A NOTATION OF ENERGY CONSCIOUS DESIGN

-- An Architectural Approach to Energy Conservation

By

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CHAPTER ONE

INTRODUCTION

1.0. The Need for Energy Conservation in Building Design

In the American Institute of Architects' energy report,[1] two major energy systems were conceptualized. The first system, called 'current income', refers to the natural regeneration sources such as solar, wind and hydro power. The second system, called 'capital energy', refers to finite sources which, once used, are lost forever. Only in the past hundred years have human energy systems shifted from those dominated by natural energy to systems powered by capital energy. Owing to the rapid increase of capital energy consumption and the shortage of available energy sources, the energy crisis has threatened the future survival of human beings.

It is widely recognized that a solution has not been reached for the serious problem ahead of us. If the present large-scale use of energy by human beings continues, the stored capital energy will be exhausted in the next century. Projecting growth in energy use on the basis of past experience and comparing the expected future demand for energy with possible supplies, energy planners predicted in the late 1960's that a gap (Fig. 1) would appear between supply and demand from domestic energy sources.[2]

One suggestion for filling this gap was the development of alternative energy sources such as synthetic fuels or some new forms of energy. But they are far more expensive than the traditional energy sources, and the technology involved is far from matured at this time.

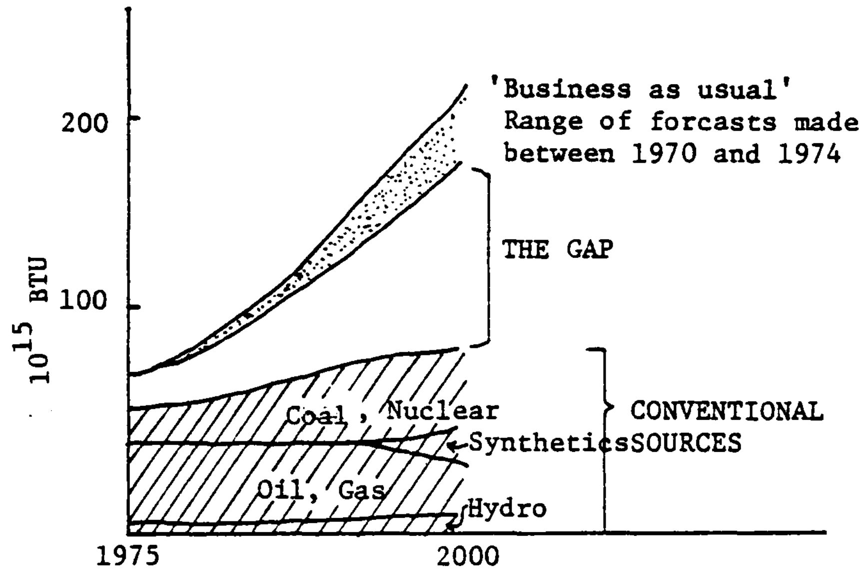


Figure 1. The Energy Gap

(The demand grows at historical rate about 4-5% per year.)

Furthermore, it would take a long time to develop a new energy source that would economically take the place of traditional sources. Therefore, methods of energy conservation should be used for the time being as a second best solution on the face of energy shortage.

1.1 The Potential of Energy Conservation in Building Design

Due to the lack of technical understanding and information and the misleading concept of energy conservation have caused the architectural design profession to be virtually ignored or dismissed in work dealing with energy. The schematic pie representation (Fig.2) of energy uses in the United States indicates that 57.3% of residential and 48% of commercial energy consumption were devoted to space heating. Most of this consumption could be reduced by conservation techniques such as the improvement of delivery of energy, the installation of supplementary system drawing in energy from the sun and the wind, etc..

According to a variety of studies during 1972 and 1973, the amount by which energy demand could be reduced if buildings were designed and constructed to be energy efficient is significant.[3] The degree of saving was a function of the technical and economic feasibility. The saving could range from 10% to 50% for retrofitted buildings and up to 80% for new building initially designed to be energy efficient. The studies concluded that 30% and 60% energy saving were reasonable average of the conservation potentials in old and new buildings, respectively.

The AIA energy report [4] presents the significance of the potential offered by energy efficient buildings, when those estimates are cast

