidized will yield approximately 5 Kcal of energy; similarly, a gram of fat will produce 9 Kcal and a gram of carbohydrate will produce 4 Kcal.[20] A nutrionally balanced diet consists of approximately 12% protein, 35% fat, and 53% carbohydrate with an assortment of vitamins and minerals (listed in Appendix 2). A series of definitive equations have been compiled by McHattie[21] to describe the metabolic products of the food-oxygen reactions:

$$\text{Heat} = 4.18\ C + 9.46\ F + 4.32P \qquad \text{Kcal/Unit time} \quad (4)$$

$$(O_2) = 0.83C + 2.02V + 0.97P \qquad \text{Liters/Unit time} \quad (5)$$

$$(CO_2) = 0.83C + 1.43F + 0.78P \qquad \text{Liters/Unit time} \quad (6)$$

$$\text{Metabolic Water Loss} = 0.56C + 1.07F + 0.41P \qquad \text{Grams/Unit time} \quad (7)$$

where C, F, and P represent the gram-weights of the ingested quantities of carbohydrates, fats, and proteins, respectively. The relationship between carbon dioxide (CO_2) produced by the metabolic processes and the oxygen consumed is formalized as the respiration quotient (RQ) such that:

$$RQ = \frac{\text{Liters of } CO_2 \text{ Produced}}{\text{Liters of } O_2 \text{ Consumed}} \qquad (8)$$

The (RQ) is dependent upon the composition of the diet as indicated by the equations 5 and 6. For a mixed diet such as the one specified above, a respiration quotient of 0.82 to 0.85 would be common, whereas with a pure carbohydrate diet the (RQ) would be 1.00.

The amount of oxygen inhaled will vary depending upon the relative composition of the diets and the level of activity. For a mixed diet (RQ=0.85) and one liter of oxygen inhaled, the amount of energy released is 4.86 Kcal; for a high carbohydrate diet (RQ=1.00) and one liter of oxygen inhaled, 5.05 Kcal of energy will be expended.[22] At high rates of activity, the (RQ) will approach 1.00 and the amount of oxygen required will similarly approach 5.05 Kcal/liter of oxygen. Thus, the body when expending energy at high rates for short periods of time (between 0 and 60 minutes) is dependent upon the oxidation of carbohydrates for its energy source (with the actual reaction occurring between oxygen and glycogen). For active periods lasting longer than one hour, the relative amount of energy produced by simple carbohydrate oxidation decreases in favor of the increasing production of energy by the oxidation of fats. For periods requiring several hours of high, sustained physical activity, the principal form of metabolic energy becomes fat oxidation with a minimization of carbohydrate oxidation. This result may be explained when one recognizes that the oxidation of fat provides more energy per unit weight and that free carbohydrates are rapidly oxidized during the early phases of activity.

When the energy produced and lost does not balance, the body attempts to recover a balance by initiating a series of involuntary regulations. The response to imbalance occurs in three stepwise modes, each more severe than the previous. The first involuntary response is known as vasoregulation in which the energy transfer is regulated by increasing or decreasing the effective flow. This autonomic condition is triggered by a nervous system control in which, for high heat loss, increased blood flow is encouraged by a dilating of the capillaries near the surface of the skin, creating a vasodilation. Contrarily for cold conditions where body heat loss is to be minimized, the capillaries constrict and vasoconstriction occurs. The vasoregulatory response allows an energy adjustment either additive or subtractive, of about 80 Kcal/hour. The second energy regulation is based upon free sweating or shivering. Both occur at the expense of the vasoregulation: sweating or shivering can be initiated only after vasodilation or vasoconstriction, respectively, has been halted. Sweating is one of two primary ways of evaporative heat loss (the other is through respiration from the lungs and diffusion from the skin). Sweating occurs as a secretion of the sweat glands, and heat is exchanged by the evaporation of the moisture. Shivering may result when heat loss exceeds heat production. Its physiological basis appears to consist of a nervous system response in which muscle contractions occur and proceed reflexively.[23] The maximum heat loss derived from the evaporation of sweat is taken as 600 Kcal/hour, whereas the maximum rate at which energy can be produced by shivering is comparable to heat produced during strenuous work (i.e., 200 Kcal/M^2/hr).[24] If these two heat exchange techniques (vasoregulation and sweating and shivering) re-create a balanced condition, the energy loss or gain is said to be compensable. Contrarily, if imbalance still results, the situation is then incompensable, and the third regulation occurs with a gain or loss in the body's core temperature. A net change of more than three or four degrees (°F) will cause an inability to function at the common relative efficiency. Core temperatures ranging below about 86°F or above 108°F are generally understood to cause death. Therefore, heat exchange conditions which result in changes in the deep body temperature should be regarded with concern.

The two following examples are intended to indicate how the body's subsystems handle the problem of maintaining suitable thermal stability. Knowledge of how the man develops a heat balance with his environment, respective of the bioclimate, the activity level, and the amount of clothing, demonstrates the basic criteria necessary for efficient artificial shelter design. Habitability, as previously described, is entirely dependent upon such thermal regulation.

EXAMPLE 1: Let us now consider a typical specimen seeking a heat balance -- an M.I.T. graduate student who spends his day in the following activities: 1) seven hours sleeping; 2) one hour dressing and undressing; 3) four hours in class -- sitting at rest but moderately alert and taking notes; 4) eight hours studying while sitting at rest; 5) two hours of active exercise playing tennis; and 6) two hours of walking slowly. He weighs about 70 kilograms (Kg) or 155 pounds, is about 25 to 30 years old, and is in good health and physical condition. His metabolic requirements will be (with the assistance of appendix I):

7 hours (sleeping)	x	0.93 Kcal/hr/rg	x 70 kg	= 460 K/cal
1 hour (dressing)	x	1.69	x 70	= 120
4 hours (class activity)	x	1.70	x 70	= 480
8 hours (studying)	x	1.60	x 70	= 900
2 hours (active exercise)	x	4.14	x 70	= 580
2 hours (walking slowly)	x	2.86	x 70	= 400
TOTAL ENERGY EXPENDITURE FOR A 24-HOUR DAY				=2940 K/cal

(In the life of a typical M.I.T. graduate student)

Assuming that he eats a balanced diet (previously indicated as being of the following composition: 12% protein, 35% fat, and 53% carbohydrate) and that the nutritional values of these primary foodstuffs are 5 Kcal/gram of protein, 9 Kcal/gram of fat, and 4 Kcal/gram of carbohydrate, then the composition of his diet will be:

(0.12 x 2940) x 1/5 = 71 grams of protein
(0.35 x 2940) x 1/9 = 114 grams of fat
(0.53 x 2940) x 1/4 = 390 grams of carbohydrate

TOTAL MASS OF DIET = 575 grams (or 1.27 pounds)

The oxygen and carbon dioxide consumption and expenditures, respectively, can be calculated from equations 5 and 5:

$$(O_2) = 0.83\ (390) + 2.02\ (114) + 0.97\ (71) = 624 \text{ liters of oxygen}$$

$$(CO_2) = 0.83\ (390) + 1.43\ (114) + 0.78\ (71) = 512 \text{ liters of carbon dioxide}$$

with a resultant (RQ) of 0.82 for the day's activities

EXAMPLE 2: If we consider one hour spent playing tennis in an environment with an overcast sky, relatively still air (wind velocity less than or equal to 2.5 miles/hour), an air temperature of 80°F (26.7°C), and a relative humidity of 85%, a heat balance might take the following form:

(a) Metabolic heat production -- figuring a highly active exercise rate of 5.25 (Kcal/hr/Kg (halfway between active and severe exercise in Appendix 1), the resultant metabolic body heat rate will be 365 Kcal/hr (= 5.25 Kcal/hr/kg x 70 kg);

(b) The heat loss by radiation and convection -- assuming the student is wearing garments rated at 1.0 clo and 0.50 for the impermeability index, the heat lost by radiation and convection following equation 2 is:

$$H_{R+C} = 5.55 \times 1.8 \times 1/1.0 \times (35-26.7) = 73 \text{ Kcal/hr}$$

(c) Similarly, the rate of maximum heat exchange by evaporation will be, by equation 3:

$$(H_E)_{MAX} = 5.55 \times 1.8 \times 0.5/1.0 \times 2.2 \times (42-23) = 209 \text{ Kcal/hr}$$

(d) Remembering that the student is in good physical condition and that the human body as a mechanism operates at an efficiency of approximately 20% of the metabolic heat rate, then the student will expend about 58 Kcal/hr in simply *playing* tennis (*i.e.*, swinging the racket, breathing, and running).

(e) Assuming that conductive heat loss is negligible and expecting that heat lost by respiration during highly active exercise is in the vicinity of 50 to 60 Kcal/hr,[25] then the heat balance equation (Equation 1) indicates that evaporation is not occurring at the maximum rate. If heat loss by evaporation were working at maximum rate and it was still not sufficient to balance the heat equation, assuming that all other mechanisms were working perfectly, then additional heat could be expended by vasodilation. If heat exchanges greater than that additionally allowed by vasoregulation were required, the condition would be incompensable and the core temperature would rise. Of course, for this sketch model, the student would most probably be more sensibly dressed. But it is also entirely possible that, for a very active game on a hot and humid day, the student's core temperature migh- rise a few degrees. A model has been developed by Goldman and Givoni[26] which allows the prediction of the rectal temperature (an indication of the core temperature) as a response to work, environmental conditions, and clothing properties. This model should provide an accurate description of the temperature-time pattern and can present a more definitive account of the individual's core state as he enjoys his tennis game.

2. Nutritional (food) Selection

The individual's use of food has been discussed in the preceding section in terms of (1) the results of utilizing a mixed or one-element food diet and (2) the amount of food material required to produce the appropriate quantity of metabolic energy. Foods common to our experience are generally a mixture of protein, fat, and carbohydrate as well as water, vitamins, and minerals. In Appendix 3, a variety of foods are recorded in quantities indicating their nutritional compositions. A mixed diet requires assessing the relative quantities of each nutritional element within the diet and the presence of each nutritional element within any given foodstuff. Once these are known, a diet balanced for any particular set of activities can be designed. A series of prototypical diets formulated for early Apollo missions is listed in Appendix 4.[27]

Reasons for the inclusion of each of the three primary nutritional elements, beyond the previously-described metabolic process, exist in abundance with appropriate sophistication and most are beyond the scope of this text. However, a rudimentary description of the basic components of the diet is in order:

(a) Proteins are the collective source of nitrogenous material occurring in the form of amino acids, which are themselves the agents which initiate and control the formation and regeneration of body tissue. A high proportion of nitrogen is present in most foodstuffs as protein, protein derivative, and free amino acids.[28]

(b) Fats are a generic term for the collection of materials in food that are not water-soluble -- neutral fat, fatty acids, nonsaponifable fractions (*e.g.*, cholesterol and other sterols), and other lipid-type materials. The fatty materials tend to be heterogenous in character and bound together with proteins or carbohydrates in plant and animal products.[29] Fats can be eliminated from the diet on a short-term basis, and there is evidence to suggest that they can be removed for extended periods also. But such omissions have caused ketosis and nausea in some individuals. An alternative to the direct presence of the heterogeneous fats in the diet is the use of fatty acids. Such acids are usually available as neutral fats that are combined with glycerol and are saponifable, allowing their separation from the glycerol.[30] Fatty acids exist both in saturated and unsaturated formulations, although the saturated fatty acids are more commonly found in foodstuffs.

(c) Carbohydrates are combinations of elemental carbon, hydrogen and oxygen and are the natural product of photosynthesis. They appear in many forms in foodstuffs -- starches, dextrins,sugars, cellulose, and others.[31] Of these, the sugars are the basic derivative and are the form to which most of the other relatively simple carbohydrates, such as the starches and dextrins, are reduced. These materials are broken down by the body into glucose and fructose (which as monosaccharides are simpler than the common table sugar sucrose, which is a disaccharide). Most carbohydrates are present in foods as starches, sugars, and cellulose, although the last is a generally indigestible commodity manifested as a fibrous ruffage. The several-stomached animals such as the goat or cow are reminants and are able to process this material. The quantities from which sugars can be obtained in the general carbohydrate are often thought of as nitrogen-free extracts and exclude all fibrous materials.[32]

The presence of carbohydrates in the diet is especially important for the so-called "high energy" needs such as are required for maximum effort over short periods of time ranging from a few minutes to an hour. As we have suggested, for longer periods, the body's reliance on carbohydrate-based energy appears to be reduced and the body seeks support from the fats present both as foodstuffs and as bodily-stored fats.

(d) The specific vitamins and minerals required in a normal diet are outlined in Appendix 2.

(e) Water required for consumption will be discussed later in this section.

EXAMPLE 3: A model (example 3 in Appendix 5) has been built around the foods and diets displayed in Appendices 3 and 4 and seeks to delineate information expressed above.

3. Oxygen-Carbon Dioxide Requirements

The interaction between oxygen intake and consumption in metabolic oxidation has already been discussed and the following conditions were noted. Oxygen consumption varies according to the activity and the relative mix of the diet. Of the intaken air, only one-fifth of the air is oxygen and only one-third of the oxygen is consumed; therefore, only one-fifteenth of the air inspired is utilized, suggesting a relatively inefficient process. Nitrogen comprises 80% of the inspired gas, and the atmosphere itself, but this element is not converted during normal breathing experiences. Carbon dioxide, a product of the metabolic oxidation is present in the atmosphere in quantities rarely greater than 0.4%.

The amount of gas (air, generally, or oxygen specifically) that the body is able to inhale per unit time is defined as the ventilation rate and is dependent upon the relative fitness of the individual. The maximum oxygen intake that the average body can maintain is approximately 3.5 liters of oxygen/minute, and this can only be raised by 10% or 15% through extensive training. By remaining dormant for a long time, the individual may lose 10% or 15% of his ability to maintain this intake level.[33] Breathing faster than would normally be required to maintain a ventilation rate of 3.5 liters O_2/minute does not improve the ventilation progress. It only serves to lessen the efficiency. The body is unable to maintain this maximum intake rate for more than several minutes at a time and rapid reduction in ventilation rates are common (e.g., the miler is able to run for only six to eight minutes at the rate required to produce a four-minute mile; until the four-minute mile was accomplished in 1954, human physiologists had thought it to be an impossible feat). For lessened ventilation rates, it is possible to extend the duration of the activity. Thus, the nature (length) of the activity is reflected in how much oxygen the body is able to intake and how efficiently the oxygen can be used in oxidation of food materials during metabolism. A particular adaptation that the body has developed is known as oxygen debt, exhibited during short sprints at high speed. It is brought about by the production of certain phosphates in the muscles which cause a tightening or rapid reduction in the usability of the muscles. For instance, the individual running the four-minute mile probably has a maximum ventilation rate of 68 milliliters O_2/kilogram of body weight/minute. The requirements to maintain a 15 mile/hour pace for four minutes are 79 to 81 milliliters O_2/Kg/minute. Therefore, the debt after such a race is: 4 x 12 + 20 to 25 ml/Kg (additional for effects of first two minutes) or about 70 ml O_2/Kg; and, for a 70 Kg man, a debt of approximately 5.0 liters would be observed.[34]

Oxygen is circulated in the blood by the compound hemoglobin which is present in blood plasma and is based upon a complex iron ion which absorbs the oxygen molecules. (The need for iron in the diet is thus demonstrated.) The metabolic reaction from which body energy is obtained depends upon the establishment of adequate quantities of oxygen in the blood. For simple sugar carbohydrates, it follows the form:

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O + \text{Energy} \qquad \text{(A)}$$

The by-products of this reaction -- carbon dioxide and water -- become the primary wastes whose partial quantities are predicted by equations 6 and 7, although substantial additional quantities are produced in the reduction of fat and protein substances. Carbon dioxide is passed back into the blood and is released by the lungs in the expired air. The presence of carbon dioxide in the blood has an inhibitive effect on the absorption of oxygen by the hemoglobin. If quantities of carbon dioxide equal to or greater than 2% of the inspired air occur, hyperoxia results with loss of perception, motor control, and consciousness.[35]

In example 2, the individual performing at high efficiency while playing tennis requires 365 Kcal of energy to participate for one hour. Therefore, if we figure that he has a respiration quotient (RQ) of about 1.000(which is consistent with the ability of the body to generate a continued dependence upon a high carbohydrate energy source for periods up to an hour) and that his energy expenditure requires approximately a liter of oxygen per five kilo-calories of energy, then he will need 365/5 or 73 liters of oxygen. He will similarly generate 73 liters of carbon dioxide. Equation 4 may be used to determine the quantity of carbohydrates consumed during this period as a source of the expended energy. From this quantity, the amount of metabolic water produced can be found using equation 7.