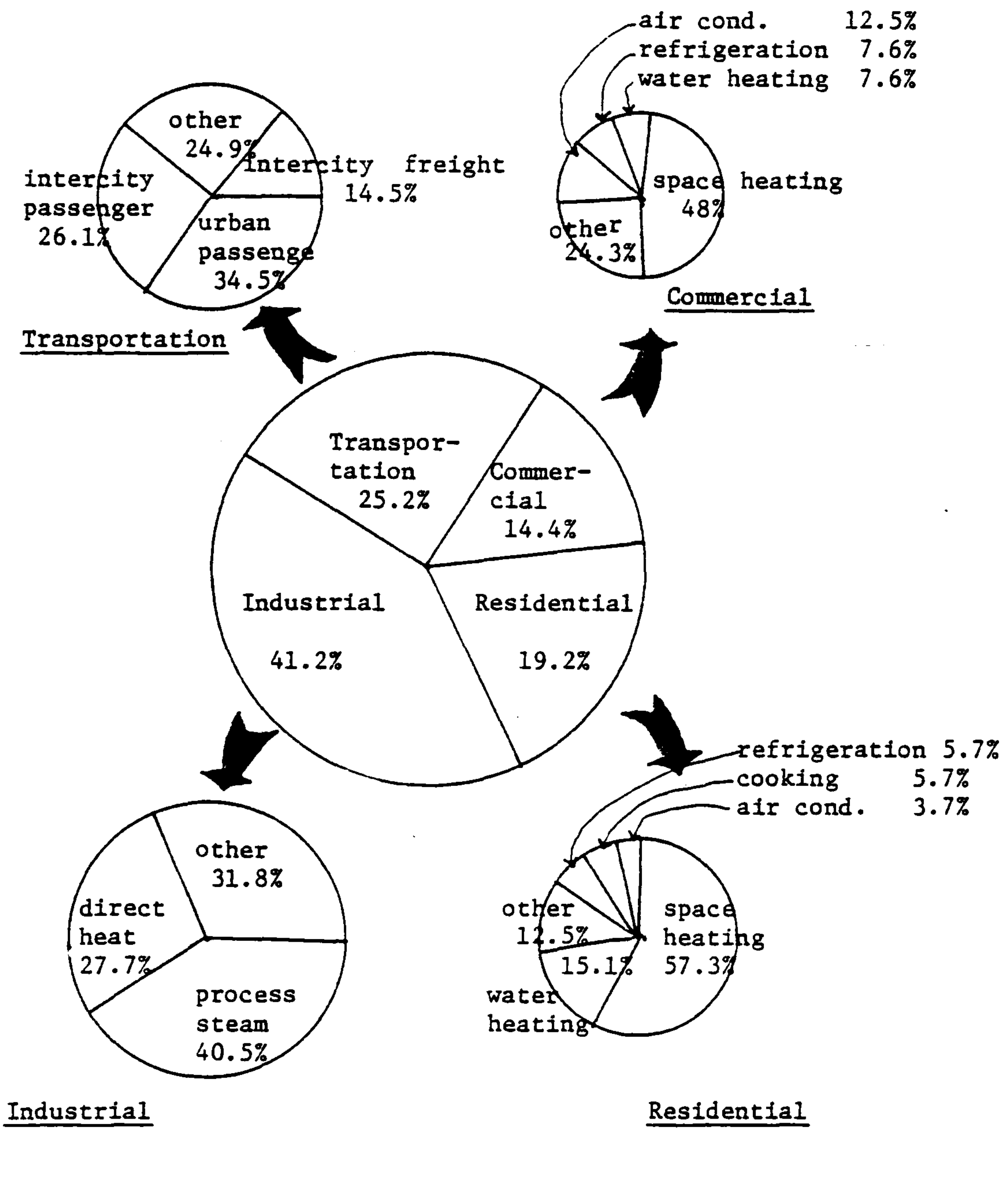


Figure 2. Energy Pie (From Oaks Ridge Asso. University, 1974)

into a national prospect that:

> "If we adopted a high priority national program emphasizing energy efficient buildings, we could by 1990 be saving the equivalent of more than 12.5 million barrels of petroleum per day. This is about as much as the projected 1990 production capacity of any one of the primary energy systems: domestic oil, nuclear energy, domestic and imported natural gas or coal." 5

1.2. Basic Principles of Energy Conscious Design

Generally, there are two major approaches to energy conservation: 'belt-tightening' and 'leak-plugging'. Belt-tightening concerns those measures which would reduce energy consumption at the present efficiency level. It aims at reversing the growth rate of using capital energy. Leak-plugging concerns those measures which would achieve energy saving by increasing efficiency. It intends to reduce wasteful energy use with little change in life style or standard of living of the users.

The approach of energy conservation in building design falls in the second category. There is much evidence that almost every aspect of building energy needs can be reduced or replaced by natural sources in some degree without affecting our standard of living. Nevertheless, there is a misunderstanding that the public and the professions alike consider the energy conservation in buildings as merely problems of construction material and techniques. Few relize that major conservation effects could be achieved by due considerations to building siting, orientation, configuration, etc.. These aspects deserve careful consideration in terms of their potential to energy conservation.

The National Solar Heating and Cooling Information Center has proposed the following design priorities for energy conservation:[6]

1. First, we make every effort in planning, design and construction to minimize heat loss in the winter and heat gain in the summer.

2. With this objective achieved, we put forth every effort to incorporate into our houses passive design characteristics which use natural energy such as solar radiation, natural lighting and prevailing winds.

3. Where possible, economical and efficient, we then incorporate active technologies which use renewable energies into our design.

4. Then, only then, should we rely on fossil-based non-renewable energy and related equipment and design features to supply the remaining energy required.

These rules could very well serve as the general guidelines of energy conscious design. The first two actions are the major concerns of this thesis.

1.3. Scope and Organization of Study

Existing design methods literature have shown little concern about energy factors. This is understandable since most design methods were formulated in the 1960's. It is necessary to develop a systematic method of approaching energy problems. The method to be developed will be a preliminary framework for considering the fundamental issues of solving energy problems. Although there is no limitation of using it in building types, the data and information provided in discussion will primarily be associated with house design. Since the necessary information for design is never sufficient and the solution for this problem is a method of finding the proper information, this thesis doesn't intend to provide designers enough information to serve as a design manual but will suggest a method of approaching problems.

The method which will consider energy factors as a design determinant is an attempt to respond to these questions:

1. How to identify energy problems in architectural design?

2. How to associate these problems with other environmental factors and to integrate them into design consideration?

3. How to select an optimum solution which will satisfy a variety of design criteria?

These questions will be answered through the discussion out of a systematic process. If a designer is aware of energy problems, he can find the proper information and develop his approach of energy design by using the method and the reference provided in this thesis.

In this thesis, Chapter Two is the literature review of design responses to natural environments in the historical and the present times. It reveals that design with nature which will obtian energy efficient strcutures is not a new idea. Many historical cases proved that it had a great potential and incentive of energy conservation. After the energy crisis, the modern designers recognized its importance yet they lacked an appropriate method to deal with it.

The third Chapter is to investigate the reasons for designing a methodology of energy conscious design and the quality, the criteria and the possible framework of it. It discusses the backgroud and the direction of approaching energy problems.

Chapter Four is the description of a six-step method of analyzing energy problems and developing alternative solutions. This method incorporates the conventional design concerns with natural factors in a systematic process. The advantage of this method is that it allows flexibility of application in a conventional design process and also it can be used as a complete approach of energy conscious design.

The fifth Chapter suggests a three-stage program of evaluating alternative solutions. This program, which is in a formative stage, is intended to deal with both the conventional and the energy conscious design solutions.

CHAPTER TWO

LITERATURE REVIEW

2.0. Adapt to Climate: Some Ancient Examples

> "There is much to learn from architecture before it became an expert's art. The untutored builders in space and time - the protagonists of this show - demonstrate an admirable talent for fitting their buildings into the natural surroundings. Instead of trying to 'conquer' nature, as we do, they welcome the vagaries of climate and the challenge of topography."
>
> (Bernard Rudofsky, Architecture without Architects, preface)

It is a natural instinct of many animals to defend themselves against a great variety of unfavorable climates, either with physiological mechanisms or with protective devices. Man's inventiveness has enabled him to construct shelters which would provide a favorable conditions for living. As the original purposes of the contruction of shelter evolved, ancient builders were able to meet the challenges of widely varying climates from lessons learned through nature and the accumulated experience in building.

One often discussed example demonstrating the importance of climatic factors on shelter design is dwelling of the American Indian. Their house forms vary greatly according to the variation of climatic environments:

In the cold northern territories, Indians solved the problems of the extreme cold weather with the Eskimo Igloo. The low hemisphical shelter deflects the winds and takes advantage of the insulation value of the snow.

In the hot-arid area, the Pueblo of San Juan (a tribe of Indians) constructed their housing with massive adobe roofs and walls, which have good insulation value and the capacity of storing solar heat. It reduces the daily heat peaks and releases the stored hest to warm the interior during the night.