4. Water Requirements for the Body

Water comprises about 60% of the total body mass and about 73% of the lean body mass (that which is exclusive of the nonsoluble fat substances). About two-thirds of the total body water is found in cellular material with the remainder in the extracellular masses (about one-fourth of that supports blood plasma and lymphatic fluid and the rest -- three-fourths of the extracellular material -- is found in the tissue fluids lying between the cells).[36] The presence of water in the body is regulated by a balancing action much like that established for the thermal regulation of the body. Water is gained and lost through a series of mechanisms outlined below:

Water gains: A general rule of thumb used to indicate the approximate quantity of water consumed per unit of time is based on the energy expenditure of the body: for one kilo-calorie of energy expended, a gram of water is required.[37]

(a) The previous discussion, concerning both food composition and the foods tabulated in Appendix 3, indicate a major source of water is <u>food intake</u>. Just as much of the human body is water, so, too, is much of most food materials except the fats. The noted range of water received during consumption of food is usually between 350 and 600 milliliters of water/day with the mean at approximately 400 milliliters.

(b) The largest source of water intake for the body is from <u>drinking liquids</u>. The observed variation in water-fluid intake is between 500 and 12,000 milliliters/day and changes widely depending upon activity, clothing cover, and environmental factors such as temperature, solar radiation, humidity, and wind velocity. The provision of water to the body by drinking is important as means of providing for thermal regulation by eventual water loss in the manner already discussed in Section III-C-1. (It will be explained later in this section in more detail.)

(c) The third opportunity for water gain occurs during the oxidation of food materials during metabolism. As it was predicted in equation 7, the amount of water produced can be determined for any diet and generally falls within a range of 300 to 400 milliliters/day.[38]

Water losses: The water emitted from the body during water balancing is directly associated with waste removal and the maintenance of thermal regulation.

(a) For low to medium activity levels performed with moderate clothing and bioclimatic conditions, the major release of body water is urine, ranging from 500 to 9,000 milliliters/day. Urine is primarily a means of removing waterborne solids and waste liquids, particularly urea which is produced by the kidneys as they cleanse the blood. The mean quantities of urine eliminated by an individual of normal activities, body configuration, diet, and bioclimate is approximately 1400 to 1600 milliliters of urine/day. The urea emitted is the principal embodiment of nitrogenous materials and the quantity of nitrogen released may be predicted by the equation:

$$\text{Nitrogen} = 0.163\ P \qquad (9)$$

where P represents the quantity of protein material in the diet.[39] Minimum urine volumes for a specific diet may be calculated by referring to the osmotic load on the kidney: electrolytes are released from the diet (particularly from protein content) and determine the amount of osmotically active material (*e.g.*, for a diet of about 3000 Kcal/day with a protein content of 10%, the total osmotic solute is 523 milliosmols/day requiring a minimum urine flow of 310 ml/day).[40]

(b) A second source emitting a much smaller quantity of waste water is that of *fecal matter*. The range of water eliminated in this way is approximately 50 to 250 milliliters/day with a mean of about 100 milliliters/day.

(c) The third quantity of water eliminated is called the *insensible water loss*. It comprises the water lost during respiration and from diffusion through the skin. As with the sweat losses, both are functions of activity, clothing cover, and the bioclimatic conditions. They vary as a sum from 300 to 1500 milliliters/day. Both are present primarily as heat regulators, although in general the respiration loss is much greater than diffusion loss. The term "insensible" indicates that this water loss is irreducible and cannot be voluntarily limited unless the water gain sources are monitored which may cause dehydration.

Water loss is thus an integral part of respiration. Insensible water loss can be generally predicted by the following equation:

$$\text{Insensible water elimination} = \frac{\text{estimated Kcal above basal}^{41}}{0.58 \times 4} \qquad (10)$$

Under moderate conditions, about 25% of the total water loss is expended in the form of insensible water.

(d) Sweat loss is the most variable form of water loss, covering a range from 0 to 10,000 milliliters/day depending on activity, clothing, and bioclimate. It is an important mechanism for heat regulation within the body, providing cooling needs as required. The maximum sweat rate generally is approximately one liter/hour, affording a heat expenditure of 600 Kcal/hour.[42] The rate of sweat production respective of temperature, humidity, wind velocity, activity, and clothing can be roughly determined by the following equation:

$$\text{Sweat loss} = 6 \times (\text{predicted four-hour sweat rate})^{43} \qquad (11)$$

in which the predicted four-hour sweat rate (P_4SR) allows relatively accurate sweat rate determination for periods of four hours for activities ranging from rest to work.[44] For a specific discussion of how the (P_4SR) is calculated, reference 40 includes the appropriate charts and variations.

Summarizing the water balance regulation, an equation describes the net balance indicating gain and loss:

$$(H_2O)_{\text{Balance}} = (H_2O_{\text{Food}} + H_2O_{\text{Liquid}} + H_2O_{\text{M.Ox.}}) - (H_2O_{\text{Fecal}} + H_2O_{\text{Urine}} + H_2O_{\text{Insens.}} + H_2O_{\text{Sweat}}) \quad (12)$$

EXAMPLE 4: If we return to our friend, the M.I.T. graduate student, whose typical day was described in Example 1, we can consider his water balance requirements. The individual requires 2940 Kcal of metabolic energy/day. His bioclimate was characterized as 80°F air temperature with 85% relative humidity and an overcast sky with little to no air movement. For tennis he had worn a light sweat suit with socks and sneakers, an ensemble rated at 1.0 Clo and with an impermeability index of 0.50. But now his outfit, following his tennis match, consists of a long-sleeved shirt, slacks, and shoes and socks which is generally rated at 1.4 Clo and an index of 0.45.[45]

Water gain: We know that, for a metabolic rate of 2940 Kcal/day he will require 2940 milliliters of water. From equation 7, the water produced by metabolic oxidation of his diet will be:

$$(H_2O) = 0.56(390) + 1.07(114) + 0.41(71) = 370 \text{ milliliters } H_2O$$

If we assume that his diet, which consists of 575 grams of food materials is about 40% solid and 60% liquid, then the water in the food intake will be (1440-575) or 865 grams or milliliters H_2O. Therefore, he will be required to drink

1705 milliliters of water or water-based liquids. It is probable that his diet will actually have a lower solid/liquid ratio than that assumed (as would be substantiated by reviewing Appendix 3).

Water loss: If we assume that his production of fecal matter is consistent with the mean, then his water loss by this mechanism should be approximately 100 milliliters. Using equation 9, his water loss from the insensible models should be:

$$(H_2O) = \frac{(2940 - 1560)}{4 \times 0.58} = 595 \text{ milliliters}$$

for both the respired and diffused water losses totalled.

The calculation of the quantity of water lost through sweat may be done by either of two methods and each is only roughly accurate:

(a) using equation 3 and generalizing over the entire 24-hour period by assuming a constant temperature (80°F) and relative humidity (85%) which might be reasonable for a summer day in Cambridge,

$$(H_E)_{max} = 5.55 \times 1.8 \times 2.2 \left(\frac{0.45}{1.4}\right) (42-22) = 140 \text{ Kcal/hr.}$$

Evaporative heat is expended at the rate of 140 Kcal/hr. It is known that the heat of vaporization for sweat is 0.58 kilocalories/gram; therefore, for a 24-hour period assuming maximum heat lost by evaporation, his sweat loss would be

1950 milliliters. Having described the student as sleeping for seven hours and studying and attending class for twelve hours, it would perhaps be more realistic to suppose that the actual sweat rate was some fraction like 50% of maximum and that the actual sweat loss would be about 975 milliliters/day. This technique is admittedly crude. But, as a first approximation, it offers a working figure. A more definitive analysis could be executed by reconsidering such a time period in hour-by-hour increments and by establishing changes in partial pressures of water vapor with changes in air temperature (if air conditioning were present).

(b) The second calculation depends upon the use of the predicted four-hour sweat rate as described previously. Using the same generalized conditions but being better able to recognize changes in activity for an average situation, the sweat loss was determined to be 880 milliliters (specific calculations in Appendix 5). Thus, if we assume a balanced water requirement where (H_2O) balance equals zero, the urine loss can be calculated to be (2940 - 100 - 595 - 880) or 1365 milliliters of urine which is well within the range established earlier.

The level of this analysis is at best a first approximation, but it does illustrate a technique that can be used for such determinations. More accurate analytical techniques are being developed or tested elsewhere and will shortly appear in writing.[46]

Two less visible issues in the general discussion of water utilization in the body are (1) the question of purity of consumed water and (2) humidity in the air (more specifically, the partial pressure of water vapor present relative to the temperature of the air and the partial pressure of fully-saturated air at that temperature). In the first instance, the water commonly obtained from the tap has a high quantity of harmful minutae, which in negligible amounts are not injurious to health. The impurities are classified in three groups: microörganisms (bacterial), chemical or mineral, and radiological.[47] The second issue -- relative humidity -- will be discussed more fully in the next chapter under bioclimatic properties. It is mentioned now to note it as a comfort index which has specific effects upon the body's ability to exchange heat and water (sweat and insensible water) with the gaseous atmosphere.

5. Waste Management in the Body

The specific waste products are generally considered as either metabolic or non-metabolic. The metabolic waste products -- carbon dioxide, sweat, respired and diffused water, urine, and feces -- are regularly wasted, whereas the non-metabolic wastes -- skin, hair, finger and toe nails, and several other minor quantities -- are wasted irregularly. Amounts of each of the major contributents have already been noted in terms of their liquid and gaseous forms. The quantity of solid materials in the urine and feces normally range between 60 to 75 grams/man-day for the urine and 17 to 20 grams/man-day for the fecal matter.[48] The actual amounts of the other contributents are measured in milligrams/man-day, and will not be noted here.

These elements of human physiology are necessary to establish bases for understanding the principle physiological criteria for habitability. It is hoped that perceptions about the nature of man and the means by which he functions will offer more cogent bases for shelter design. This brief explanation about the most important physiological processes excluded several psychophysiological operations such as hearing, sight, and smell, each of which are important as guides to interaction with external stimuli. An interesting presentation of these other issues appears in Halldane's work.[49]

The recognition of physiological variables in the investigation of habitability can be made more valuable when similar work done in psychological and social aspects of habitability are interfaced, and the combination forms more humanistic and rigorous bases for development of the individual's resources within the context of activity and habitat design.

IV. THE BIOCLIMATE GENERALIZED

The bioclimate is, essentially, the collection of natural elements which characterize and determine man's existence. These natural elements may occur as part of the processes that are not controlled by man; or on the other hand, they may be products of artificially-induced processes (*e.g.*, the rain *versus* a farmer's crops). It is generally true that while man cannot control the first subset he is able to influence some and, in limited situations, to negate the others (*e.g.*, under laboratory conditions, atmospheric pressure can be reduced to near vacuum). The specific elements will be delineated below.

The bioclimate is, therefore, the surround in which the individual pursues time activities that describe his life process. Additionally, it is not sufficient to think of the bioclimate as *influencing* the individual's life process; instead it should be recognized that the bioclimate is the *basis* for the life process. In Chapters V and VI, we will consider the development of a series of life support mechanisms which can extend task capabilities by either (1) developing more interactive and assistant organizations, or (2) reproducing the bioclimate at a microcosmic scale. But, with both of these and in reflection of Goddard's postulation,[50] the presence of the bioclimate is still fundamental. It might be noted that the preceding description may be similarly derived from the system-environment analog of Chapter II, particularly if one considers the man-system and bioclimate-environment exchanges).

The bioclimate has -- in a much larger sense than the individual man -- a systematic character. It consists of a number of physical and biological entities working together, often in a complex manner and generally in a cooperative one. The bioclimatic organization in which man is most always involved is the ecosystem (a structure that will be more fully explored in Section VI.B). This environment for man exists as a many-layer hierarchy of activities and interdependencies, organized as a community of biotic and abotic materials and controlled by energy presences. The resources, activities, and products of this aggregation are cyclic (and rhythmic) and have generally evolved through generations of increasing maturity, seeking equilibria.

A. The Primary Constituents of the Bioclimatic Environment

1. Solar radiation.

Solar radiation is experienced as both light and heat energies and ultimately controls all activities in the bioclimate. This energy penetrates the atmosphere of the earth as short-wave radiation. Its relative incidence is qualified by a number of bioclimatic factors, which diminish the amount of incident energy that would be experienced on a "black box" surface in space. The primary determinant of the direct incidence is the sun angle which describes the angle at which the solar radiation strikes a specific geographic location, relative to a projection normal to the earth at that point. Becuase of the earth's relative inclination and its rotation on its axis, the time of day and the season of the year strongly influence the sun angle. The significance of the sun angle as an indicator of direct influence lies in the relative "thickness" of the atmosphere through which the radiation must pass. As the angle increases, the likelihood also increases that atmospheric presences will modify and diminish the direct incidence reaching the ground surface. The other qualifiers -- cloud cover (or water vapor present in the air over the specific location), particulate matter (naturally or artificially generated), the presence of carbon dioxide, and the atmospheric turbulence -- limit incident energy. The effect produced by these modificants is that part of the radiation is diffused. This condition is indicated by the ratio of diffuse to direct radiation incident on a specific location: on a cloudless day, the ratio is approximately 0.15 whereas with an overcast sky, the ratio is more nearly 1.00.[51] The amount of diffused radiation also increases according to the sun angle. In Anchorage, Alaska, the ratio is about 0.35 for a cloudless day.

The other primary form of solar radiation occurs as reflected radiation, characterized by a long-wave configuration. The reflection occurs as incident radiation for any of a number of surfaces, including the ground, or water, buildings, atmospheric matter and other material. Once reflected, and if it is not re-reflected radiation is more likely to interact with atmospheric matter than is the short-wave radiation of incident solar radiation. Therefore, the escape of the former is minimized relative to the latter and less energy is lost for any specific time when the atmosphere contains reflecting material. Naturally, for specific locations whose ground surfaces are highly reflective like sand or snow, and which have little cloud cover, a high percentage of heat is lost by reflected radiation (a fact that is substantiated by the high tanning possible on the ski slopes). Alternatively, for an industrial city with a high density of particulate matter in the atmosphere over it, short wave radiative energy entering through this cover is not generally lost as reflected energy. This contributes to a warmer city. It has been suggested, for instance, that the bioclimate of New York City is approximately five to ten degrees warmer now than it was when Manhattan was purchased from the Indians in 1624.

2. <u>Air temperature.</u>

The importance of the thermal environment is demonstrated in terms of a comfort zone or "zone of thermal neutrality."

for man, it is the thermal condition in which the body is able to maintain heat balance between production and loss without significant changes in activity or heat transfer.[52] The mean temperature for the zone of thermal activity has been ascribed as 73 (±2)° F, and the zone itself is primarily dependent upon the air temperature, air movement, water vapor and radiation. A series of thermal indices have been developed to describe the environment and man's relative comfort within it, accordint to the environment's thermal properties and man's ability to experience heat. All of these indices are directed at warm, humid environments and do not offer any understanding of cold climates. The four primary thermal indices -- effective temperature, mean radiant temperature, the heat stress index, and the index of thermal stress -- are described in Appendix 6 and are accompanied by example 5.

3. Atmospheric pressure.

This property of the environment was described in Section III.C.3. with particular reference to man. The normal atmospheric pressure at sea level, 760 millimeters Hg, is the result of an atmospheric gas mixture approximately composed of 78% nitrogen and 21% oxygen, with small amounts of water vapor, carbon monoxide and dioxide, hydrogen, and several inert gases. Atmospheric pressure decreases with increases in altitude (e.g., at 18,000 feet, the atmospheric pressure is 380 mm. Hg.).

4. Wind (or air movement).

Wind is the product of thermal turbulences in the air and is experienced in the presence of intermixing high and low pressure zones. This intermixing is generally associated with changing or unsettled weather patterns. Wind frequency and intensity follow these patterns, period of greater activity based upon more unsettled atmospheric conditions. Air movement is also manifested as an atmospheric turbidity.

As indicated previously, increasing air motion increases the amount of heat lost to the environment by evaporative and convective actions. This condition is especially relevant for man and indicates the potential effect of wind on thermal comfort. At high rates of activity and high air temperature, wind presence can be pleasant. Contrarily, in cold climates, heat loss increases by wind need to be minimized.

5. Moisture in the atmosphere.

Moisture is present as water vapor, water droplets, and ice crystals. Moisture initially enters the atmosphere as water vapor, as established by evaporation of surface water. The evaporation is initiated by solar radiation and is the first step in the three-part primary cycle of evaporation, condensation, and precipitation. The air's capacity to accept water vapor increases with increasing temperature so that air at 95°F. can carry twice as much water vapor (by weight) at saturation as air at 73°F. For instance, air saturated at 73° F. (relative humidity = 100%), if suddenly heated to 95° F. with no loss of water vapor, would be only half saturated.