In the hot-humid area, the climatic problems are excessive solar radiation and moisture. To cope with these problems, the Indians built their houses with large gable roofs covered with grass as solar insulation and with open walls to permit maximum breezes for evaporation of moisture.

Such examples of adaptation to climate can be found in every part of the world. The Japanese traditional house, influenced strongly by China, had its unique ways to cope with climate. Several items developed from experiences have had significant effects on environmental control.

1. The roof is constructed with tile and mud. The mud has thermal insulation effect.
2. The eaves and veranda serve the function of solar control.
3. The house orientation of facing to the south permits the maximum solar radiation gain.
4. The openings and movable partitions provide ventilation to evaporate moisture.
5. The floor is stilted up in order to protect it from moisture in the earth and keep the room cool in the summer.

Human adaptation to climate is not only recorded in ancient architecture, but also preserved in cultural and political affairs. For example, the Chinese mystic art of geomancy was based on the knowledge of climatic and topographic variations. Climate also affects the Chinese political concept. Facing the south, for example, is the symbol and privilege of the emperor. Two reasons probably nurished this concept. First, most historical Chinese Capitals were located in northern China so that facing south had the symbolic meaning of ruling the entire country. Second, the climatic factors such as the north wind and solar radiation favor the south exposure of buildings. This concept was probably enhanced by the traditional south-north orientation of palaces.

Climatic factors have a direct relation with building energy consumption. Ancient structures which were designed to adapte to climate had great advantage in energy conservation. The modern technology and the concept of overcoming nature make human beings less affected by and aware of nature. It is the reason for the present suffering from the energy crisis and the future problems of survival. A designer should be conscious of energy conservation and the relationship between design and climate after reviewing these historical examples.

2.1. Recent Studies in Energy and Design

Design with climate was a mandatory attitude in ancient time, when 'technology' was primitive and energy supply was limited. Although the majority of modern designers are unaware of it, many studies of architecture and the climate have been completed over the recent years. For example, Dr. Paul Siple's House Beautiful Climate Control Project provides the designers with information of climatic analysis for architectural consideration. Givoni's book, Man, Climate and Architecture has also made great contribution to design with climate. These studies, however, do not address specifically to energy factors as design problems and sources of solutions. The remainder of this chapter will be devoted to the review of several significant theories which have incorporated energy factors in the design process.

I. Ralph Knowles' "Ecological Approach"

Knowles' book Energy and Form suggests that design for the built environment should adapt its attitude to the future problem of human survival in three ways:

1. First, economic purpose for urban growth stressing the long term costs of maintaining equilibrium in the built environment over the short term costs of development.

2. Second, a large scale view of a community as a set of association in which the diversity of community needs is met not by suppluing ever increasing mobility but building diversity into a closer contact arrangement.

3. Third, an aesthetic value is based on 'form as a natural adaptation for survival'.

The method he used to establish the relationship between form and energy is associated with D'arch Thompson's concept of "form is the diagram of forces."[7] Knowles considers that the static aspect of environmental forces can be measured in terms of variation and interval.[8] The maintenance cost of the built environment is primarily a function of the variation in the natural forces. He calls it stress. Stress occurs when natural forces such as ambient air temperature, incident energy, precipitation, topography and wind, change daily and seasonally. The larger the amount of variation, the more serious the stress is. Stress influences the built environment on the ratio between exposed surface area and contained volume. Then a mathematical relationship between stress and s/v ratio can be established as the logarithmic graph. (Fig. 3)

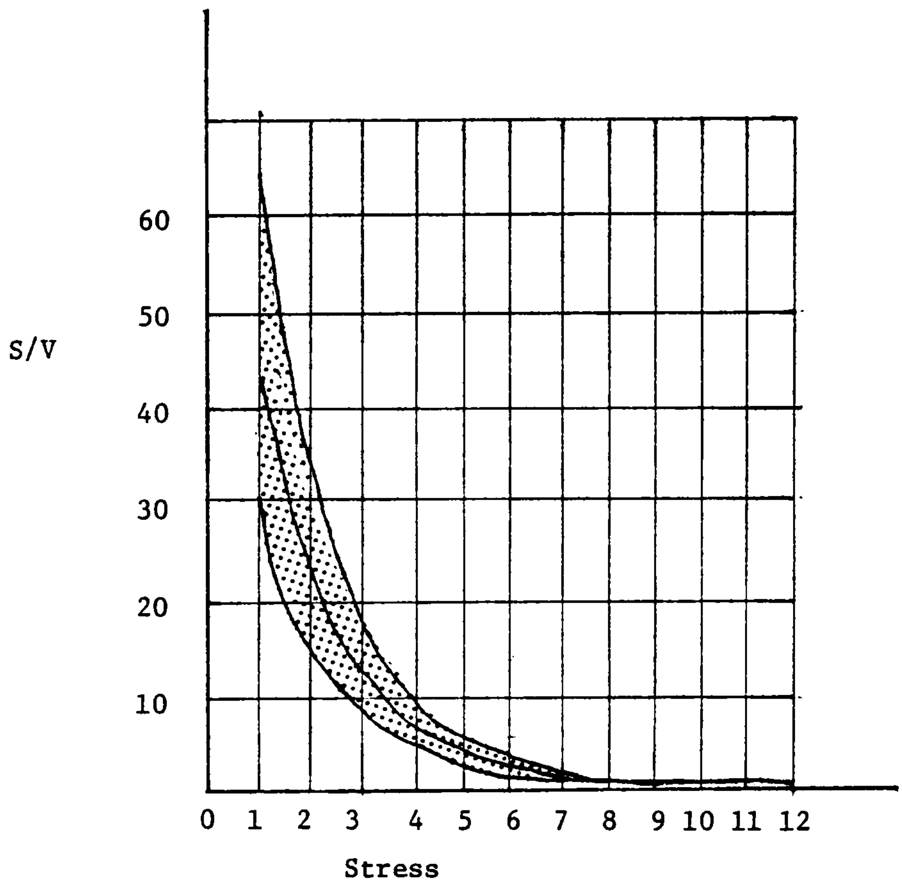


Figure 3. Logarithmic Graph Correlating surface-to-volume ratio (From Knowles' Energy and Form) Gray area indicates surface-to-volume ratio range for each stress value.

The second form descriptor is concerned with slope-orientation of the land. The insolation and its shadow on site has a fixed relationship with the slope and orientation. Generally, north, west and east slopes have larger shadow areas than that of the south. Its result is a 'form descriptor', hight-to-area ratio. (Building height to its influenced site area ratio is a function of slope and orientation.) This ratio will affect the incrementation of the land.[9]

Knowles' theory is an innovation in design with nature. But it still has a long way to go to be of applicabel value to the designer. The major weakness of his theory does not lie in his concept; it is in the lack of enough knowledge of the interaction among the natural forces. There are two weaknesses in his method, first, his use of the simple summation of variations of natural forces to calculate the degree of stress, which is a determinant of surface to volume ratio, is questionable. Second, the ratio of height-to-area judged only by the amount of insolation is an oversimplication also questionable.