If air carrying a specific amount of water vapor is cooled, its ability to support that water vapor is reduced and the relative humidity will increase until the air is totally saturated. Any cooling beyond saturation will cause condensation of the water vapor into very small water droplets. Similar condensation produced by adiabatic cooling of large air masses causes cloud formation and eventual precipitation in the form of rain when the water droplets become too heavy and are able to withstand evaporation as they fall through the clouds. In clouds at high altitudes or in cold air, water may be present as ice crystals.[53]

Fog and dew are other manifestations of water in the atmosphere and are caused by water vapor-laden air mixing with cooler air or coming in contact with cold surfaces such as dust or industrial particulate matter (as in smog). For a more definitive discussion of moisture in the atmosphere the reader is referred to Givoni.[54]

6. Water temperature.

Water temperature greatly influences the climate over both land and sea areas: most or all major weather activities are initiated over water or ice surfaces. On a smaller scale, man's interaction with the effects of water temperature occurs during submergence in it. For such activity, the principal heat loss mechanism is conduction which is occasioned by the much greater density of water, relative to air. Ocean water temperatures are seldom warmer than 70° F. at the surface and decrease readily with increases in depth. An appendix indicating thermal responses to water immersion has been prepared by Ralph Goodman and his associates and is included as Appendix 7.[55] Water temperature and pressure are particularly important criteria for shelter design for hydrospace activities.

The remaining bioclimatic elements should be recognized as man-centered factors, which, though present in the natural environment, exist primarily according to how man experiences and utilizes them.

7. Fuel.

Possibilities for fuel provision exist in both naturally and artificially derived power sources. The natural opportunities that have been or can be controlled are (a) solar radiation in which incident light is focused, received, and converted; (b) tidal power based upon advanced hydroelectric principles; (c) geothermal power in which the heat of the earth's inner core is controlled; and (d) power produced by wind-driven mechanisms such as has been used for several thousand years. Artificially-derived power can be obtained from a number of natural sources: (a) fusion and fission, both of which are based upon the primary energy of atomic matter; (b) combustion of fossil fuel (oil, natural gas, and coal); and (c) combustion of other organic material (such as peat or wood).

8. Food

The primary types of food are products of either natural (wild) or artificial (man-induced) cultivation, whether the sources are animal or vegetable. As demonstrated previously, man's diet can be either herbivorous or omnivorous. At both global or man-centered levels of food production, the energy-nutrient flow follows a nearly cyclic path in which nutrient producers in cooperation with the sun create foods that supply the herbivores and the carnivores. All then supply nutrients and energy to the microorganisms responsible for decomposition of food and waste, during biodegradation. This process is the basic support process for all ecosystems, including those with man as element and as center. The flow chart for nutrients and energy cycling is reproduced in Appendix 8.[56] The elementary process in all food production is photosynthesis and it is characterized by this equation:

$$CO_2 + H_2O + \text{Solar Radiation} \xrightarrow[\text{Chlorophyll}]{\text{Green Plants}} CH_2O + O_2 \qquad (B)$$

The carbohydrate (CH_2O) produced is a simple sugar and in this instance is recognized as formaldehyde, a building block for many, more complex carbohydrates. It is also of extreme importance to man that the other product is oxygen.

9. Animal life.

The part of the bioclimate that includes animal life also includes man. The presence of animal life is one element within the various ecosystems that constitute the bioclimate and, as such, is not the prime actor because of the interdependence of all elements (perhaps contrary to man's fantasies).

10. Regional disease.

Disease is a product of various microorganisms present largely as viruses, bacteria, and fungi, which are pervasive and in great or small concentrations depending upon the specific regions of the earth.

11. Sound.

Sound is the product of mechanical vibrations, and evidence exists that it is recognized by all animal life. Mechanical vibrations audible to man occur within a spectrum spanning approximately from 20 to 20,000 cycles/second. The intensity of the sound characterizes its presence as well; the threshold of audibility has a rating of zero decibels. Loud thunder, close in proximity, has been measured at 120 decibels.[57] A more thorough discussion of sound and its perception can be found in Halldane.[58]

To summarize this section, the important microclimatic variables that must be established before mechanism design can be initiated for the system's activity support include: (1) air temperature; (2) solar radiation; (3) wind intensity and direction; (4) moisture content in the atmosphere;

(5) botanical growth; (6) animal life; (7) topography and ground cover; and (8) the primary sensory perceptions including sound. In extreme environments, such as aerospace or hydrospace, atmospheric or water pressure and water temperature are also important.

B. Performance Within the Bioclimatic Environment -- A Question of Attitudes

It is important to note, as in the preceding section under food that man, while seeking food sources, is only one element of a larger biomass. This fact, thus established in the concept of ecosystems, questions man's general intention to see himself as being at the top of the primary food chain rather than simply within it. The effect of the collective man upon the natural environment is gradually being recognized as one in which man is creating an ecological debt. It would appear that any such debt must be minimized and neutralized by a more sympathetic use and ordering of the support organizations. An alternate solution, however, could be created if the debt were allowed to accumulate while man continues to develop more successful and ingenious methods to support himself, thus separating himself from the bioclimate. While this perhaps disregards the ultimacy of Goddard's statement, it is true that man is now able or will soon be able to build artificial environments which could minimize or negate the need for a natural bioclimate.

The evolution of the man/system has occurred almost continuously in the so-called temperate climatic zone, which is characterized by the presence of comforts -- thermal, water, and food. But even so he has been able to exist in a series of apparently hostile climates by either adapting himself to fit the environment or by changing the environment to fit his needs. In both instances, his continued existence within these uncomfortable zones has depended upon the support of specially developed mechanisms.

A list of cioclimatic environments, generally viewed as hostile, has been compiled and is found in Appendix 9. Most of the bioclimates have sustained human life for millenia.

V. THE SYSTEM/ENVIRONMENT INTERFACE -- A MECHANISTIC SOLUTION

A. The Requirements of the Interface

The role of the interface has been previously defined as an arrangement that provides sustenance for a system whose capabilities do not match the demands of a possible hostile environment. Similarly, the issues of fit and introduction during the translation of the system into the environment have been considered. The interface is, thus, characterized as an entity which is able to extend the capabilities of the system and allow its entrance into environments whose elements offer increasingly fewer viable means for sustenance and activity. In Section III.B. (and summarized in Appendix 10), a list of the primary requisites for the continuance of human life was compiled, and a more definitive description of the five most critical bases was presented. Several bioclimatic environments were delineated in Appendix 9. From a comparison of these two appendices, it is apparent that there are gaps between system capabilities and environmental provisions, and these are further listed in Appendix 11. Interfaces are required to create the adaptability needed. Seemingly, these artificial boundaries, while perhaps separating man and bioclimate will actually extend the activity scope. To accomplish this goal without placing further duress on the environment, a series of mechanistic interfaces has been developed and will be presented in this chapter and the next.

The mechanistic interface is intended to be a complete life support mechanism (LSM or mechanism) which provides assistance for whatever gaps exist between man and the bioclimate. It would not be inappropriate for the mechanism, while supporting the various activities, to also offer a certain measure of comfort above the basal life-sustaining features. The mechanism will be required to support the five primary life needs denoted in Section III.C. -- maintenance of a thermal equilibrium, nutritional balance, provision for gas transfer, fulfillment of water requirements, and removal and treatment of waste. The mechanism is also expected to provide for each of the other stated needs in Appendix 10 and to offer opportunities for control -- automatic and manual -- and for mobility. This mechanism could generate such support in a cyclic mode, requiring supplies from some central source or municipality on a very infrequent basis. The overall structure of the mechanism is determined by the relationship of man and mechanism arranged to provide life support for one or several individuals. The man-mechanism bond suggests a cellular organization in which this cooperative arrangement is the basic unit. Ready growth opportunities for this unit would include (1) attachment to other mechanisms or a central source (on an infrequent basis) and (2) expandability as activities or life functions become more numerous or complex.

B. Factors Influencing Mechanism Design

A number of criteria have been developed by the author to serve as design bases for any support mechanisms. These are essentially the programmatic requirements for a successful mechanism. The criteria should be regarded as goals which may only be manifested as attitudes in the early designs rather than accomplished in a comprehensive manner. Later mechanisms would be expected to provide all of these factors.

1. Internal organization of the mechanism

a. Integration of submechanism elements. The various submechanisms must be joined in an organization in which the relationship of the pieces forms a whole. It is not necessary that the submechanisms be entirely independent; and it would seemingly be preferable to establish an "open" framework, allowing for exchangeability of parts. But it is unclear whether this "open" arrangement would necessarily be more or less efficient than a "closed" organization in which all of the subcomponents were mutually dependent.

b. Modularity of submechanisms. The submechanisms should exist within a common scale (size) and capacity (power). Excessive size and power may cause inefficiencies or lead to overloads and waste. It is absolutely imperative that efficiencies of a high order be demonstrated and the most likely basis is a balanced framework.

c. Maintainability of submechanisms. Removal and repair of the various submechanisms can be easily and efficiently accomplished, hopefully by the user or at least by any of a network of trained service personnel, similar to some automobile purchase and repair networks. Additionally, it must be possible to remove and repair discrete units without rendering the entire mechanism inoperable and requiring extended periods of non-support.

d. Relationship of submechanisms to the energy-core. It would be hoped that each element derived its power directly from the core rather than from another element. Such an arrangement would probably insure more efficient use of power, removal of potential inactivity or one element while another was down or being repaired, and the prevention of power overloads passing through elements when power surges were required by another submechanisms for initiation or operation.

e. Redundancies of provisions minimized within active elements. The possibility of two or more submechanisms being present to perform a primary task as each one's specific responsibility creates unnecessary inefficiencies. It would be most appropriate for each submechanism to be responsible for the provision or support of a single system requirements. Duplication in operation would inevitably lead to competition, loss of energy efficiency, and probable greater operating times.

f. Back-up capabilities for specific submechanisms. Contrary to the previous criterion, it would be entirely appropriate to have submechanisms which provided, as stand-by or normally inactive service, capabilities to support specific requirements if a primary support submechanism was not functioning properly. Such arrangements could be structured to occur automatically or by manual control as the need arose. Such timing would, of course, depend on the relative urgency of back-up support.

2. Performance of the mechanism and its components

a. Reliability. The mechanism must offer high confidence for general use, assuring the required support. A secondary issue in this requirement is predictability -- can the behavior of this mechanism be forecast within supposed combinations of human needs and bioclimatic conditions? Additionally, the specific lifetime of the mechanism and each of its subcomponents should be known and opportunities for monitoring of use and its effects be built in, allowing for self-testing (and perhaps in a later generation, self-correction).

b. A programmed response to change. Because of the relative unpredictability of environmental conditions and the hope that the mechanism could serve over a wide geographic area, it would be appropriate if the mechanism had the capability to analyze the immediate bioclimate and adjust its support provisions on an automatic basis. Perhaps in the earlier models of this mechanism, such adaptation would be expected to be initiated and controlled by the individual manipulating or directing the mechanism. Only in advanced versions in the relatively distant future could it be expected that the mechanism would not only analyze current, but also predict ensuing bioclimatic conditions and change the organization of the mechanisms or the conditions of the immediate environment. It is also conceivable that the mechanism might be able to interpret changes within man and provide for suitable additional supports (*e.g.*, if the operator came down with a cold or the flu, the mechanism might offer a sympethic front).

c. *Quality of life support*. This is the most important criterion of all. If the life support is insufficient, man could experience conditions deleterious to his well-being. The question inherently is: does the mechanism satisfy the "functional analysis model"(in appendix 10)? If the answer is yes, then the secondary issue becomes: does it provide sufficient assistance to generate specific comforts?

d. *Lifetime of mechanism is maximized*. Specifically the length of usability of the mechanism is maximized. A "trade-in" should be unnecessary unless significantly new mechanisms become available. There should be some way of testing the mechanism periodically to determine its relative well-being.

e. *The length of a complete operating cycle is maximized*. The primary cycle within the mechanism, of course, depends upon man and this, most often, is a twenty-four hour day. However, depending upon storage, regeneration, and power efficiencies, the mechanism might work on a periodicity that covered several of the man-cycles. The relative maximization would therefore be determined by a responsiveness to these issues.

f. Self-replenishment during and between cycles. Development of a cycling format for the mechanism's operation implies a matter-energy transfer between cycles. Within any periodicity, it would be expected that waste material could **either** serve as the basis for the new growth cycle or be regenerated without specific growth processes. The central point of this criterion is whether or not additions will have to be made within the nutrient-energy cycle and if these additions can be internalized within the mechanism. It is highly probable that additions will occur because of the inherently depletive process characterizing life, but it would be significantly more efficient if the actual replenishment of the specific cycles from outside the mechanism occurred infrequently. Both the range and the adaptability of the mechanism would be increased. Additionally, the bioclimate would also benefit from such internal cooperation because:

(1) less might have to be removed from the bioclimate and (2) fewer harmful or wasteful products would be released to the environment. This second premise assumes a more generally efficient process based on the necessity for greater inclusivity of matter and energy in the cycle.

g. Ability to relate to a higher-scaled mechanism for replenishment. It would be most suitable that, for the infrequent resupply operations, the mechanism be easily absorbed or received by the supply mechamism. A probable modularity should exist between the relative mobile mechanism and its supply core mechanism, allowing for repair and replenishment. An alternative view to this concept could be centered upon the throw-away idiom of the American automobile industry in which, after a short time, as the equipment loses its effectiveness, the vehicle (or in this case, the mechanism) was simply dispensed with and replaced. Naturally, the development and construction of such a short-term mechanism would probably be based upon inferior equipment.

h. Cost and benefit. A primary attribute of any support mechanism, second only to the total provision of life assistance, is the relative availability of the mechanism (i.e., who would be able to afford or to utilize such a mechanism?). What are the establishment and operation costs for the user and his environment? An important distinction would have to be observed between monetary and environmental costs. Naturally, if the benefits involved both long-term efficiency and complete activity support within an assisting tenant/habitat relationship, the costs could be justified.

In assessment of costs, an opportunity for cost savings could exist with the introduction of industrialization to the construction process. Important cost reductions could be accrued within a continuous building program based on a large, aggregated demand.

i. <u>Current availability of the required technology</u>. The development of the life support mechanism will inevitably need innovative skills and hardware. Therefore, it is important to recognize the stage of readiness that any such required equipment or technique is in, and to allow sufficient lead time for the appropriate development. If such time is unavailable, then existing hardware at whatever level of efficiency must be substituted. A secondary issue would concern submechanisms suggested theoretically, but whose specific concepts have not yet been carried through a preliminary stage of development. Work could be accelerated by implementing crash programs; or proposed advancements, progressing by generational developments, might skip intermediate generations. This would be indicated for designs based on work where practical application is probably several generations away. As an example, the aerospace industry currently is involved in theoretical conceptualization that is at least three or four generations beyond the highly complex hardware and skills now in use.

j. <u>Safety</u>. A mutual understanding between man and the mechanism, about the capabilities of each, is required. Naturally limits exist upon all equipment and skills, and even with a highly reliable mechanism, it is probable that a confidence interval of 90% will be significant. Operation of any such mechanism has risks which can be minimized if the interactive processes are well understood.

3. The Mechanism as an interface for man.

a. The man/mechanism relationship. A relationship will develop between the man and the mechanism and will depend upon both the interactive process and the attitudes of the designers and the users. Symbiosis, antagonism, or relative neutrality (or indifference) could each be the principal form of involvement. Seemingly, the bond will vary according to the individual, his activities, and the level of success with which his life processes are maintained. Attitudes will similarly be developed within the context of performance: it would be most appropriate if the individual directing the mechanism's operation were able to use the mechanism in an efficient, non-wasteful way, perhaps even getting the maximum capabilities from the mechanism, without coming to depend on it to the exclusion of his own ingenuity and adaptability. It is the author's opinion that such a balance might well be difficult to achieve, requiring unusually disciplined individuals.

b. Growth of man or the mechanism. Hopefully, through some mutually appreciative relationship developed between the system and the mechanism, growth of or within the relationship would occur. The essentially dynamic characters of both the man and the mechanism necessitates a design solution which allowed flexibility. The importance of growth is established within any discrete change in activities or individuals. While it is probable that a mechanism structured for a specific task would not be expected to display universality; it is nevertheless expected that, as the individual developed new capabilities or interests, the mechanism could change to meet them. The inherent nature of this criterion is similar in intent to those of section V.A.2a and V.A.2b.

c. Portability. The mechanism must be mobile, if not portable, such that its range is wide and that it is easily transferable in either continuous or discrete locational changes. The mobility would also be enhanced if the mechanism was able to adapt to a variety of terrains. Because of the comprehensiveness of the support provided, it is likely that, for the early generations, the mechanism will be styled in a vehicular mode rather than as a backpack arrangement. Seemingly, with reductions in the comprehensiveness of the unit, it would be possible to reduce the package to one which a man could carry. The loss of portability in the conventional sense is more than compensated for by the gain in absolute life support, as long as mobility is also provided.

The mechanistic package should be small and lightweight, and it should have its own vehicular-style power source.

d. Independence from public networks. The mechanism should not require support from specific, existing networks commonly used to obtain power, heat, food, and other publicly provided facilities. If the mechanism needs to make frequent stops at various public sources,it will begin to resemble the static enclosures of the city.

e. Presence of a discrete shell. In any mechanistic design which provided life support, a shell would be required whether as a vehicle body or as a tent. The form is of less importance than the controlled environment, internalized and providing each of the requirements of the functional analysis model. For any form, the submechanisms should be arranged so that (1) some access to all of the components is afforded and (2) freedom of movement is provided for the individuals within.

f. Adaptability to other bioclimates. This criterion has been discussed before in section V.B.2. with regard to performance. A universality of use would be preferable, but this requirement might not be realistic in the early generations. An unlimited adaptability would require an assistance mechanism whose components, excepting thermal balance, are not affected by the immediate bioclimate. But such an overall assistance could only be established within a relatively internalized array.