Knowles' ecological approach is probably more useful to planning problem solving than to architectural design, but his idea of relating form and energy is nevertheless worthy of future investigation. It would be particularly powerful in the building of a simple and reliable model in dealing with energy problem in architectural design.

II. Olgyay's "Bioclimatic Approach"

Olgyay was the first person to use a systematic method of considering climatic factors in architectural design.[10]

The purpose of his method is to achieve a 'balanced structure' which, in a given environmental setting, reduces undesirable stress and at the same time utilizes all natural resources favorable to human comfort. His systematic approach to climate-balanced house can be divided into four steps:

1. Survey of climatic elements at a given location,
2. Evaluation of each climatic impact in physiological terms,
3. Application of the technological solution to each climate-comfort problem,
4. Finally. architectural expression.

In the technological solutions, he considers the following items would be distinctive: site selection, orientation, shading devices, house form, air movement and indoor temperature balance.

The major climatic factor considered in his process is the solar radiation. To Olgyay the problems in design are the reduction solar radiation gain during the overheated season, and the absorbtion solar heat during the underheated period.

Olgyay's idea of climate-balanced structure is not new. The houses of the Pueblo Indians can be considered as an example of the application of the principles. But he uses the scientific procedure to analyze the climatic data that provide designers a reliable way in dealing with the climate.

III. Caudill's "Humanistic Approach"

The idea of this humanistic approach to building design for energy conservation is based on "maximum results with minimum means."[11] This approach is not really an organized method as such; rather it provides a few principles and giudelines for the energy conscious designers. Six guidelines are:

1. Use the climate;
2. Make the envelope lean and clean (to have less roof and wall areas);
3. Design lighting systems for specific task;
4. Design on the edge of comfort zone;
5. Use energy efficient system;
6. Provide controls.

The humanistic appraoch doesn't take energy issue as a design problem and source of design creation. Therefore, its effect is small.

IV. AIA's "Energy Conservation in Building Design"

This report is most helpful for conventional designers concerning energy conservation at this time. It outlines areas and actions of the building process where energy saving may be achieved. Basically, it respects the humanistic, esthetic and other traditional values of architecture. Due to the lack of quantifiable technical data and design criteria, this method can only provide limited effects on architectural solutions for energy conservation.

Today, the assistance available for design professions concerning energy conservation is very primitive. The established major concerns in design approach are the three dimensional form, human factors and construction costs. Since it is generally believed that the ultimate task of architecture is to act in favor of man, modern designers are well equipped with sensitivity and knowledge of human factors but seldom are concerned with energy. An example of this trend is the so called 'international style' of the 1930's which exemplify the lack of concern for the variation of climate between different parts of the world. In this situation, design guidelines can only have a small effect on energy solution. Significant effects in energy conservation can only be achieved if we treat energy factors as equally important as human factors in design considerations.

CHAPTER THREE

A STRATEGY FOR DESIGN INNOVATION

Architectural design system is considered in this study as being composed of three environmental sub-systems: spatial, visual and physical, and their interactions with human activities. The spatial environment is associated with building performance and functional requirements. The visual environment is associated with building forms and the aesthetic value. The physical environment is relevant to building site conditions and available resources with which to build. The fundamental energy solution in architectural design can only be achieved by interfacing energy factors with these environmental systems. The four energy design methods discussed in the previous chapter have not attacked this strategic issue of the design process. Knowles' theory takes solar energy as a major factor of form generation, but it doesn't relate it to human, spatial and visual environments. Olgyay's method considers human comfort and spatial standards and their relation to climatic factors. This method only includes a physical approach, and is difficult for a designer to adopt in his intuitive creation. Approaches advocated by Caudill and the AIA respect the conventional profession method. They treat energy factors as design guidelines and can have only limited effect.

Conventional design attitudes and methods cannot meet the challenge of the energy crisis. Architectural design needs a new movement which would consider energy factors as the sources of design problems as well as solutions. This new attitude could lead to innovation in the architectural profession.

3.0. Reasons for Constructing a Methodology of Energy Conscious Design

Besides the reason of energy conservation, a few thoughts also support the need for design innovation.

I. Philosophically, design is an action of dynamically balancing the interaction between needs and forms. Alexander considers needs as forces which generates forms, order, natural organization and man-made objects.[12] He proclaims that "The ultimate object of design is form." This manifesto is meaningful, because he adopts D'arch Thompson's definition of form, i.e. "form is the diagram of forces." In this sense, the world can be perceived as a non-homogenous system organized by entities and forces. The characteristics of forces determine the property of the environment. The designer's function is to investigate forces and interactions between existing forms and forces in order to build new forms which will compensate for world's irregularities. The forces can be classified into two categories, physical and non-physical. The former has its specific way of acting such as the force of gravity. The latter which includes human actions is not easy to predict. Energy is one of the natural forces which obey the rules of physical laws.

Energy consumption is also associated with entropy which is another concept of energy. According to the entropy theory any natural process has the waste of inefficiency and increase the amount of entropy in the environment. Entropy as well as the energy consumption can be a measure of chaos and high entropy is a most likely state in the natural system. Chaos and lrregularity, therefore, always move toward a higher degree. The purpose of energy conservation can be considered as the effort to increase the energy efficiency in order to reduce environmental chaos and complication.

II. Theoretically, the objective of architectural design is to build a three dimensional form to accomodate designated activities. Broadbent said in his book Design in Architecture , "Building and its services control the physical climate. They act as a set of filters between a given, external environment and the activities we want to perform." Architectural design is approached by establishing activities they are to house, the space standards and environmental conditions these activities would require, the physical condition of the site and the available resources with which to build. The building itself, which serves as an environmental filter between man and his environment, is a means of reconciling these forces. Therefore, architectural design should recognize the inseparability of these four factors. Energy (or resource) is one of the determinants for design objectives and solutions.

III. Economically, design decision always involves cost-and-benefit analysis. The initial construction cost has been considered a prime design controller until maintenance cost becomes inflationary due to the ever increasing energy price. The cost of maintenance includes the costs of repair, painting, cleaning and energy need for supporting a comfortable condition. Energy cost has become a major expenditure of the total cost. Projecting the continuing inflation of energy price, ir is necessary to save energy in building design.

IV. Morally, the designer's objective is to make contribution toward improving the order and organization of the total environment.

His action influences not only his clients and designated users but also the community and futher generations. Many studies have estimated that if the present rate of energy consumption continues the stored natural gas will be exhausted in 35 years while the oil won't last more than a hundred years. These energy resources are the major chemical energy source for industry. Their shortage will cause tremendous economic problems and would even threaten human survival. It is not morally right to delay or avoid the critical issues when the fate of future generations is at stake.

V. Legally, building construction should obey the building codes and regulations. The increasing concerns of the public and the legislature about energy conservation in building design will force the architectural profession to consider energy problems in the design process.

3.1. Design Method and Energy Conscious Design

The strategy for seeking energy solution is first to construct a new value system and life style by changing designer's and the public attitude about energy, then to have a new design methodology in work dealing with energy problems. The objective of this method is to treat energy factors as a force of creating form. The conventional methods of creating form are pragmatic, iconic, analogic and canonic design.[13] Broadbent gives the difinitions for these designs in his book Design in Architecture. The pragmatic design is a matter of translating practical need into form. The iconic design is based on a "fixed mental image of what a structure should be like." In the analogic design, the creation of a new building form to new usage is based on a designer's visual experience. In canonic design, the geometric system, pattern or proportional system will provide the designer with an orgin of his design drawings and with authority for a great many decision about the shape of a figure.

Energy conservational design and design with climate seem only a matter of pragmatic problems. If the pragmatic design proved to work in many ancient cultures, why should we look for new ways of energy conscious design? The obvious answer is that the design context and property of problems have been changing and becoming more complex. A designer cannot cover a variety of variables in one time. The pragmatic design can't cope with non-physical problems. The iconic design is useless in solving problems across a wide variety of site conditions. And the analogic and canonic designs do not aim at analysis of problems.

Since energy factors are quantitative variables, the energy design method should include both qualitative and quantitative components. There are a few requirements that an energy design methodology should satisfy in order to be effective in dealing with them.

1. It can solve the conflict between logical analysis and creative thought.
2. It is capable of manipulating both the qualitative and quantitative variables.
3. It is possible to feed back both physical and non-physical solutions to problems.
4. It can evaluate design solution of non-physical quality in terms of energy forces.

A few considerations for meeting these qualities are:

I. First, it should be a systematic approach. Christopher Jones said in his paper "Method of Systematic Design","The method (of systematic design) is primarily a means of resolving a conflict that exists between logical analysis and creative thought." He asserts that this aim can be achieved by: (1) a system of analysis and record of every item of design in terms of performance specification; (2) synthesis solutions for individual performance specification to build up complete design; and (3) evaluation alternatives against performance specification.

II. Second, it is necessary to use logical structures to present design problems. Architectural design problems are becoming more complex and involve the problems of site planning, structure and environmental control. Consider a simple example of a design problem such as the decision about building orientation of a house, it will involve many variables affecting design decision. They are the approach traffic to the site, the relationship between the site and existing structures around the site and climate. Each variable may be controversial to the other. For example, opening to a beautiful view bring exposure to the cold wind. To cope with this complexity of problem, Alexander claims the need of rationality,[14] especially, need for using logical structures to present design problems. He believes that "a logical picture is easier to criticize than a vague one and increased precision gives us the chance to sharpen our conception of what the design process involved."[15]

III. Third, it will generate a concept of form from energy variables. Energy design methods can refer to the second step of Thronley's "design method in architectural education" [16] that the insolation of a general concept of 'form' is from the purposes of building, its relation to physical and non-physical surroundings and preliminary considerations of spatial and structure organization.

IV. Fourth, it has a trade off evaluation program of analyzing visual or spatial qualities in terms of energy criteria. Considering the assessments of design, Bruce Archer thinks that there is a line of limit between solutions are acceptable or unacceptable.[17] Therefore, an important prerequisite for an ultimate solution is that it be in the area of acceptability. In energy design, this acceptability should be justified by all major design considerations, energy, performance and aesthetics. Alternatives above this standard will accept a further evaluation of these visual and spatial qualities against energy criteria. The further discussion will be in Chapter Five.

3.2. The Structure of Energy Design Method

A design method is composed of design objectives, variables, problems, solutions and decision-making. The variables can be classified into two categories: non-controllable and controllable variables. The non-controllable variables are associated with environmental forces which are given on the site and cannot be manipulated by designers. These include climatic factors and human activities. The four environmental forces (activities, spatial conditions, site situation and resources) which have been discussed in the previous section are the major non-controllable variables in architectural design.

The controllable variables are the sources of energy design problems and solutions. They include the three dimensional form, design idea, building components and available materials and technology.

Architectural design activities are a dynamic balance between the unsatisfactory conditions and human needs. Their objective is for adjusting environmental interactions among physical and non-physical forces, human activities and thoughts and buildings. Designers play a critical position in an endless interaction. (Fig.4) It shows the importance of designers' considerations about the interfacing between human and nature in the design process.

A systematic method is necessary to perform this action. This method will include:

1. Establishing design objectives,
2. Exploring design situation,
3. Analyzing the problem structure,
4. Developing design criteria,
5. Investigating sub-solutions,
6. Synthesizing alternative solutions,
7. Evaluating and decision making.

Fig. 5 shows the interralationship among energy, spatial and visual environments through this systematic procedure. This will be the basic structure of the energy design method in this thesis.

There is a critical question about this methodology. How does it incorporate energy issues with other environmental factors in this systematic procedure ? The elements in physical environment can be examined in terms of energy. Therefore, it is reasonable to establish an energy system to take place of physical consideration in order to emphasize the energy influence on design.