4. The Relationship of the Mechanism to the Environment

a. Initiation of the mechanism into the environment. The implementation of the mechanism as an interface between the system and the environment again raises the dual issues of fit and introduction. Similarly, the question of what will be required for activation of the mechanism is also appropriate. Consistent with these issues, the mechanism should be self-activating and able to continuously adapt, so that it is able to respond to changes in conditions much as in sections V.B.2.a and V.B.2.b.

b. The result of the introduction of the mechanism into the environment. It is of great importance that the mechanism must not upset the ambience and systematic existence of the bioclimate. The chances of upsetting an ecosystem functioning at any scale must be minimized. Therefore, for any mechanistic designs for a life support package, the initial requirements and the final products of the system/mechanism cooperation must be delineated with special attention to what is removed from the immediate bioclimatic environment and what is left behind. Seemingly, within the criteria established in sections V.B.2.d and V.B.2.c, an efficient, regenerating mechanism would use all of its products to initiate new cycles rather than depending upon a continued source of replenishment from outside the mechanism (i.e., self-replenishment is the basis for cycled support).

c. Minimization of energy lost to the environment. The ratio of energy lost or generated to the environment compared to the energy produced by the vehicular and mechanistic power supplies must be reduced to a minimum. Such a relationship minimized would allow greater efficiency and longevity for the various power supplies. The reuse or controlled exit of energy already utilized as heat could similarly offer bases for new efficiencies.

d. Minimization of materials released into the environment. Consistent with the preceding section, the reuse and regeneration of wasted materials will improve the efficiency of the mechanism (*i.e.*, within modes already discussed in sections V.B.2.d., V.B.2.e., and V.B.4.b and produce less polluted bioclimatic environment. If particular materials are to be diffused to the environment (e.g., gases and quantities of water), it is imperative that these substances be purified of any deleterious organisms or noxious elements.

A list of submechanism selection criteria, which parallels those stated in the preceding text, has been produced by the United Aircraft Corporation for the National Aeronautics and Space Administration (NASA), and is reproduced in appendix 12.[59] The work of the United Aircraft Corporation was prepared for designs of advanced integrated life support systems, suitable for extended-duration space flights. In both sets of design philosophies, an important understanding in the evaluation and selection of suitable submechanisms is that compromises or "trade-offs" are essential to the successful development of a final product. As such, optimizations are most generally sought by information systems (computer) searches covering large quantities of variables delineated from design criteria lists as structured above.

The applicability of a highly mobile mechanism,whether structured for long or short durations, is dependent upon logistic support. Such support can be minimized if the lifetimes of the particular submechanisms are long and the need for specific replenishments is small; and it is entirely conceivable that the actual activity support period will be far shorter than any design lifetime. Criteria for logistic support would therefore b- based upon the relative needs of specific submechanisms for repair and resupply. Cored or central supply depots would have to be provided within some sort of a framework, and it would seem likely that a vehicular mechanism would have to be developed to fit the primary activity of rescue and repair.

Regeneration of support capabilities within a cycled frame should be characteristic of a man-centered existence. Because man requires certain inputs within specific frequencies, a mechanism structured around him would either have a stored supply of a scale proportional to the duration of any activity period or would require a regenerative mode. The primary link between man's cycles occurs with the replenishment associated with the five basic physiological needs. Any supply organization must recognize these as fundamental to a cycling frame.

The nature of the structured organization of submechanisms can be established as either an "open" or "closed" framework consistent with section V.B.1.a. With the use of an "open" frame, it is possible to freely exchange any number of support elements, each capable of performing the same task. The other alternative, the "closed" frame, presupposes a fixed network in which the entire mechanism is composed of specific elements which cannot be easily replaced by elements formulated to perform in the same manner but with different organizations or process techniques. A mechanism based upon an "open" framework, while perhaps not offering a universality of support applications, does allow for a universality of submechanism choices and thus provides the basis for developing new organizations by replacing one or two submechanisms. An example of this technique could follow an "open" framed support mechanism organized for applications in an arctic bioclimate which might be adapted to a tropical environment by simply replacing the air heater utilized in the former with an air cooler to be used in the latter instance.

The mechanism structured around a number of submechanisms requires an outer boundary or shell. Three specific alternatives could provide a shell-like enclosure:

(1) The shell could exist as a discrete boundary which was primarily utilized for separation and protection of man and a mechanistic component package internalized within the outer shell-hull.

(2) Within the shell and as part of it, a series of submechanisms could be included so that, while the shell is a discrete physical boundary, its inclusion of the life support mechanism renders it as an almost continuous presence between the man and the bioclimate.

(3) In the most advanced conceptualization, the shell is merely an abstract provision substantiated by a mechanistic package which is comprehensive and negates the specific need for a discrete shell or boundary (this image is formalized in some science fiction literature as a force or energy field that can be felt but not seen).

All of these criteria when followed should form the basis for a new architecture, one based on efficiency and offering a life experience which does not misuse or pollute the bioclimate. The mechanism so structured provides complete activity support with suitable comfort for an individual or group of individuals. Thus, it should be explicitly understood that the mechanism is in essence a complete building block, one which offers life assistance, mobility and freedom from the existing static urban framework. If the user is able to develop a symbiotic or interdependent relationship with the mechanism, independence from the urban infrastructure of electricity, food, transportation, sewage and other quantities would be a natural outcome.

The life support mechanism/man organization can be thought of as a single cell. This cellular model is then the basis for restructuring man's urban existence: why does he live in the city? How well does it support him? And how well does it provide for change? The man/mechanism model, at the very least, delineates a whole new opportunity for developing an evolutionary habitability.

C. Discussion of Submechanism Techniques and Performance

In Section III.C., the five interrelating physiological necessities of the life process were described; in this section, mechanistic provisions to support these requirements will be discussed in coordination with a series of listings (in appendix 13) of the submechanisms suited to meet these and other elements of the "functional analysis model." The intention of this section is to offer some insight into how the submechanisms of Appendix 13 provide for requirements of the model. Additionally, the discussion is based upon the understanding of the several specific modes of provision that allow the various submechanisms to satisfy a need. As a limited example, water can be treated by the individual in several ways: (1) he can purify "used" water; (2) he may wish to produce it be reacting oxygen and hydrogen gases and cooling the product (he can also draw off the considerable energy so produced); (3) he can store the results of such a reaction; and (4) he might then distribute the water as needs occur. These four general treatments characterize how water as an entity is used. Seemingly all other modes are deviations of one or more of these.

The purposes of such treatments are different, and so is the relative degree of sophistication practiced within any of these four definitive techniques. The application of a recycling technique for furnishing suitable quantities of water in an aerospace vehicle is more sophisticated than the simple desalinization of sea water. Similar to this comparison describing adaptations used, respectively, by NASA and the U. S. Navy, differing levels of sophistication or ingenuity may be noted within pairings like the backpacker versus the Airstream camper or the Alaskan trapper versus the weekend hiker. Treatment afforded by a submechanism appears to follow three definitive modes of intake/output relationships: (1) the intaken material is interred within the submechanism and some ingredients are added, subtracted or substituted; (2) the intaken material is simply rearranged without addition, subtraction, or substitution; or (3) the material is prepared within the submechanism for further handling in another submechanism.

The components satisfying specific requirements within the "functional analysis model" are listed in appendix 13 and are variously described in terms of several questions listed below. These questions are not to be taken as substitutes for the criteria for mechanism development displayed in the previous section. Rather they are included to indicate the specific technology and its responsiveness to a particular functional requirement. These questions are: (1) What and how does the component provide for a demonstrated need? (2) When can the component be made available for use? (3) What is the scale of implementation? and (4) Can the component be adapted for personal or small group use, either by itself or by a network offering relative independence? The appendiced catalog is meant to be representative: it should not be regarded as inclusive.

The following pages in this section are presented as a discussion of the mechanistic provisions for the five physiological necessities displayed previously.

1. Maintenance of thermal comfort.

In section III.C.1., the ability of the human body to create an internal thermal well-being was described by the heat balance equation whose terms reflected particular gains or losses. The use of a submechanism to assist the body's thermal regulation is intended to maintain a stable equilibrium between heat produced and lost, or rather to coordinate heat transfer requirements with activity. In example 3, the M.I.T. graduate student might have been more comfortable, while playing tennis, if he had worn clothing better suited for a high rate of heat transfer -- shorts and a knit, short-sleeved shirt. In example 5, the same individual could have found greater comfort while studying if he had simply gone into a building which had lower temperature and humidity (afforded by air conditioning). Control of heat exchange may thus be managed by clothing or built form, both of which are adjustable. Heat energy may be provided, removed or expended, or kept in or out (by insulation). Such heat transfer may also be controlled allowing for real assistance. As a specific example, a suit which has a network of tubes woven into the fabric may be used to heat or cool the individual by running liquids through the tubes at appropriate temperatures. Seemingly, the personal space could also be controlled by a force field supplying or removing heat. The use of this technique has been suggested in science fiction literature, but its use has not yet been realized.

The production (or removal) of heat for artificially adjusting the immediate environment is well known. The primacy sources of heat in an enclosed space separate from the bioclimate are the human being and the various kinds of equipment, some whose principal task is heat generation and transmittance and others which, while discharging other duties, also emit certain quantities of heat. The individual under average sedentary conditions is known to give off as much heat as a 100-watt lightbulb (86 K cal/hour). The amount of heat specifically released by the individual is directly related to his activities and is equal to the quantity of heat expended in performing these activities. Equipment used to provide thermal comfort most generally translate energy developed from a primary source (e.g., combustion products) through a network of energy conductors (*e.g.*, pips moving steam or hot water, or via wires carrying electricity) to a device which transfers heat to the atmosphere principally by radiation and convection. In these arrangements, air from the enclosure is generally forced over the heat exchanges at high rates. In the common American dwelling, there are several other pieces of equipment that generate heat while providing other services. Appliances such as the water heater, stove, refrigerator, lights, or the coffee percolator normally emit heat at rates consistent with their power ratings, demonstrating the relative inefficiency of each piece of apparatus. Even such highly sophisticated equipment as the computer expends heat from electricity passing through resistive circuitry. Naturally, if the energy loss is noted and planned for, its presence can be advantageous where increased thermal presence is required. The heating of air taken in from the colder bioclimate for use in a warmer enclosure requires energy expended in two ways: (1) sensible heat is needed to warm the outside cooler air to the appropriate level; and (2) latent heat is expended as the heat equivalent required to add moisture to the incoming air.

For an individual pursuing a set of activities common to the average American person, heat may also be required to cook food or to compensate for heat lost to a colder bioclimate by heat transfer through walls and leakages through crevices or openings occurring during the individual's entrance or exit from the enclosure. Heat loss by transmission through the surfaces of the built-form and heat addition requirements to fulfill ventilation rates and overcome leakages can be described by a series of equations reproduced in appendix 14. The use of these formulae allow prediction of heat needs through durational occupancy whether the thermal gradient is positive or negative (*i.e.*, whether heating or cooling is required for the enclosure). Energy may be required to drive units providing cooling both to the air or to foodstuffs stored at low temperatures. In either of these two situations, heat is generated to remove heat, often at rates of generation in considerable excess of the actual heat removed, thus again indicating inefficiency. But, in machine design, inefficiency is a basic property: the theoretical capacity of a refrigerating unit simulating the ideal carnot engine may be only 80% of the capacity of the reversible adiabatic and isothermal gas expansion and compression of the carnot cycle. The capacity of a working refrigerating unit following the design of the theoretical unit is probably one-half of the 80% anticipated for the theoretical model.[60]

In essence, the built enclosure resembles the skin of the human body because both are membranous structures which surround the internal equipment and the circulatory network, that provide the actual life assistance required. In both instances, the generation and transfer of energy are basic to activity support. The development of submechanisms for heating and cooling the immediate enclosed environment depends upon both the power source and the heat exchanger. A high quality integration of components responsible for the thermal conditions is additionally dependent upon the operational efficiency of the components.

2. Food procurement.

Food utilization or provision is the result of three processes (all of which lend themselves to submechanism development as will be shown later): growth and gathering; treatment and preparation; and storage. The growth phase is most critical, particularly with regard to how food provision interrelates to the other four basic issues in the "functional analysis model." The development of a food production technique that integrates with the other basic necessities, in terms of scale, comprehensiveness, and form is essential.

Production of foodstuffs may be described in terms of the several primary quantities -- proteins, fats, carbohydrates, and vitamins and minerals. Additionally, production may also be viewed in terms of the growth (naturally and artificially) and gathering of plants and animals, the chemical synthesis of specific food quantities, and the special concentrating of others. Protein is generally provided by animal poultry, and fish sources, but it may also be supplied by the growth of algae or _hydrogenomonas_ (a hydrogen-based bacteria). Fats can be supplied through the use of some animal, poultry, and fish sources (_i_._e_., conventional foods) or it may be obtained in the form of various fatty acids developed as chemical supplements. To date, no successful artificial techniques have been developed for fatty acids, and food securement is dependent upon the generalized "animal" life as the source of fatty acids. Carbohydrates are mostly obtained from vegetation grown in a soil bed which supports germination and growth. Some plants have been grown using a hydroponic technique in which seeds germinate and grow in either an aqueous solution or a semi-liquid inert aggregate base (e.g., vermiculite).[61] A distinct alternative to the growing of plants to generate carbohydrates is a chemosynthesis process in which water and carbon dioxide are reacted under elevated temperatures and pressure to form simple sugars of the configuration DL-$(Ch_2O)_n$.[62] In their simplest form, they are exhibited as a formaldehyde-water solution upon process completion.

The use of flesh from higher animals for the direct production of protein and fat supplies is well-known and understood. But the requirements for the support of animal life are similar to man. If we are primarily concerned with sustaining man in a simple, regenerative way, then we would further complicate an already difficult process by having to support animal life as well. There are limiting efficiencies in terms of size, unusable quantities of material on the carcasses, and the minimization of recycling opportunities. Similarly, the use of higher plant life has limiting efficiencies also, particularly from the standpoint of the amount of edible foodstuffs relative to (1) the total amount of plantstuffs, and (2) the volumetric size and energy requirements for the growth support (soil bed, nutrients, water, and photosynthesis continuation). Further reason for concern regarding the use of higher animal or plant life is centered in the dependence upon these species: there is less assurance of success (or rather a higher probability of failure because of the inherent complexity of the food source itself). On the basis of this limited set of prequalifications, the food procurement techniques offering the most interest for completely regenerative process are the use of algae or hydrogenomonas bacteria for protein supply, stored fatty acids, and chemosynthetic carbohydrates. This conclusion should not be taken as a blanket statement covering all submechanism development, but it should be understood that these selections seemingly offer the best opportunities for closed cycle, regenerative mechanisms which have a high degree of efficiency, modularity, and integrity between the various submechanisms listed in appendix 13 and those yet to be described in this text. Other techniques have been used successfully for applications such as the Apollo flights, but these were provisions developed for shorter experiences and were also relatively inefficient in any cyclic or regenerative sense.

Algae, as dietary substances, do not entirely fulfill all of the requirements expected. Initially, the human digestive tract is able to accept only about 20% of its diet as algae (50 to 100 grams); larger quantities cause gastro-intestinal difficulties which result from the tract's inability to digest the additional material. But there are two more definitive limitations on the use of algae: (1) algae is similar in nutritional value to seaweed (listed in appendix 3), namely, high in protein and low in carbohydrate; therefore, the tolerance range of 50 to 100 grams may also limit the amount usable for a mixed diet; and (2) the number of amino acids that are directly obtainable from algae without the introduction of artificial digestive techniques is insufficient to meet the human requirements. If man were outfitted with some sort of ruminating stomach similar to the cow or goat, he would be able to consume greater quantities of algae (and cellulosic products) and perhaps derive the appropriate supplementary amino acids from the algae. It is generally noted that algae is found to be more acceptable in human diets when consumed in the form of various bakery products such as breads and cakes.

Hydrogenomonas bacteria (or bacterial protoplasm) may be used as an alternative to algae, but as a foodstuff it is similarly high in protein and low in carbohydrates. Thus, its use as a single food source is limited. But hydrogenomonas bacteria provides all of the amino acids required by man and in digestible forms.[63] A further comparison of algae and hydrogenomonas indicates several additional benefits for the latter food source: (1) light energy is not required to initiate or to maintain its production (simple electrical energy is used to provide electrolysis); (2) the production rate is higher, offering greater yield for similar beginning quantities; and (3) the overall process can be automated allowing for computer controls.[64] Both food production techniques afford the use of treated human waste (urea) and require carbon dioxide in quantities consistent with the daily output of an individual. Each also requires processing following harvesting, as was noted previously for the algae. For further information regarding these two food sources as well as other food possibilities such as yeasts and molds, the reader is referred to the paper by Drake <u>et al</u>.[65]

The evaluation of artificial food production techniques can best be carried out in terms of a comparison between the density of photosynthesis and the quantity of biomass. The greater the photosynthetic material relative to the original amount of biomass, the higher the efficiency. But even with a high production rate, no one untreated food material generated by a single biosystem (or biomass) supplies all the food required for a balanced diet, either physiologically or psychologically.[66] Additionally, a treatment process is a necessity for general acceptance.

Vitamins and minerals are present in most foodstuffs, but the actual balancing of diets from food selections based with strict concern to the vitamin and mineral contents is rarely practiced. The usual procedure is the supplementation of the primary food sources with a capsule, taken daily, containing quantities of each of the required substances. As the reader is probably aware, this is a technique that has been used by the general public for many years and is an easy method for diet balancing. It is possible to balance a diet without supplementation, but such alternate arrangements greatly limit the number of food choices.

The immediately preceding discussion has dealt with the development of artificially induced and controlled food sources, primarily because of their relative simplicity and high efficiency. This consideration has ignored the fact that, aside from the usual commercial sources, food may be gathered from natural or farmed sources, as in "living off the land." The problem with this technique may be that such reliance prohibits the overall integration of a mechanism and negates the cooperative presence of the submechanism responsible for nutrition. Regeneration based upon recycling becomes more difficult to achieve when one or more of the basic needs of the life process is provided for outside of the mechanism. But, in large concentrations of people, perhaps these arrangements can be established efficiently and within a cyclic framework.

Another food provision technique has been established by NASA for space flights. A series of diet types have been developed based upon a pre-gathering and processing of foodstuffs that are then packaged and stores for later use. The five specific types of food preparations are (1) dried, (2) frozen, (3) freeze-dried, (4) liquid, and (5) chemical. These dietary forms are thought of as alternatives to the various growth and chemosynthetic preparations previously discussed. Specific diets were indicated in appendix 4, and a freeze-dried diet of 2600 K-cal following these recipes occupies only 130 cubic inches. The basic food quantities involved do not allow for regeneration, although the water used for hydration of the dried foodstuffs can be removed from the urine and waste and purified for later use. A prime NASA contractor, United Aircraft Corporation, investigating food provision techniques for 500-day space flights for crews of up to nine men (with the restriction that the diets be operational by 1980) suggests the use of freeze-dired diets stored in quantities sufficient to feed the group for the period indicated. Nine men using a mixed diet consisting of 2600 k-cal for 500 days would require 5050 pounds of foodstuffs or approximately 500 pounds per man. These figures do not recognize the probable additional presence of water within the freeze-dried foods, which rarely are totally dehydrated. Such additional weight (for water inclusion) may be anywhere between 25 and 50% of the original totals. If we know that a diet of 2600 k-cal per man a day occupied 130 cubic inches, then foodstuffs for 500 man-days would have a volume of 37.7 cubic feet/man. These weight and volume figures do not include package allowances.

Storage techniques are currently being investigated using ultra-rapid freezing and the storing of food materials in pure nitrogen atmospheres. This later development resulted from the discovery that oxygen is the principal element causing degeneration of foodstuffs and that storage in nitrogen atmospheres exclusive of oxygen negated or sharply reduced decomposition. Oxygen may thus be recognized as the basis of the biodegradation process. If life assistance techniques founded upon the principle of "living off the land" provided for the immediate treatment (preparing and storing) following gathering such food procurement could be integrated into a comparatively structured framework.

The discussion about food provision has been organized around techniques that provide the best chances for sub-mechanism development. Such development is intended to be consistent with the overall integration of components into a total mechanism equipped to handle all of the basic life needs. A general requirement characterized by several of the design criteria established in section V.B. is the need for opportunities for regeneration based on recycling of materials after human consumption. The construction of life support mechanisms suggests the presence of closed or open frameworks which integrate not only the hardness but also the varying degrees of specific life provisions upon which the hardware is based. A more definitive discussion about closed and open ecologies or ecosystems will appear in a later section.

3. Water provision.

Consistent with the example of water provision techniques at the beginning of this section, water can be treated by purification, production, storage, and distribution. Each of these is a non-specific operation which often includes other treatment types within its scope. In addition to the water balance characterized by the internal operation of the body (as demonstrated in section III.C.), an external water balance may be created including both internal and external body functions. An efficient model has been set up for this latter balance by the United Aircraft Corporation and its requirements and sources are listed below for the daily consumption of a man in space.[67]

a. Requirements

1. Food preparation and drink	Food preparation	1.14 lbs/day	(160°F)
	Drink and beverage preparation	5.86	(45°F)
2. Washing machine	Wash clothes	3.01	(105°F)
	Wash utensils	0.90	(105°F)
3. Personal housekeeping	Shower	5.55	(105°F)
	Local body cleansing	1.50	(105°F)
	Housekeeping	0.44	(105°F)
	Urinal flushing	6.00	(160°F)
	TOTAL	24.40 lbs/day	

b. Sources

1.	Urinal water	9.30 lbs./day
2.	Humidity condensate	5.30 lbs./day
3.	Wash water	11.40 lbs./day
	TOTAL	26.00 Lbs./day

First of all, several notes concerning this table: (1) for food and drink preparation, the assumption was that both diet components would be dehydrated and require water additions; (2) the temperatures indicated are those required to help destroy bacteria (160°F) or to make the liquids pleasing for consumption (45°F); and (3) the non-balance demonstrated by this listing is explained by several features. Initially, in the space vehicle, a certain quantity of water is electrolyzed for oxygen production, and secondly, the human body produces more water (during the metabolic oxidation and other processes) than it requires, usually in quantities of about a pint a day. This extra water is outside of the internal water balance described in section III.C. The amount of water (24.6 pounds/day or about 11.2 liters) required for a manned operation in space is not appreciably different than for normal consumption on earth. Any discrepancies are probably the result of inefficiencies practiced on earth that are deleted from the space activities. The primary sources of water in a balanced condition are from the collection and purification of water from urine, fecal matter, and from the reclamation of water vapor from the air. Fecal water is generally added to wash water collection and both are processed separately to promote a better psychological acceptance of the regenerated waters. Purified urine and water vapor condensed are the bases for the derivation of potable water. Nonbalanced earth water supplies are most often those obtained from central, public networks and from bioclimatic sources such as precipitation and flowing water. The problems associated with the public networks should be well understood after a quick review of the design criteria listed in the previous section. Water obtained from bioclimatic sources for much of North America would require substantial purification beyond that normally required to treat urine and body expenditures. Urine is essentially a sterile liquid (when passed by healthy individuals) which is, however, an excellent medium for bacterial growth following elimination. Most natural sources are victims of assorted kinds of industrial wastes and organic wastes which have had time to allow microorganism development and growth.

Water production can be instituted both as the primary process within submechanism operation (e.g., potable water obtained from urine) or as the product in a submechanism devoted primarily to other tasks (e.g., the chemical reaction of oxygen and hydrogen gases produces energy and water and such a reaction is the basis for fuel cell operation, particularly in the Apollo vehicles).

Water stored for long periods of time often becomes a sink for contaminants and microorganism development unless it is totally sealed and the seal remains unbroken until required. Two techniques are frequently used to negate the effects of these undesirable quantities: (1) the first is a pasteurization process in which the water is heated to 160°F and held at that temperature for 30 minutes; and (2) the alternative choice is based upon the use of a silver ion generator.[68] Bacterial filters are often used with either of these techniques as a supplementary measure. The heated condition (water at 160°F) is often maintained continuously when water is kept in a static holder. Some water is allowed to cool or is even chilled depending on requirements and potable water is generally available in a thermal range of 45 to 115°F (the upper limit of comfortable usage, both internally and externally).

4. Oxygen-carbon dioxide control

The primary concern in controlling the immediate atmosphere is maintaining an appropriate ventilation rate. Ventilation is necessary (1) to remove air, providing fresh air as required; (2) to help control the thermal conditions of the body and the air around it; and (3) to regulate air temperature when interior and exterior conditions differ too radically. Therefore, the major concerns are air temperature and freshness. A variety of potentially harmful quantities are generally present in air surrounding the human body, and any of these allowed to accumulate into larger amounts can have injurious effects. The most common agents are carbon dioxide and monoxide, pathogenic germs, odors, and dust. Water vapor, while not harmful, is always present and may exist in quantities uncomfortable to the inhabitants of any enclosure. Carbon monoxide and dioxide are both products of fuel combustion and the latter is also a product of animal respiration. The dioxide form has a gradually debilitating effect on man which can cause serious limitations on activity performance if quantities accumulate. The monoxide can cause death even in very small concentrations because of its ability to combine with hemoglobin (in the blood), negating the latter's oxygen absorptivity. Pathogenic germs potentially released from respired air and odors associated with both organic and inorganic sources also require removal. Ventilation is necessary therefore to remove these unwanted materials and to provide a fresh air supply.

Ventilation rates, predicated on the principle of eliminating used air and replacing it with fresh air, are thought of in either of two ways -- (1) air changes for a specific enclosure/time period or (2) a specific volume of air exchanged/unit time. From both points of view, and in reality, air is not removed in any discrete action, but rather the used air -- air containing respired and other human gaseous discharges and gases associated with other (non-human) activities within the immediate environment -- is greatly diluted by the addition of fresh air. The ventilation rate is generally determined in terms of air flow necessary to keep the carbon dioxide concentration below a specific level. This quality is, of course, a product of human activity; and as such the ventilation rate required for proper comfort can be directly related to density of population, the nature of the activity, and also the rates of heat production and expenditure. Givoni states that the ventilation rate for enclosed spaces should be

$$Q = \frac{q}{4.5} \quad \text{(cubic meters/hour/person)} \qquad (13)$$

where Q (in cubic meters/hour) is the volume of fresh air required per person to keep the concentration of carbon dioxide below 0.5% and q (in liters/hour) is the volume of carbon dioxide produced by an individual and may be found using equation (6).[69] For example, Givoni points out that, for sedentary activity rated at 100 k cal/hour, q will be 18 liters/hour and the ventilation rate required is 4 cubic meters/hour. Similarly, for work rated at 300 k cal/hour, q is 54 liters/hour and Q required will be 12 cubic meters/ hour. The actual respired air contains approximately 16.3% oxygen, 4% carbon dioxide, 79.9% nitrogen, and other gases associated with bodily gaseous discharges (primarily ammonia). This air also includes about 45 grams/cubic meter of water vapor which is the quantity that saturated air will absorb at 37°C (the core or deep body temperature.[70] Therefore, within such calculations, the capacity of any submechanism responsible for air cleansing and oxygen regeneration can be determined.

If air is exchanged between the enclosure and the bioclimate, each at a different ambient temperature than the other, it is probable that both heat and water vapor control will be required (as was indicated earlier in this section). Energy will be necessary both as sensible and latent heats (positive or negative) and these can be described by equations noted in Appendix 14. Water vapor, in quantities greater than those established for the comfort zone can be removed by vapor compression and condensation, allowing humidity control. The process may be reversed for atmospheres containing below standard quantities. In general, enclosure air for most sedentary activities should normally be maintained within a thermal range of 65 to 75° and with a relative humidity of about 35 to 70% (depending upon seasonal times).

Odor is the result of gaseous or particular matter, the latter of which may also have absorbed gases present.

Odor removal may be accomplished by any of several techniques generalized under the following: (1) open venting using clean outside air; (2) activated absorption on substrate or liquid surfaces; (3) odor modification or neutralization; and (4) catalytic combustion.[71] In many situations, olefactory fatigue will negate all but the most persistent and unpleasant odors, rendering the mildly unpleasant ones bearable.

One remaining issue for carbon dioxide control and utilization is that the gas is a primary basis for photosynthesis (an initiator of the food cycle). The development of balanced or regenerative food-waste cycles is thus organized around the need for sufficient retention of carbon dioxide within the atmosphere to promote plant growth and carbohydrate synthesis. On the other hand, excessive quantities must be removed to protect animal life. This situation has led to the recognition of an assimilatory quotient (AQ) -- the ratio of carbon dioxide used relative to oxygen produced -- which must be equal to the respiration quotient (RQ) for balanced conditions between plant and animal life. Because of the apparent difficulties in attempting to maintain an exacting natural balance between these two measures, the need for submechanism control is explicit. Such submechanistic operation would be required for adjustment of the varying water, carbon dioxide, and oxygen balances; and subsystems establishing quasi-balances could thus be sustained with appropriate replenishment or removal as specified.

5. Waste control

The primary waste treatments are generically removal, purification, and recycling or regeneration opportunities. Waste can be characterized as organic or inorganic. The former consists mainly of human products, food preparation remains, paper, and wrappings; the latter is normally dirt and nonbiodegradable or non-nutritive materials. The amount of material that may be recycled through any system is limited: no biosystem whose production is maintained at a rate to supply one individual is able to convert all of the individual's wastes quantitatively for reuse.[72]

The purpose of any submechanism associated with waste treatment, beyond the simple collection and distribution of the liquid and solid wastes to their respective treatment centers, is the sterilization of the waste which reduces the chance for contamination of other usable matter and the production of nutritive materials to support later regeneration. An alternative to the last procedure is a simple storage process in which the residue is held for later disposal under different conditions. During treatment, fecal water may be evaporated after sterilization and released to the bioclimate to offset imbalance in water requirements (as established earlier in this section).

The role of the submechanism in each of the five physiological processes indicated in this section is to adjust imperfect balances or to create bases for recycling and regeneration. The primary body functions can, of course, be performed without artificial support; but, by helping to supplement these natural processes, more cooperative and efficient arrangements can be found with application of various submechanisms. Mechanistic standards may be developed for the other, non-directly physiological elements of the "functional analysis model," and mechanisms that are associated with those elements in Appendix 13.

VI. A MULTI-GENERATIONAL SERIES OF LIFE SUPPORT MECHANISMS

The development of a group of models or sketches of what an interfacial mechanism can be requires the dual recognitions that design is a resource allocation and that any ordering of a many-element catalogue will be founded upon a relatively intuitive sorting process. Within those bounds, conceptual images can be proposed and will be presented below. The models should be regarded in terms of their abilities to offer life assistance and to satisfy the criteria established for mechanism design. Additionally, the mechanisms should be viewed as a group characterized by differing levels of sophistication, an attribute which may or may not provide greater probabilities of success.

A. A Problem Statement

For a problem that might offer the greatest opportunities to examine several generations of complex mechanisms, a relatively bizarre bioclimate has been chosen and the mechanisms have been designed to meet the difficulties thus imposed. In a sense, the hostile environment requires arrangements best described as "muscle-flexing"; but, seemingly, mechanisms designed to fit the specific bioclimate could, with slight alterations, be adapted to any bioclimate.

The specific location chosen is Port Radium, Northwest Territories, Canada. This small town of 500 people (permanent population) is situated on the southeast corner of the Great Bear Lake and has the coordinates of 66.04° north, 118.00° west. The time selected is winter, and the activities specified are trapping (commercially) and hunting (by rangers seeking to thin out caribou herds which have overpopulated the area and now face gradual starvation because of insufficient food supplies).

In the first instance, the trapper usually retires to his shack and ventures out only to examine and bait his traps. Such a trapper would normally not enter the town for several months at a stretch, keeping to his cabin and his trapping range almost exclusively. The dimensions of the trapping area are determined by the distance that he is able to walk during one-half of the daylight hours, which are few during the winter. The trapper is usually past middle age, is a recluse, and is skilled at living very efficiently off what little the land provides. A model of a life support mechanism suited to the trapper is, in every sense, a mechanistic analogue of what he long ago established. Any such mechanism, however, could replace the incredible hardships and discomforts. It could also allow him greater freedom and productivity while providing him with support to pursue his occupation.

On the other hand, the ranger, who comes infrequently into an environment such as this one, is likely to have been flown in for several days to complete his hunting. An equal likelihood could be that he is entering the area to conduct research on the winter habits of the caribou or the bear, particularly migration, eating, or adaptability to extreme conditions. The ranger's own adaptability is likely to be severely limited, having come from a much less cold climate, and he might, therefore, require greater assistance. His task demands a high degree of ground mobility. If the mechanism had rapid mobility, it is probable that the ranger might have brought it with him from some distant station, rather than picking it up at Port Radium.

To describe the actual winter conditions, we shall follow the general bioclimatic model and attempt to identify key problems. Solar radiation is limited in both frequency and intensity. At latitudes consistent with Port Radium, daylight in winter more nearly approximates twilight and lasts only several hours. The common diffuse/incidence radiation ratio is at least 0.40 as an annual mean and during the winter is greater. The winter minimal design temperature is -54°F (-48°C), but this is reached on the average of only a few times a year for short periods. A more reasonable design temperature is probably -45°F (-43°C). In either case, and generally for the Northwest Territories, air movement (wind) is regarded as very light (which is defined by the <u>ASHRAE Handbook of Fundamentals</u> as winds occurring for 70% or more of the time of cold extreme hours, and the winds are said to be less than or equal to 7 miles per hour).[72] The absolute quantity of moisture in the air at -40°C is 0.03 grams/pound of dry air (versus 18.3 grams/pound of dry air at 98.6°F). The ground surface is generally snow-covered frozen tundra. Natural food sources are scarce in the winter, but include caribou, bear, and fish found below the frozen lake surface. Roots and vegetation such as low bush berries and some wild grains are available during the summer and are often stored by the local inhabitants for consumption during the winter. Fuel in the conventional sense is nonexistent.