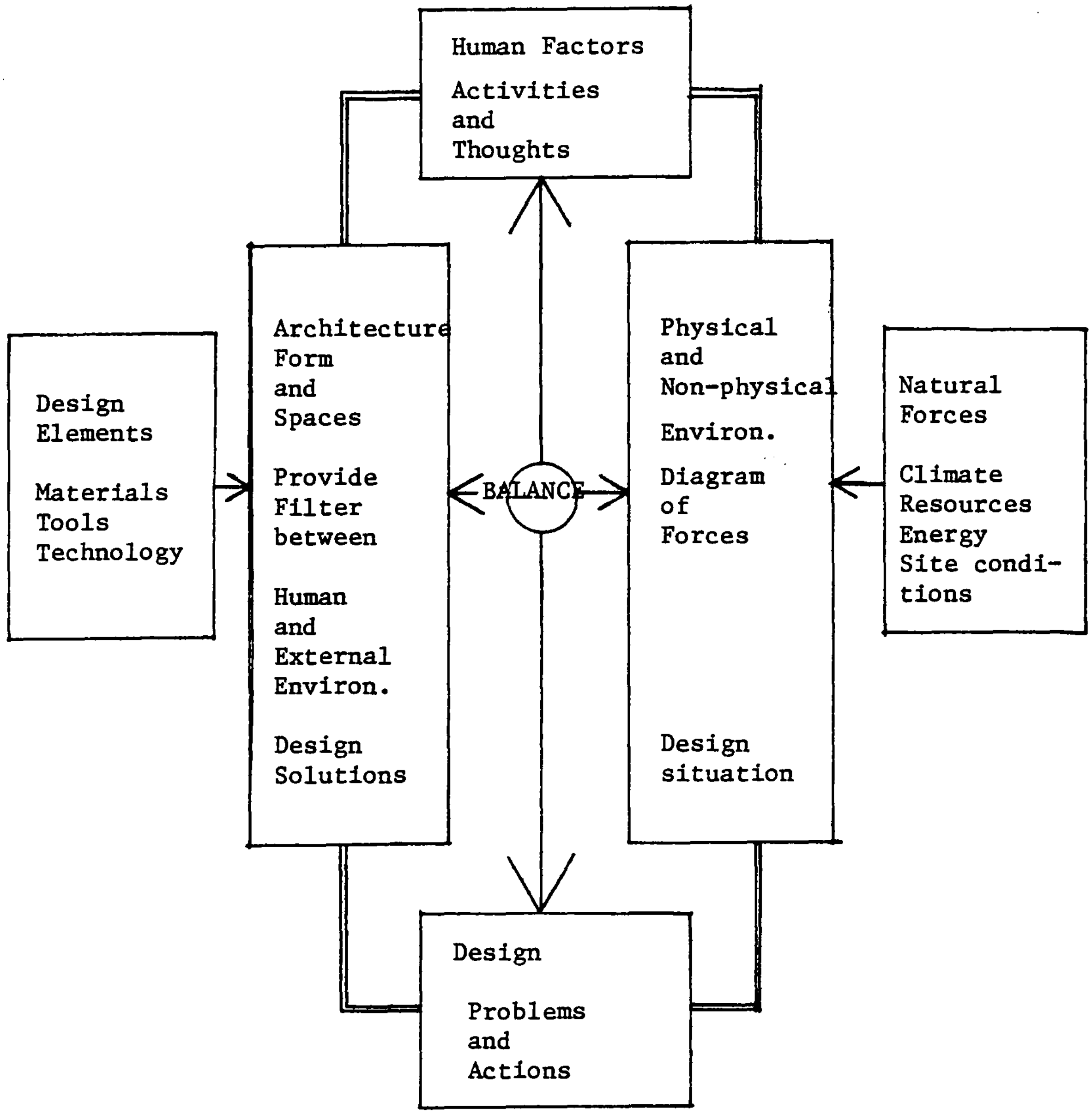


Figure 4. Environmental Interaction Diagram

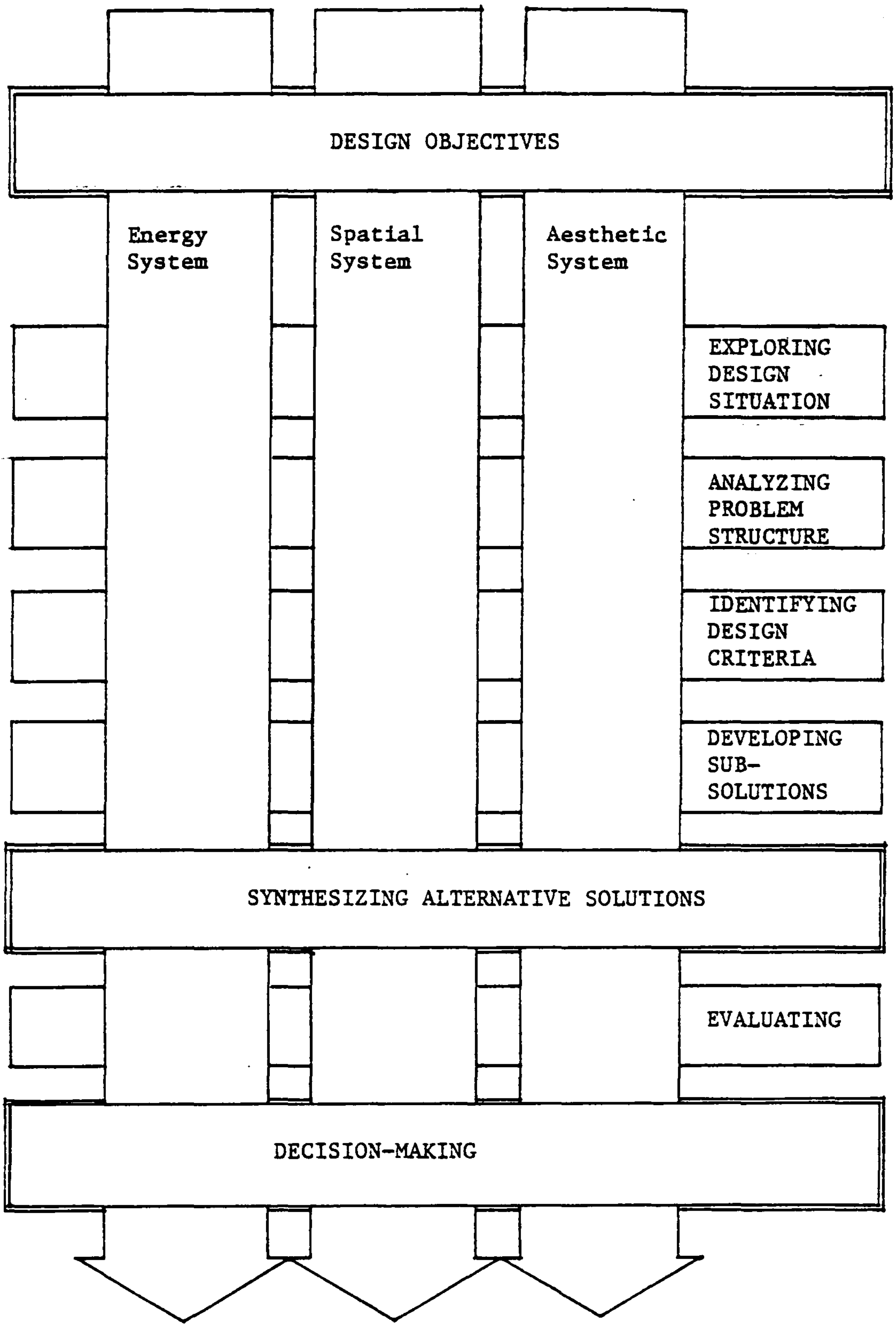


Figure 5. Systematic Approach of Energy Conscious Design

CHAPTER FOUR

DESCRIPTION OF THE METHOD

The previous chapter integrates energy factors with spatial and the visual environments to construct a systematic process of approaching energy problems. In this method, analyzing the problem structure and selecting solution play the critical parts in making energy factors to be design determinants. Nevertheless, each step of the method requires the designer's attention to the interaction among the three environments and contributes to an optimum solution. The following sections will discuss energy environment and its relation to architectural design through the systematic procedures.