Therefore, the specific requirements needed for life support that are obviously not provided for by the bioclimate include food sources, thermal provisions, waste recycling to assist in regenerative techniques, mobility (vehicular), communication assistance, light, and opportunities for cleansing the body. The two greatest needs are some form of discrete shell and a comprehensive power source suited for both vehicle and mechanism drives. The most sustaining and flexible solution is a mechanistic interface.

B. Thermal Comfort in a Very Cold Bioclimate

Design conditions for habitability development in cold climates, such as Port Radium's, are centrally concerned with the provision of heat. Cold is, thermodynamically, the absence of heat. It also minimizes survival opportunities, growth rates, and comfort. Matter at higher temperatures entering cold environments may rapidly lose its heat by energy exchange until an equilibrium is established. Man entering such a bioclimate experiences the same rapid heat loss. It is characterized by energy transfers from his body through each of the usual exchange methods (*e.g.*, primarily radiation, convection, evaporation, and respiration). However, he is not able to expend energy until a relative equilibrium is reached, because a drop in the deep body (rectal) temperature of more than 15 to 20°F will inevitably cause death. Therefore, heat loss must be minimized by some insulating technique (it should also be noted that high metabolic heat production can negate high heat loss effects if a heat balance can be achieved). Insulation is best provided by clothing and/or buildings. The conventional building generally has only limited flexibility and does not provide for highly mobile activities. On the other hand, clothing affords both, but its common heat production opportunities are only as good as the wearer. Both clothing and buildings transfer heat to the colder air and thus require at least intermittent heat production capabilities. The thermally-assisted body suit, as efficient as the Stillsuit[74] concept, would be ideal for this application, offering flexibility for activity support, mobility, and comfort. A discussion of heat regulation within the body and by insulation on the body appears in appendix 15. As an alternative to both the building and the clothing, the life support mechanism can provide the flexibility, mobility and comfort an individual needs.

C. Ecosystem Application to Mechanism Development

Throughout this thesis, discussion has been entertained about the integration of the mechanism both as a collection of components and as an entity, paralleling man and forming a cooperative interdependency with man. The dual integration is intended to respond to a variety of deficiencies in each and to provide a basis for a cyclic regeneration. Seemingly, the man-mechanism relationship is symbiotic, offering both an opportunity to achieve stability. The development of this relationship is primarily centered on the problem of keeping man alive in uncomfortable or uninhabitable bioclimates. It is, therefore, based on interactive life processes and its ecological context should be recognized.

We have also considered the opportunities for both open and closed mechanisms. The relative openness of the life support process is derived from the ability to freely substitute different methods or components, each to provide for essential materials. In an arrangement with a very complex interlocking framework, substitution will be difficult at best and the process must be regarded as closed. The relationship of the components must be cooperatively based to achieve efficiency and stability. But this does not mean that the components of the process must be mutually dependent. Efficiency will be developed if the components can be assembled into an organization that allows integration either by a task performance or by a commonality of form. Additionally, the process once initiated should be self-maintaining. If we accept these principles and recognize an ecosystem as an assemblage of organisms and abiotic materials, then we have the design basis of the life support mechanism as an essential part of the man-mechanism ecosystem.

From the nutrient-energy cycle displayed in appendix 8, we can see that an ecosystem would consist of the biotic actors--the nutrient producers, the nutrient consumers, the waste decomposers -- and the abiotic environment, both organic and inorganic. The regenerative nature of this life process is established with the cyclic return of decomposed, or wasted, organic materials, released by the consumers and decomposers and reused by the producers. The structure of the ecosystem is described by three factors: (1) the quantity of the biomass; (2) the relative stratification of living and nonliving matter; and (3) the biochemical and component diversity. The structure is also made apparent by the number of components involved.[75] The ecosystem may also be described by its ability to regulate itself, where self-regulation is determined by the number and diversity of the components. As would be expected, increasingly larger or more diverse gatherings also are capable of increased independence. But, of greater interest and usability, the structure and regulation of even such large, many membered ecosystem can be influenced by natural or external mechanistic procedures.[76] Therefore, life processes once thought of as being ungovernable, can be artificially controlled or replaced by mechanistic support techniques.

The other primary feature of the ecosystem is its ability to grow in diversity and interactive relationships, thus forming bases for more stable and better self-maintaining forms. An ecosystem, reaching a mature or climax state, is able to adapt to changing environmental conditions and to sustain itself. It is thought that the period required for a young forest of a few years growth to reach a climax state is about 70 years. The climax state is characterized by both stable and efficient interactions, allowing for a disciplined self-maintenance. But the time required to artificially develop such systems around man is prohibitive. The arguments are recognized that mature ecosystems have existed with man as a consumer for hundreds of millenia and that, as such, there is no real necessity for constructing artificial ones. But, if man wishes to extend his activity, or alternatively, if man does not learn to live more efficiently and less destructively, then there will be a need for life support mechanisms predicated on artificial growth and control, especially as in the latter condition in which a specific requirement may become a general condition if solutions are not devised soon.

The disparity between the young and mature ecosystems is often exemplified in terms of the differences between the two-species (or two-component) ecosystem and the multi-species ecosystem.[77] Thw two-species (young) ecosystem is characterized as having: (1) a small number of pathways for energy transfer between producers and consumers, and (2) pathways which are direct and generally linear. The multi-species ecosystem has a highly complex food web whose pathways are rarely direct. The younger, two-species system, while more fragile, is also more responsive to external control. It also offers higher productivity rates per unit biomass and is a more efficient gas exchanger in terms of the oxygen produced and carbon dioxide absorbed per unit biomass.

A life support system mechanism patterned after the multi-species ecosystem, while providing a greater likelihood of stability, would not be practical in terms of time required for development. Additionally, the young, two-species ecosystem offers better opportunities for support and is probably going to be better able to recognize specific demands. The relative simplicity of the two-species ecosystem with its linear energy and nutrient transfers could be more easily approximated within a mechanistic framework. Although the young ecosystem may not be able to respond immediately and properly when dramatic changes occur, its revitalization would seemingly be simpler than waiting for the multi-species ecosystem to complete a long reverberant self-adjustment after experiencing a similar condition.

The development of life support mechanisms based on ecosystem organizations would, therefore, be desirable, especially if it is predicated upon the simpler and more flexible two-species ecosystem.

D. The Life Support Mechanism

In this section, and in the next chapter, a series of four models, providing life support for activities near the Great Bear Lake will be discussed in a generational sequence. The models are increasingly more inclusive and each offers longer and "cleaner" support than the previous one. They are presented as sketches or conceptualizations indicating variant attitudes about mechanistic support -- cleanliness and efficiency. The reader viewing these models should keep in mind the mechanism design criteria established in section V. The mechanisms have been designed primarily around a food-waste cycle, each developed to a degree more sophisticated than the last. The specific individual pieces have been taken from the listing in appendix 13 according to their capabilities.

1. The Four Models Generalized:

In this section, the four models will be briefly described and their basic premises delineated.

a. The Short Visit Runabout: This model offers a usability of about five to seven days and has a near complete dependence on a central supply core (separate from the mechanism itself). Its provisions are stored on a short term basis and frequent replenishments are mandatory. The unit has no means for recycling or regeneration and resembles, in sophistication, the Airstream caravan. Its availability is immediate.

b. The Camper: This shelter is optimally used for one to six months. The Camper provides for limited regeneration, but its primary source of material is the immediate bioclimate, from which the quantities like food, water, and oxygen are accumulated by gathering and treatment. Similarly, the wastes are treated and released to the surrounding bioclimate. The equipment required for such a shelter is currently "on the shelf" and the model's general, commercial availability is thought to be 1975-1980. For limited, private production, however, the unit could be created almost immediately.

c. The Motor Home: The occupational duration anticipated is one to three years without replenishment, thus offering a near complete independence, if situated on earth. The mechanism is based upon an open cycle organization in which the submechanisms can be introduced or removed according to the specific bioclimates or needs of varying numbers of individuals present in the unit. Because of both the relative openness and the near complete regenerative capabilities of the unit, the power requirement is likely to be the greatest for the four generations. The Motor Home is designed around various NASA submechanisms currently under development and with anticipated component availabilities of 1975-1980. It is entirely likely that the commercial availability of this unit, organized as a life support mechanism and based on these submechanisms, would be 1990 at the earliest. However, it should be well noted that equipment developed for NASA has often appeared earlier or later than originally forecast and that its marketability might be established swiftly following declassification.

d. The Mobile Man/Mechanism Ecosystem: This unit has a predicted use-length of ten years and, it is thought that with either a very limited replenishment periodically or a slight design modification, the mechanism lifetime could well be extended to equal that of the user or users. The mechanism would be at home on the earth or the moon and probably represents a third-generation lunar module exclusive of descent-ascent engines. This adaptability, or rather flexibility, is demonstrated by its virtually total enclosure of the life process and the low power requirements. The software for this mechanism is currently available and will be displayed later in this section. Hardware design has not yet been initiated. The general availability of a life support mechanism following the software design will probably occur no earlier than the year 2000 at best, without an accelerated program based on research for a long-term, manned flight. An estimation of availability for this unit is dependent upon other issues than research capabilities. It would also be determined by use, cost, consumer acceptances and attitudes, and the overall need. In essence, though, this model is the introduction into the real search for the "Gizmo" or the "Ultimate Mechanical Goody."

VII. THE SPECIFICS OF THE FOUR MODELS

Sample calculations have been displayed in Appendix 16 indicating how more definitive selections of appropriate submechanisms can be determined. Sizing, organizations, and efficiencies would thus be established.

A. The Short Visit Runabout

1. Oxygen-Carbon Dioxide Control: The provision for appropriate gaseous atmosphere is based simply on a forced ventilation subsystem in which fresh air is heated (to 73°F) and introduced into the mechanism at the rates of one to four cubic feet/minute. The specific rate is determined by the nature of the inhabitant's activities. By this means, odors can also be controlled by simple removal similar to the common exhaust fan placed over the kitchen stove.

2. Water Provision: Sufficient quantities of water required for the several uses indicated in chapter V will be stored. The rate of use was shown to be 24.6 pounds/day/person (or 11.2 liters/day/person), so that for a seven day trip, 89.4 liters (about 2.81 cubic feet) would be necessary. The water is heated, prior to use, to 160°F and filtered to remove any microörganisms and insoluble, inorganic salts. Once purified, the water may be obtained from the faucet or fed to other fixtures requiring water for their use. An additional pipe can be routed through the refrigerator to provide cold water.

3. Food Provision: Food will also be stored in frozen forms. The food can be provided either as the Apollo-TV dinner diet, or it can be packaged as individual food materials to be chosen by the consumer, much as one buys from the supermarket. Because of the relative shortness of the trip, more advanced techniques like freeze-drying or general dehydration will not be necessary. In fact, it may be appropriate to simply provide the food in a refrigerated form, ready-to-serve after heating. If the diet of the individual living in this mechanism resembles that of our graduate student in quantity and organization, then he will need 1.27 pounds of primary foodstuffs. If we further assume that the food material is constituted in a normal hydrated manner is actually 75% water, then the diet (primary foodstuffs and

hydrating water) will weigh 5.08 lbs/day. Packaged in a reasonably efficient and edible form, the daily diet should occupy no more than one-fourth of a cubic foot (excluding potables).

4. Waste Control: All wastes will be stored in a single tank, probably only slightly larger than a fresh water storage tank (perhaps 3.5 versus the other 2.8 cubic feet). The wasted materials -- both organic and inorganic -- will be drawn off and processed following the return of the unit to its home base. A germicide will be added to prevent micro-organism growth during storage, and as an additional measure, the wasted material is cooled to 40 degrees (by a careful venting to the outside), reducing or decelerating unpleasant growths or odor formation.

5. Thermal Well-being: Air vented from the outside is passed over part of the power source or an intermediate power source is specifically used for air heating much as with conventional electric heating panels. As the air is vented into the mechanism, water vapor can be added using a pan humidifier[78] producing the appropriate relative humidity. The water vapor would most likely be added by passing the warmed air through or over a water source and the specific absorption could be limited by the rate at which the air was circulated.

6. Power Source: Power is provided by the direct conversion of chemical energy to electrical energy, and the electrochemical potential is maintained by either a battery or a fuel cell. Batteries have a lower current capacity and storage capabilities and require more frequent recharging. The fuel cell delivers power based on a chemical reaction between two substances and requires replenishment. A central point in the choice between the two is that the battery essentially stores energy in a latent form, ready to be tapped; the cell stores the reactive commodities and produces energy via a manufactured process. This distinction is indicated by the nature of the re-supply technique: recharging of energy *versus* replenishment of material. The energy generation capabilities of these two power sources is manifested by the power density-time characteristics. The fuel cell is generally able to provide higher power densities for longer periods of time than is possible for the battery source.

The internal operation of the fuel cell, based on the reaction of two chemical substances, is nearly 100% efficient, and the conversion of this chemical energy to electrical energy is approximately 90% efficient. The Apollo fuel cells have been fueled by a hydrogen-oxygen combustion, which, if not entirely economical, is clean and relatively efficient. Energy for the crew's activities has been supplied for as long as two and a half weeks in space, and for longer periods during testing on earth. A more economical fuel combination would be methane and air, but this mix, as well as most other alternatives, does not burn without releasing carbon dioxide (other potential products could be carbon monoxide and carbon aceous particulate matter). If combustion is complete and carbon dioxide and water vapor were the only products, aside from the electrochemical energy, then an alternate to releasing the gases would be to collect them and decompose the carbon dioxide to oxygen and particulate carbon, the latter of which could be accumulated and stored for disposal at the central supply area.

B. The Camper

1. Oxygen-Carbon Dioxide Control. The gaseous balance is sustained by the same technique utilized in the Runabout. This method is simple and easily-maintained, but it does not offer opportunities for regeneration or recycling of the expended carbon dioxide and water vapor, which suggests an inefficient technique.

2. Water Provision. Water is primarily sought from the bioclimate either as collected precipitation or from rivers or lakes. Water from the latter source would require purification if industrial waste or microorganisms were present. Water supply for the Camper used near the Great Bear Lake could be obtained from the lake by drilling through the ice on the lake and purifying the water by heating it to 160°F

as previously discussed. Water could also be produced by melting snow.

Heating for both techniques will easily be provided from a heat coil powered by induction or by resistive circuitry. Quantities of heat required are indicated in appendix 16. In addition to the water production techniques, a small tank holding two or three days' supply (25 to 35 liters) should be included.

3. <u>Food Procurement</u>. Food can be obtained from the bioclimate: protein and fats are sought from fish or caribou; carbohydrates come from berries, roots, and wild vegetables, gathered during the summer and stored for later use, These quantities could be harvested in season, by the individual directing the mechanism. Alternately, he could get the appropriate carbohydrates from a replenishment source at the beginning of the use period and then store them for later consumption. Planting food is disadvantageous because of the short growing season and the potential loss of a free mobility (assuming that the plantings would require periodic care). Vitamin and mineral supplements are provided as capsules.

For all of these organizations, a freezer, whose size is determined by the length of the specific use period, will be required.

4. Waste Control. The liquids and solid wastes are separated by a filtration process. The solids are shredded and a biocidal agent is mixed with the shredded material to kill any microorganisms present and to prevent their further growth. This mix is then stored in a tank which is emptied at the replenishment station periodically. The materials then receive further treatment.

Liquids are collected in a rank, chemicals are added to negate the presences of ammonia and bacteria, and then the mixed liquids are circulated to a wick where they are rapidly heated and evaporated. A carrier gas is introduced to escort these evaporated liquids. The gases are selectively condensed, and the condensed water vapor is drawn off and passed through bacterial and charcoal filters. If the gases are "clean" and contain no noxious materials, they are released to the atmosphere. If liquids still have waste substances present, they are recycled until no contaminants remain. Then the liquids are passed to the atmosphere.[79] In this arrangement, both wicks and filters can be replaced. The plumbing of the submechanism is flushed out, and the wicks or the filters snap out as closed units, allowing easy maintenance. The overall process is intended to operate continuously and, to implement changing elements during use, two such organizations can be parallel or interlocking. The presence of a dual channel unit would be appropriate for groups of more than three or four people. But, for fewer people, one channel would be sufficient.

As an alternative to the liquid evaporation process, the liquid wastes may simply be filtered using a series of bacterial and charcoal filters, arranged in multiple, alternating pairs.[80] Such treatment is performed without any chemical additives. This filtration of the liquid tends to have less total cleaning efficiency and requires a more extensive filtration than the evaporation-selective condensation process. However, it is safer (no wick required) and uses less power for operation.

Any soap used for cleaning clothes, utensils, or the body should be biodegradable so that, if it is not removed entirely by the filters in either process, the soap will decompose without harm to the bioclimate.

5. Thermal Well-Being. Heat is provided in the same manner as it was in the Runabout model. The air vented from the outside is heated by a series of electrical panels from which heat is exchanged by radiation and convection. Humidification of the air is accomplished using a pan humidifier.

6. Power Source. The primary power source chosen is based on heat engine techniques. Fuel is burned, forming gases and expending heat which is used to form steam. The steam drives a generator which provides an electric current.

The process generally has an efficiency of 40%. Included in the power source is a gas afterburner which ensures near complete combustion of the exhausted gases. The heat from this secondary burning is recycled to the steam formation, increasing the overall efficiency (perhaps as much as 5 to 10%). But, even with the additional combustion, gases are still exhausted to the atmosphere. A filter -- usually a molecular sieve -- entraps the small quantities of nitrogen and sulfur oxides. The more substantial amounts of carbon dioxide and water vapor may be similarly captured or they may be expanded.

Two other power submechanism candidates can be employed, although each is also based on fuel combustion. The first would integrate the vehicular drive with the electrical energy used to sustain the life support submechanisms. Fuel is burned and the primary energy expended drives a gas turbine which powers the vehicle. The secondary heat energy expended is re-directed and used for steam formation as in the first method. An interim heat chamber is provided for energy generation when the vehicle is at rest and the turbine is not in use.

The third submechanism supplies energy for the life support but not for the vehicular drive. The source is based on the direct conversion of thermal energy to electrical energy by thermoelectric principles, particularly the *Seebeck* effect. Heat energy is derived from fuel combustion but the energy is transmitted to a thermopile. The thermopile is a number of metal-metal junctions (<u>i.e.</u>, copper-iron) arranged in series so that when heat is passed over it, electric current is generated.[81] Both the second and third methods also require a gas afterburner and a pollution filter.

C. The Motor Home

For this model, four of the six primary submechanistic requirements -- atmosphere, waste, water, and temperature -- have been provided for by equipment suggested by the United Aircraft Corporation in its study for NASA concerning advanced integrated life support systems.[82] Their overall conceptualization previewed technology necessary for a Mars flight lasting 500 days, supporting nine men, and having a regenerative organization. The study was based on a projected flight departure occurring sometime between 1976 and 1980.[83] The submechanisms recommended for specific duties in the Mars mission have been re-evaluated in light of a different set of requirements for the life support mechanism, namely, those of earth-based use for a single individual or a small family. A reliability criterion (MTBF or Mean Time Between Failures) has been projected for the various submechanisms and will be noted for those of interest to this model.

1. <u>Oxygen-Carbon Dioxide Control</u>. The atmospheric provision is based on an overall mechanism that is not open to

the bioclimate except when doors or windows are being used. The gaseous controls do not depend on vented air from the outside.

The first control requirement is the removal and concentration of the carbon dioxide taken from the mechanism's atmosphere. A reasonably high purity for the carbon dioxide is also necessary if the CO_2 is to be used in food production, a process which will be described later. Two alternatives exist for gaseous regulation : the first submechanism uses a solid electrolyte oxygen generator with a carbon dioxide concentrator and does not provide bases for food production[84]; the second removes carbon dioxide from the atmosphere, transfers it to the food process submechanism, and produces oxygen from hydrolysis of purified waste water.

The unit based on the solid electrolyte concept removes carbon dioxide from the air through the use of a steam-desorbing resin based on a regenerable ion exchange resin. This material absorbs and collects the carbon dioxide from the atmosphere and is desorbed by the steam which displaces the carbon dioxide from the sorbent bed. The air minus the carbon dioxide is returned to the mechanism enclosure. Water vapor is carried along with the carbon dioxide to the solid electrolyte reactor where, in a two-step reaction (the first at 1800°F and the second at 1000°F), the water and carbon dioxide are reduced, respectively, to hydrogen and oxygen and carbon monoxide and oxygen. The oxygen is cooled and returned to the mechanism atmosphere, the hydrogen is also cooled and then passed to the bioclimate, and the carbon monoxide is cooled to 1000°F and moved to a disproportionate reactor where carbon is deposited and a carbon dioxide remainder is formed. The last gaseous product is cooled and returned to the solid electrolyte. The heat derived from the cooling phases is also returned to the electrolyte. The MTBF for this unit working as a whole is projected as 145 days, with a repair time expected to be 1% of the total use period. This highly accurate prediction of failure frequencies suggests that the equipment could be renovated within a time cycle shorter than the MTBF, thus negating difficulties caused by unscheduled shutdowns. During renovation and repair shutdowns, air from the outside could be vented in and heated by techniques standard for this model. Space parts will be included in a repair kit and can be used for any renovation.

The alternate unit gathers the carbon dioxide from the mechanism atmosphere by the same method (steam-desorbed resin) as the first component choice. The collected gases -- carbon dioxide and water vapor -- are then passed to the food production submechanism.

2. Water Management. The entire water balance is maintained on a regenerative, cyclic format of a vapor distillation/compression unit. This submechanism resembles, in intent, the equipment used simply for waste water purification in the *Camper* model. But here the water, once purified, is returned to the man and the mechanism atmosphere (for humidity control), establishing a continuous cycle between the man (men) and the submechanism. The extra metabolic water established after cleansing is directed to the food processor.

The vapor distillation/compression unit[85] accepts the wasted water which has been separated from the solid wastes by filtration. Chemicals are added to destroy bacteria and chemically fix the free ammonia (from the urine). At ambient pressures, the waste liquids are drawn across a hot, membranous surface and water is evaporated. The vapor is diffused through the semi-permeable membrane which prevents passive of the solids and other contaminants. The water vapor is compressed and condensed on porous surfaces, and the heat is recovered during the compression phase and returned to the evaporation chamber.

The vapor diffusion/compression unit is able to recover 95% of the water present in the undiluted urine, and the water derived is entirely potable. The MTBF for this unit is projected as 600 days with a scheduled repair time of 0.3% of such a use period. The specific elements requiring the most frequent replacement are the several membranes. The removal of the used pieces and the subsequent insertion of new membranes are easily accomplished. The solids obtained at the membranes are mostly urea (an individual produces about 35 grams of urea/day) and nonelectrolytic inorganic salts. These are all transferred to the food processor to be used in the development of protein foodstuffs.

3. Food Procurement. The provision of foodstuffs for the Motor Home is primarily developed around a series of chemosynthetic processes, organized to produce both protein and carbohydrates. Two techniques are suggested for the synthesis of edible protein: the first is based on the continuous chemical fermentation of natural gas (methane)[86]; the second utilizes a pansynthesis in which urea and a substance "formose" are reacted to provide quantities of the required amino acids.[87]

The Continuous fermentation process uses methane (CH_4), oxygen, water, and mineral nutrients. The methane can be produced by reacting carbon dioxide (20% of the total daily human output) and hydrogen (from the electrolysis of water) at elevated temperatures and pressures in a Sabatier reactor. The oxygen and water are easily obtained from other submechanisms present in this model; and the nutrients are derived from ash left from the waste control device. The result is a rod-shaped, single-celled microorganism which has an approximate composition of 60 to 70% protein, 5-15% fats, 15-35% carbohydrates, 2-6% ash, 2-6% moisture, and 15-45 milligrams/(kilogram of product) of vitamin B_{12}. The protein provides sufficient quantities of all the primary amino acids and is as nutritious as soybean and fish meals. The protein and other food materials may be harvested continuously.

The alternate chemosynthetic protein source employs a reaction between urea (which is easily obtained from the processed urine) and formose. The latter material is a mixture of the several common monosaccharides (or simple sugars). The reaction occurs when both are heated to temperatures above the boiling point of water and allowed to remain there for several days. The pansynthetic formation of protein material is slow, and the total conversion of nitrogen from urea to protein has been observed to be less than 2%. The monosaccharides are furnished by a chemosynthetic production of carbohydrates (to be described below). An analysis of the protein formed by pansynthesis has demonstrated the presence of the several amino acids in their required quantities. But because of the slow, inefficient pansynthetic technique, the process based on the fermentation of natural gas is preferred.

Carbohydrates are generated by a chemosynthetic formation in which carbon dioxide (the remaining 80% of the daily human production) and water vapor are reacted through a series of Sabatier reactors to form simple sugars:

$$CO_2 + H_2O \xrightarrow[\text{catalyst}]{\substack{\text{high temperature} \\ \text{and pressure with a}}} \frac{I}{X}(CH_2O)_x + O_2 \qquad (C)$$

These sugars are present as a mixture of monosaccharides (pentoses or hexoses), present as both dextro and laevo stereoisomers.[88] This technique is currently under development and conclusive data have not been ascertained. Some of the various stereoisomers produced are nutritional, and others are toxic. It is generally expected that suitable quantities of nutritional sugars will be present in the mixture and that these can be separated chemically from whatever toxic substances may be present. Therefore, it is highly likely that sufficient carbohydrates can be obtained from the process to support human activity requirements.

Fatstuff provisions remain the most difficult product to supply by artificial means. Aside from the limited fatty materials derived from the fermentation of natural gas, the chemosynthesis of fats or fatty acids has been considered only in a speculative sense. It is thought that fatty acids can be produced by reacting organic acids (such as acetic acid) with glycerol, but the common industrial synthesis of glycerol is based on previously-obtained fats.[89] While chemosynthesis of fats or fatty acids may indeed be possible, it will probably have prohibitive costs in terms of complexities and production requirements. For nutritional balance, the primary source of fats, or more likely fatty acids, will continue to be the storage rather than the artificial production of these materials. If a natural gas fermentation is used for protein formation, then the secondary fat products can be employed as supplements. An individual requiring 120 grams of fatstuffs/day would use 96 pounds/year. This quantity could be easily stored. Various foods whose compositions are high in fat are recorded in appendix 3. Because these foodstuffs rarely contain 100% fat, stored quantities greater than 96 pounds will be required.

Vitamin and mineral supplements are included for this mechanism also and will be used as capsules, taken daily.

4. Waste Control. Solid wastes, once separated from the liquid wastes by a filtration process, are passed to a shredder. The material is then sealed in a heat chamber and the temperature is raised sufficiently to vaporize the liquids present and to sterilize the waste matter and the gases. Once this step is completed, the gases are vented to the bioclimate. The waste solids are then heated to 1000°F and air or pure oxygen is fed into the chamber. Incineration occurs and is maintained for several hours. The process leaves a residue of only 1 to 3% of the original, and this inorganic ash is turned over to the food processor for protein production. The gaseous remain can be directed to the mechanism's atmosphere control or it may be released to the bioclimate.

This process, known as flush flow oxygen (air) incineration,[90] has an MTBF projected as 400 days with a repair time estimated as 0.5% of the mission use period. This unit was chosen over several other candidates because of its relative simplicity as a solid wastes handler and purifier. Its most serious drawback is the high temperature required for incineration. The relatively high heat effectively decreases the lifetimes of specific parts and of the whole submechanism. Most of the other equipment suggested by United Aircraft requires vacuum conditions more easily arranged in space. This unit, however, appears to be the most efficient in an earth-bound environment.

5. Thermal Well-Being. Air temperature and humidity are both controlled by a variable speed fan which forces the mechanism air across a face wick.[91] The wick is simply on or off. If "on," the rate at which heat is induced into the enclosure is dependent on the velocity of the air drawn over the wick. The speed of the fan is maintained by its motor which can be regulated by varying the frequency or the voltage of the electricity. The humidity is controlled by a coolant flow regulation. A faster coolant flow cools the air and raises the humidity. If the air becomes overcooled, then the air velocity across the activated wick is increased with a resultant increase in air temperature and a drop in the humidity level.

The projected MTBF for this organization is 475 days with an expected repair time of 0.25% of the total use period. An arrangement can be made so that, when this unit is shutdown, any airflow from the outside (*e.g.*, by opening doors or windows) is minimized entirely.

6. Power Source. The overall mechanism is characterized by a highly mechanistic organization which is sustained by large power requirements. As a result, high current densities are needed to operate the several submechanisms. The power source must also be capable of providing energy for a long supply period without replenishment. These two requirements nullify the use of the conventional heat engines, such as the automotive engine or turbine, each driven by internal combustion, because of the need for fuel re-supply. Additionally, the reactions present in internal combustion create products which, if not treated, will pollute the bioclimate.

The power source chosen for this model is a nuclear plant (*i.e.*, either the radioisotope or the reactor). This power plant is -- or, more accurately -- will be capable of generating appropriate current densities for use periods of one to several years (when the mechanism is finally assembled by 1990). The nuclear reactor is selected over the radioisotope, because it can provide higher specific current densities.

The particular reactors that offer the most interesting opportunities are those that are being developed for power source applications in space vehicles and are known as the SNAP series (Systems for Nuclear Auxiliary Power).[92] These units are essentially composed of three parts: (1) a compact fission reactor that generates heat; (2) an energy converter that transforms heat into electricity; and (3) a heat exchanger that transfers excess heat. The performance of the reactor depends on the reaction between fissionable material in the reactor core and neutrons launched either from an artificial neutron source or as the partial product of a previous fission reaction. The primary fuel materials for the SNAP reactors are uranium-zirconium hydrides or nitrides, all of which contain fissionable quantities of the isotope uranium-235. This isotope is commonly used in a mixture with the uranium-238 isotope which, by itself, is neither radioactive nor fissionable. This mix is generally composed of 99% or more uranium-238 and 1% or less of uranium-235. The products of fission for uranium-235 are atoms of elements of considerably lower atomic weight, neutrons, and large quantities of energy as heat. A primary task in reactor design is the control of the rate of energy release, and the production of heat energy demonstrates the fact that the reactor fundamentally works as a heat engine (much as the turbine described for the Camper model). It is, therefore, subject to the problems of energy conversion and the maintenance of efficiencies.

Two alternatives exist for the conversion of heat energy to electrical energy: the first is based on the use of thermoelectric elements, and the second uses a turbine-generator combination. The thermoelectric conversion is presently being accomplished by heating one end of either a silicon-germanium or a lead-tellurium couple to 500°C while cooling the other end. A current results from the electric potential created by the previously-mentioned *Seebeck* effect. These materials raised to this temperature produce an efficiency of about 2%. Much higher efficiences are possible for thermoelectric energy conversion at temperatures around 700°C, but such conversion is dependent upon the development of materials able to perform at the higher temperatures. The additional constraints on the use of either of these two couples are that (1) their densities are high, and (2) the units do not have higher efficiencies when produced in larger sizes. The production of currents greater than that obtained from a single cell requires multiple units. Thus, the use of these couples is most successful when low power levels are needed (probably 1.0 to 2.0 kilowatts maximum). The alternate conversion technique is founded on a turbogenerator where the fluid transfer is not steam-based as in the *Camper* model, but rather uses hot mercury vapor. Efficiences of up to 30% are thought likely, but this technique is also dependent upon materials development.

A definitive problem that exists for both of these methods is indicated in the amount of heat lost, which is demonstrated by the low efficiences of the energy conversion process. If the heat lost can be recycled within the unit for further thermoelectric generation, the situation may be acceptable; if not, then heat exchanged to the bioclimate may negate use of this technique.

A number of suitable SNAP reactors are listed in appendix 17.

A schematic diagram describing the food-waste cycle of the Motor Home life support mechanism is presented in appendix 18. The plan indicates the submechanisms, their relationship to each other and to man, and the materials that pass between them. The food-waste components are integrated, but they are not necessarily balanced. This last condition provides both a major advantage and a major disadvantage. In the first case, a lack of balancing allows a near complete exchangeability (or total "openness") between the submechanisms suggested for this model and those components listed in appendix 13. Also, the number of individuals supported by the different submechanisms and the total mechanism can be varied. The primary detraction of this non-balanced state, however, is the probable loss of an efficiency that would be probable for a balanced mechanism.

The Motor Home is the most mechanistic of the four organizations presented in this chapter, and it is primarily established on the cooperative bases between the several sub-mechanisms. As such, the criteria for mechanism design established in the previous chapter are most applicable. A second property of this model is that, though the presence(s) of the individual(s) within the support mechanism is continuous, the human needs are not all experienced as continuous (*e.g.*, waste treatment or thermal boosts of enclosure atmosphere). Therefore, not all the equipment is employed continuously, and the power draw is not always at peak capacity. If power requirements can be so arranged, a lower continuous current level could be maintained.

The limiting feature of the Motor Home life support capabilities is the food supply techniques. The need to store fatty materials, because of the lack of a technology sufficient to synthesize them, limits the overall regeneration capabilities of the model. To circumvent this problem, several hundred pounds of fatty materials could conveniently be stored (providing a multi-year supply). An additional possibility that might become reality by 1990 is the development of fatstuffs produced synthetically. The second problem for these food supply techniques is the general uncertainty about the acceptability of foods such as the bacteria and the chemosynthetic sugars. Long-term diets based on these materials have not been investigated and their feasibility (i.e., physiological and psychological acceptances) must be demonstrated.