4.0. Establishing Design Objectives

The overall objective of architectural design is a humanistic action of organizing architectural elements in order to provide appropriate environmental conditions for human activities. These conditions are determined by the four forces (activities, spatial standards, site conditions and resources). Design objective is to integrate these factors for maximum environmental performance with minimum means. The minimum means refers to both human and natural energy consumption. The trend of human civilization and technological innovation aims at using natural energy to replace human energy needs and to txtend the human ability to control environments. Western civilization proved that a large amount natural energy consumption provides great incentive for humans in growth of production and enjoyment of a high living standard. Unfortunately, most natural energy resources on which human civilization has depended are finite and non-renewable. Two ways of solving this problem are, first to lower the living standard and the rate of growth in order to decrease the use of energy; second, to utilized the infinite natural resources. The first action is almost impossible to carry out unless there are no other alternatives. Therefore, the second action should be the objective of human effort. Architectural design will consider the goal in two ways by decreasing building energy load and supplying building energy needs with renewable energy supplies. The plan is to reserve the present living standard with more efficient ways of using natural energy. These energy design objectives can be achieved through:

1. Decreasing the building energy load by
   a. increasing the solidity of the building envelope,
   b. avoiding the negative effects of natural forces,
   c. changing user life style,
   d. having more efficient building systems.
2. Supplying the building energy needs with renewable energy by
   a. utilizing solar energy, wind power, etc.,
   b. taking advantage of natural forces.

4.1. Exploring Design Situation

The three steps in design activities are: divergence, transformation and convergence. The exploring design situation is a stage of divergence. Christopher Jones gives a definition of this stage: [18]

> "The aim at this stage is to generate doubts, to pose the right questions, to discover what is critical and to test the sensitivity of sponsors, users and others to possible ways of dealing with the problems."

In other words, the activity in this stage is the discovery and accumulation of information connected with the problem: what in the community or personal value systems, products and component is susceptible to change, and what fixed points can be regarded as reference?

Bruce Archer also gives a good definition of this activity: "identifying the properties or conditions required by the objectives to be exhibited in the end result."[19] Any environmental force has both positive and negative effects on human activities. For instance, the sun and water provide the basic resources for human life, but too much precipitation or excessive solar radiation will cause damage and uncomfortable conditions. The activity of exploring design situation is to discover the effects of environmental forces on the available site. These effects will provide constraints and opportunities for design consideration.

In considering the energy problem, the environmental forces which contribute to building energy conservation are primarily the site conditions, climatic factors and human comfort.

1. Site conditions
   a. existing structures
   b. access to and on the site
   c. land slope and orientation
   d. landscape and vegetation
   e. geological condition

2. Climatic factors
   a. available solar radiation
   b. sun's path
   c. wind speed and wind velocity
   d. air temperature
   e. humidity

3. Human comfort
   a. human comfort standard
   b. life style
   c. activities

The items listed above are the independent variables which are not controlled by designers. These variables determine the properties of design problems and possible solutions.

I. The analysis of site conditions

A. The purpose of site analysis

It is to fully understand the site, the problem and the potential optimum solution. The activity of site analysis aims at the purpose of: [20]

1. Natural processes as form determinants

Architectural design decision largely depends on the interaction between natural forces and human factors. The potential form determinants such as materials, social factors and aesthetics have varying effects depending upon the specific place and time.

2. To understand natural constraints or barriers

The natural constraints or barriers of architectural design may be climate, geology, soil, vegetations. To arbitrarily destory or disrupt any part of the complex natural system without fully understanding it may be not only dangerous but inordinately expensive in a particular situation.

3. Cost and benefit analysis

The cost of proper initial planning at the appropriate stage may be less expensive than the remedial or retrofit activity needed to correct the oversight for lack of adquate preliminary analysis.

4. Site selection, orientation and activity placement

Proper site and problem analysis will insure the right thing or the right activity will be placed eventually in the right location on a particular site.

5. Life cycle costing

Site analysis data could be a basis for life cycle costing analysis.

B. The process of site analysis

The importance of site analysis is not only to understand factors of form determinants but also to discover the opportunities for energy conservation. Various aspects which normally are studied in the site analysis and their relation to energy problems are as follows:

1. Existing structures around the site

   a. Shade from existing structures reduces solar gain.
   b. Reflection from adjacent buildings increases heat gain.
   c. Wind induced by adjacent buildings increases heat loss.
   d. Wind blocked by adjacent buildings reduces heat loss.

2. Access routes to and on the site

   The analysis of access routes includes,
   a. Adjacent streets for vehicular access to the site,
   b. Walkways for pedestrian access to or through the site.

3. Slope and orientation of the site

   Slope and orientation with the relation to solar insolation has an important effect on building heat gain and design of shading devices.

4. Topographic conditions

   a. The grade of slopes is associated with construction cost.
   b. Topographic conditions have effects on microclimatic condition.

5. Geological conditions

   The analysis of geological conditions includes:
   a. Depth and type of rock on the site,
   b. Unbuildable area on the site,
   c. Soils with engineering limitation unable to support structures,
   d. Soils with agricultural limitations unable to support vegetation.

6. Existing vegetations

   a. Size, variety and location of vegetation would impair solr collection.
   b. Building sites should provide for minimum disturbance of existing vegetation.

7. Water

   Water has higher specific heat than land and helps to moderate extreme temperature variations.

8. Natural cover or man-made surfaces

   a. Plants and grassy covers reduce temperature by absorption of insolation and cool by evaporation. It is generally found that the temperature over grass surface on sunny days is about 10 to 14 degrees cooler than that of exposed soil.
   b. Man-made surfaces tend to elevate temperature. For example, asphalt surfaces can reach 124°F in 98°F air temperature.

The appropriate way to integrate any building and its site is, first to analyze the site very carefully and then to place the building on the site with a minimum of disruption and greastest recognition and acceptance of the site's distinctive features. A good reference on site analysis, planning and energy conservation is the Environmental Design Press report Landscape Planning for Energy Conservation.