D. The Mobile Man/Mechanism Ecosystem

The primary difference between this model and the previous one lies in the food-waste cycle. In the Motor Home each major physiological requirement was provided for by a discrete submechanism functioning independently. But for this model, one inclusive submechanism sustains four of the five basic requirements: specifically, atmospheric management, food procurement, water supply, and waste treatment. In this reference, the term "submechanism" is recommended because the level of provision is considerably more sophisticated than the submechanisms of the previous models. The degree of openness in the Motor Home is equaled by the closed quality of the Mobile Ecosystem. This latter mechanism is organized around an interlocking structure in which the components are interdependent.

The second disparity between these two mechanisms occurs within the attitudes around which each is designed. The Motor Home is entirely mechanistic and is founded on relatively powerful equipment which, while generally efficient, still requires high current densities for use. The bonds in this model occur initially between each submechanism and the power core, and secondly, between the man and the mechanism. Thus, the development of the Motor Home is based on a man-centered organization, and man is placed at the top of the supply network. In the <u>Mobile Ecosystem</u>, the attempt to generate an ecosystem negates the independence of the several components. Each component is structured into an overriding framework in which man is an element within the food-waste cycle and an important element at that. But the human being is still part of a larger chain. This situation is neither the simpler two-species (man and mechanism) ecosystem of the <u>Motor Home</u> image nor is it the mature climax ecosystem based on a multi-species population. As a system-environment cooperation it falls somewhere in between. The cooperation is less mechanistic and requires less power, and it has a higher efficiency. A regenerative cycle is developed and the process can be balanced. Hopefully, this model begins to resemble a natural cell and sustains itself accordingly. A single drawback, however, might result from this cellular organization: if the model is closed and balanced, then its expandability (its ability to support changing numbers of people) is limited. Rather than the cell increasing in size, perhaps the basic growth process occurs with discrete increases in the numbers of the cells as opposed to a simple change in size.

The food production techniques for these last two models are essentially similar in structure. The intermediate treatments and products are different (as should be noted in specific provisions like protein formation and urine treatment). The difference between the two models is also reflected in the varying organization: for the Motor Home, each submechanism relates directly to the human being; whereas for the Mobile Ecosystem, the components (including man) relate to each other equally, suggesting a more uniform cyclic structure. This basic variation can be noted by comparing the schematic food-waste diagram in appendix 18 for the Motor Home with the schematic plan for the Mobile Ecosystem in appendix 19. This latter diagram will be discussed below.

1. Atmosphere--Food--Water--Waste. As noted on the schematic plan, this work represents a proposal by Drake et al. to NASA as a prototypical life support system usable for extended space flights. This diagram is suggested as the basis for the Mobile Ecosystem and the discussion of this model will be presented as an explanation of the systematic plan.

If we begin with the wastes produced by man (feces, urine, and residual food material), the mixed quantities are run through an activated sludge reactor in which some of the solids are dissolved into the liquids. Those that do not are re-cycled through the sludge reactor. The characteristics of the sludge are that, by passing the liquid through raised temperatures and pressures, a slurry can be formed in which the microörganisms have been eliminated, solid organic materials have been dissolved or removed, and the useful waste substances such as urea and inorganic nutrients are maintained in an aqueous solution. This solution can then be passed on to the food production components. Any solids which are not effected by this treatment can be combusted, and the ash can also be used in food production. Combustion gases (primarily carbon monoxide and water vapor) will be collected and charged to other components for further treatment. An important distinction between waste treatment in this model and the preceding one should be noted relative to the intermediate products of the waste treatment. In the Motor Home all of these were separated. Each was purified individually and then re-united with the other treated materials when they were used in the next submechanism. Here the treatment is common and the process recognizes the next step in the cycle: an example of incompleteness where such incompletion provides an increased efficiency.

Food production follows an arrangement similar to the previous model. Protein material is developed from a culture of hydrogenomonas bacteria, and the carbohydrates are produced by the identical chemosynthesis. The protein generation depends on the ability of the bacteria to utilize quantities of the aqueous slurry containing urea and nutrient salts and the gases (oxygen, hydrogen, and carbon dioxide) collected from the atmosphere and from an electrolytic reaction (both to be discussed below). The bacteria is stimulated by electric energy, rather than the light energy required by algae and the hydroponics, an application that is much more efficient because little energy is lost by rejection. The energy is produced by an oxidation of the hydrogen gas, so that much of the energy required for water electrolysis is regained. The bacteria produces a protein-rich biomass which can be harvested in quantities suitable for fulfilling daily requirements (50 to 100 grams/day depending on the composition of the diet and the activities performed). Water and unused nutrient salts also can be removed at the intervals chosen for harvesting. Foods derived from the <u>hydrogenomonas</u> bacteria incorporate sufficient amounts of all the required amino acids.[93]

In a manner entirely similar to the chemosynthesis of the carbohydrates employed for the <u>Motor Home</u>, edible sugars are derived using a series of catalytic reactions based on increased temperatures and pressures. In the schematic plan in appendix the various intermediate products and by-products are identified for a further clarification of this process.

The several gases present both as products of man and as the by-products of other component activities are collected and separated much as they were in the <u>Motor Home</u>. Carbon dioxide is removed from the mechanism atmosphere by the steam-desorbed resin technique, and it is concentrated and exchanged with the food production techniques (again 20% of the daily production is used in the hydrogenomonas culture and the remaining 80% is fed to the initial chemosynthesis reactor). Water vapor is collected, condensed, and electrolyzed. Quantities of the oxygen thus produced are passed to both the bacteria and the mechanism atmosphere. The hydrogen is delivered to the hydrogenomonas unit for an exothermic oxidation. The gases occurring as intermediate products of the carbohydrate chemosynthesis are maintained in a closed organization and only the final sugars are opened to the mechanism.

Water processing occurs at three primary locations: (1) water is generated from the initial and final steps of the sugars chemosynthesis; (2) water is recovered from waste combustion; and (3) water is also obtained as the principal by-product of the hydrogenomonas production. In the last instance, water is obtained both from the nutrient slurry and from the hydrogen-oxygen reaction, which is also used for energy production for the culture growth. The water generated by each of these processes is suitable for re-use, although only the first and second processes furnish water for human consumption. Water used in the culture as the slurry medium is recycled either for further slurry creation or for use in the electrolysis unit.

2. Thermal Well-Being. Heat for the mechanism atmosphere is supplied from energy wasted during food production, particularly by venting some of the heat present in the chemosynthesis phase. The drain on the catalytic reactors is occasional and small, relative to the heats employed during carbohydrate production. This heat is circulated around the enclosure by a fan similar to the one in the *Motor Home*.

3. Power Source. Two power plants are suggested. Both are currently in the developmental stage, with each probably requiring ten to twenty years of research preliminary to implementation. The first technique is based on the *SNAP* series nuclear reactors for which, in this more advanced version, the core elements and heat production capabilities are the same, but the thermoelectric conversion has been changed. Rather than using the mercury-vapor driven turbogenerator, a *thermonic* converter is employed.[94] This energy conversion is based on the ability of certain metals (*e.g.*, tungsten or molybdenum), when heated to near-liquid temperatures, to "boil-off" electrons from the surface of the metal. In the reactor based on this concept, metal electrodes are similarly heated by fission reactions; and an electron stream forms and is collected on a cooler electrode nearby. Thus, a voltage potential is initiated and an electric current is established by the passage of electrons. This process offers efficiencies much better than either the thermoelectric

Seebeck effect on the turbogenerator. Not all of the heat generated in the reactor is transformed, but the quantity that is lost is small. The opportunity to capture this secondary amount should be explored.

The second method for power generation incorporates the fueld cell concept suggested for the Runabout with a technique employing regeneration of the gases used in the fuel cell. Solar power collected by a set of highly-focused mirrors is employed to drive an electrolysis cell which produces hydrogen and oxygen for use in the fuel cell. The ability for this concept to succeed is predicated on two conditions exhibited by the fuel cell and the Mobile Ecosystem. First, the fuel cell is a highly efficient electrochemical conversion technique in which the actual electrical energy realized by the chemical reaction approaches the theoretical, predicted amounts; and the amount of energy required to produce hydrolysis by electrolytic cell action is only slightly greater than the theoretical value for this reduction. Secondly, the amount of power required continuously to drive the Mobile Ecosystem is small relative to the Motor Home model (the Mobile Ecosystem analog suggested by Drake et al.[95] for a ten-man Mars mission requires approximately 1.5 kilowats). The amount of power required for the specific Mobile Ecosystem model supporting a single individual is probably slightly less; and the quantity of energy required from a solar cell for the electrolysis of water is probably similar. An additional requirement for this technique would be the development of a storage capacity allowing storing of "power" or the reactant gases for subsequent utilization when the sun was obscured by atmospheric conditions. This method of energy production is entirely clean (or non-polluting), but it would experience difficulty if used in the arctic or near-arctic areas where sunlight is minimal during the winter. A solution to this last problem could be the development of artificial satellites which receive and focus the solar light. If a very small percentage of that energy could be directed to this mechanism, sufficient power would be provided (this concept was noted in appendix 13).

The difficulties with the <u>Mobile Man/Mechanism Ecosystem</u> model are similar to some of those anticipated for the <u>Motor Home</u>, particularly the lack of prior experience with the food production techniques. The <u>hydrogenomonas</u> bacteria have been produced in the laboratory in quantities suitable to feed at least one individual, but it has not been extended in multiples, supplying several or more people. Carbohydrate chemosynthesis also requires development. There is some question of whether the amount of starting materials (carbon dioxide, water vapor, and hydrogen) can be balanced relative to the amount of carbohydrates that are needed; and the techniques used to separate the edible sugars from the toxic carbohydrates (that will probably be present) also require further research.[96] Fat supply, as indicated in the Motor Home model, still is based on a storage capability. A truly long-term occupancy is, therefore, dependent on the initiation of a method for artificial (or induced) synthesis of fatty materials. If a substitute could be found for fat quantities in the diet or if a fat synthesis can be developed, the use period of this mechanism without replenishment could easily exceed ten years and the utility of the mechanism would be determined only by its infrequent need for repair and its ability to provide activity support and to allow group or multiple individual interactions.

The other primary question for the Mobile Ecosystem concerns its ability to produce a balanced relationship between the several contributents to ecosystem formation. The additional concern is the level of efficiency available, particularly with reference to power development and how much heat is lost to the bioclimate if a SNAP reactor is employed. At this time, it appears entirely likely that a balance can be initiated between the four segments of the food-waste cycle; the only problem may be how soon such an organization will be feasible.

A thirty-year development time is probably reasonable assuming continued interest and no major difficulties within the theoretical foundations. It would probably be of much interest to investigate anticipated successes for the Motor Home and the Mobile Ecosystem mechanisms using a Delphi forecasting technique. Such forecasting might also indicate possibilities for further mechanism development following these models.

The four models described in this chapter have been developed primarily to fulfill the first set of criteria noted in the "functional analysis model," specifically the physiological necessities of human life. These criteria (including power generation) are understood to be non-reducible and, therefore, are basic to life support and mechanism design. The other elements of the "functional analysis model" are also of importance in mechanism design, even if they represent non-critical requirements. A brief descriptive list of components that could be expected to be present in any of the four generational models has been compiled and is displayed in appendix 20.

VII. SOME FINAL OBSERVATIONS

A summary or set of conclusions to the previous chapters seems inappropriate. From the outset of the thesis, this work was structured as only the beginning of a new interdisciplinary approach to architecture and environmental control techniques. The text has dealt primarily with those facilities which offer support for a range of activities and which provide a comfortable setting in which to perform these activities. The nature of a habitable surround has also been explored, and criteria presented in a "functional analysis model" have been delineated. The physiological aspects of habitability have been described in some detail and a series of generational models have been developed supporting the human physiological needs. These models are based on a specifically extreme and hostile bioclimate; but, with minor alterations that have been indicated in the text, the several mechanisms can have universal adaptability for land-based (and perhaps water surface) conditions.

Several major opportunities for continued research are now open for investigation following from the work established in the thesis. The two primary areas differ in direction: (1) the first project would take the <u>Camper</u> or <u>Motor Home</u> model as a basis, and a hardware unit would be built approximating these generational models; and (2) the second possibility suggests that a game can be empirically derived, much as contemporary planning games, such that the winner is the individual who is able to perform a required task while living in an optimized comfort. The hardware model would necessarily require specific approximations made relative to the paper models because of the non-availability of certain of the components such as the SNAP reactors (which are understood by the author to have only a very limited subscription). The approximate model is likely to be less efficient, and its operation, particularly its generation of power, may appear dirty relative to the paper models described earlier in the thesis. Such could be the case if, for instance, a turbine driven by fuel combustion was used for a power source. The amount of the harmful combustion products could probably be reduced if an afterburner was used and these end products were cycled back through the atmospheric and water treatment submechanisms. The unused heat could also be re-used either for the enclosure's thermal setting or for the heating of water or food. The game, on the other hand, is an opportunity to examine a wide variety of scenarios generated by considering variable activities, bioclimates, numbers of individuals, and levels of comfort. The game could be scored in terms of the use of energy, the relative efficiencies with which the activities are carried out, and the amount of waste products not treated by the modeled life support mechanism. Play involves the resolution of conflicts between the individual or individuals and the bioclimate while pursuing tasks that may simply be professional or may include life sustenance. For skilled players employing this game the challenge could be encountered in either the degree of amenity or utility provided for the user or the relative artistry or *élan* with which the player conducts himself. Naturally, throughout play, the game is automatically forfeit if the user or users perish.

Having described within this thesis the approximate nature of the physiological aspects of habitability and the mechanistic opportunities to support such requirements, a more thorough analysis of the social and psychological criteria for habitability must be established. Obviously, when these are better understood, it would be imperative to examine the mechanistic models developed for physiological support to determine how well they provide for the total range of habitability requirements. The more general criteria for social and psychological habitability acceptance were displayed in the "functional analysis model." These, however, comprise the relatively simple needs and do not really explore the multiplicity of more complex issues which offer differentiation between man as the singular being and the machine. The life supports and opportunities that are required to assist the individual are not well understood. The planners in the

American space program when designing the life support facilities for manned flight try to approximate the earth-bound environment as nearly as possible. What characterizes the earth-bound existence is not well quantified or closely analyzed, and thus any attempt to establish near approximations tend to produce disparities which may cause stressed situations. The difficulty that results occurs because life in an enclosure, that supports activities in an extreme and hostile environment, accelerates or accentuates the stresses so that problems that may be insignificant on earth appear very significant in space. Life experiences in enclosures for hydrospace activities can be comparable.

Use of a life support mechanism thus will probably be characterized less on how well it alone provides physiological comfort and more by the extent that the mechanism supports the social and psychological natures of the individual. The material in appendix 20 begins to offer supports for the other elements of the "functional analysis model" beyond the primary food-waste cycle context. However, the appendiced submechanisms will likely undergo rearrangement and change several times before a suitable organization might be found. The ability of the mechanism to support the non-physiological conditions will most probably determine the level of consumer acceptance that any life support mechanism receives.

The final observation is founded upon a recognition that the concepts for nearly all of the contemporary appliances used for environmental control were developed during the second half of the nineteenth century. Exclusive of the work carried on by NASA and its contractors, most of the industrial research since then has resulted in many refinements of the older concepts but few innovative developments. Simultaneous with this period of limited growth, our society is experiencing an environmental crisis caused by its inefficient use of its supporting mechanisms and the wasteful and polluting characters of their operation. Similarly, as we continue to consume at increasingly higher rates requiring ever greater supplies of material and energy, our existence is organized around non-regenerative, non-cyclic life patterns that result in continued inefficiency and wastefulness. This thesis has been predicated upon a new organization which seeks a clean and efficient mechanism that supports the required activities and offers growth opportunities, while providing environmental control based on a regenerative, cyclic operation.

The thesis has indicated four generations of mechanism development, each one better able than the last to exist within a completely regenerative and cyclic operation and to develop greater efficiencies, both in terms of cycle end products and power requirements. Seemingly, some day an Nth generation life support mechanism will be developed for which the entire package of this mechanical goody can be easily fitted into a backpack similar in weight and size to those used by the Sierra Club hiker. This pack will provide a total life support capability and in so doing will remove the need for "architecture." At that moment, the need for a physical shelter created by a built form will be rendered obsolete; and our society then will have need to retain built architecture only for the values of its symbolism and historical reminders. Contemporary with this development, man will be able to return to living in a balanced manner with nature, confident of a life support that allows activity pursuance and exploration without being bound in static constructions of form, inefficiency, and wastefulness.

If we thus negate the need for built form by the development of such a life support mechanism (or mechanical goody) and the mechanism fulfills our habitability requirements, then the next question becomes what does this mean for urban form and growth? If an individual or his small group or family is able to pursue activities and interests in a life style that is both highly mobile and independent of the previously acquired bonds of the city infrastructure, does this not dissolve the function and need for the city? Perhaps, as these questions are answered, an understanding will develop about the opportunities for urban existence beyond the then-removed life necessities that the city as a support mechanism had provided since man first gathered into formalized town and city groups.

Thus, new opportunities exist for the individual as he seeks to control his environment and to understand its relative habitability.