II. The analysis of climatic factors

Climatic analysis is not a stranger to the architectural profession. The methods and data have been fully investigated and applied in architectural and building mechanical designs. A few significant studies have been published since the 1930's. One is Dr. Paul Siple's House Beautiful Climate Control Project. It provides the macroclimatic information on thermal, solar, wind, precipitation and humidity analysis for architectural consideration. Another is Victory Olgyay's Design with Climate.

Olgyay was the first person to propose a systematic procedure to analyze climatic data in terms of architectural consideration. His method includes four steps:

1. Compilation of local climatic data, including temperature, wind, radiation and humidity.

2. Tabulation of climatic data on an annual basis and construction of a series of charts showing annual distribution of the climatic elements.

3. Plotting of the tabulated data on air temperature and humidity on bioclimatic chart.

4. Planning of design factors such as the building forms, orientation, location, size, shading of opening and glazed area, etc..

Energy conscious design needs to emphasize the climatic analysis and to examine each climatic factor in terms of its energy effects.

A. The process of climatic analysis

1. Available solar radiation

The solar radiation arriving at the earth's surface is a constant. Its mean value is 1.94 $cal/cm^2/min.$ which is equivalent to 420 Btu/ ft^2/hr.

The amount of solar radiation on site at ground is considerably less and varies with altitude.

1977 ASHRAE Handbook of Fundamentals, Table 26-22 provides information of solar intensity.

2. Solar angle

The solar incident angle on the site is related to the amount of solar nergy falling on the site and the design of shading devices for windows. There are many methods of calculating soalr angle. One is the "Shading Chart" developed by Kayess Enterprise Co.. Another is the "Solar Chart" by Libbey-Owens Ford Glass Co.. This information can be found in Aronin's book Climate and Architecture.

3. Sun path diagram

The sun's position with reference to the horizon is usually expressed by altitude and arimuth. The sun's path determines the design of shading devices and building orientation.

4. Other solar data

The other solar data which are associated with energy problems are "solar percentage" and "hours of possible sunshine". These data are the important factors in designing passive and active solar systems. The information can be found in the U.S. Weather Bureau's Local Climatological Data.

5. Ambient air temperature

The ambient air temperature determines the heating and cooling load. The concept of heating (or cooling) degree days is the sum of annual temperature differences on a base of 65 degrees. It is an important index of building mechanical design.

6. Wind

Wind is an important factor in increasing heat loss in winter and providing a cooling effect in summer. Wind velocity will increase the coefficiency of heat transmission of building materials. Therefore, during an underheated period, the design problem is how to block the cold wind, and during an overheated period, the design problem is how to utilize the prevailing wind for cooling.

7. Humidity and precipitation

Water vapour is continuously generated in an occupied building by breathing, perspiration, cooking and other habitation processes. Condensation happens on those surfaces where temperature is the lowest.

The relationship between the indoor and the outdoor vapour pressures depend on ventilation. It is directly associated with human comfort.

Moisture not only causes construction problems but also increases energy load by requiring energy to be consumed to humidify in winter and dehumidify in summer.

B. Climatic analysis and building design

Another significant study of climatic and architectural design was done by Givoni. He analyzed climatic effects in terms of building performance.[21] The major features of design which affect the response of a building to exposure to climatic elements are: (1) the quantity of solar radiation absorbed by and penetrating the building, (2) the air and surface temperature, (3) the air velocity and the vapor pressure. Through experiments, Givoni found some relationships between indoor climates and building envelope:[22]

1. The solar radiation absorbed in the wall can vary from 15 to 90%, depending on the absorptivity of the external surface.

2. Solar radiation penetrating through windows can be varied from 10 to 90% of incident radiation, depending on shading devices.

3. Indoor air temperature can vary, depending on the structure insulation such that:

    a. Indoor maximum air temperature is -20 to +20 degrees from outdoor temperature.
    b. Indoor minimum air temperature is 0 to +13 degrees from outdoor temperature.
    c. Indoor surface temperature is -12 to +50 degrees from outdoor temperature.

4. Average internal air speed varies from 15 to 60% of outdoor wind speed, depending on window openings.

5. Indoor vapor pressure is 0-7 mm hg above outdoor level.

6. Houses positioned at 45 degrees from the wind direction will reduce the wind velocity on the surface on 50%.

The design usually examines the climatic factors in terms of the most extreme physiological stress in order to induce the optimum solution. Givoni's analysis procedure is an example:

1. What are the optimum and minimum temperatures required for comfort, different age groups, activities, degree of acclimation and clothing habits?

2. What are the indoor conditions which should be considered as the threshold for the provision of heating under the conditions mentioned in step one?

3. What is the relationship between the outdoor conditions of temperature, wind and rain and indoor thermal conditions, for different types of buildings, taking into account the materials, windows area, orientation, external color, etc.?

4. What are the outdoor conditions under which the indoor conditions necessitating heating should be provided in a given type of building during the period and hours of its occupancy?

After answering these questions, a designer should plot several climatic elements, (suitability of ventilation, air temperature and vapour pressure) on a psychometric chart to gain a comprehensive idea of the design factors of climate.

III. The analysis of human comfort

"Experiments on animals in a variable-temperature tunnel at the John B. Pierce Foundation showed that animals prefer to stay at 70°F about midway between the points calling for maximum expenditure of energy in adjustment to the environment."[23]

The ideal air temperature for human beings varies by the change of vapour pressure, air movement and radiation. It ranges from 70 to 80 degrees which is about midway between the upper temperature limit (sunstroke) and the lower limit (the freezing point). The ideal comfort condition also differs slightly depending on variations in cultural and physical factors. For instance, the British ideal temperature with slightly air movement of 50 fpm or less, is 66.1 degrees in summer and 62.1 degrees in winter. The comfort zone for the British is between 50 to 70 degrees, but the comfort zone in the U.S. lies between 69 to 80 degrees, and in the tropics, it will rise to 76 to 85 degrees.[24]

For design purposes, the bioclimatic chart, which includes several climatic elements (air movement, grains of moisture, solar radiation and air temperature), will set a clear comfort condition for human activities.

4.2. Analyzing the problem structure

The stage of problem structure analysis is one of the most important parts of the method of energy conscious design. It determines the success of integrating energy factors as a design consideration. In the conventional design approach energy issues are seldom considered as a design problem or a source of solution. Usually, the creation of forms is based on the needs of human activities, spatial performance and aesthetic values. Energy plays a very insignificant role as a design determinant. The opportunities for conserving energy in building design primarily exist in the design consideration of arranging buildings to utilize natural energy and to avoid energy loss. This design concept cannot stand by itself without considering other factors. Integrating energy factors with spatial and visual factors at this stage determines the success of energy design.

Returning to the early discussion about the concept of form, Alexander considers that design is a matter of finding the fitness between form and context, where context is described in terms of forces.

The design problem is a matter of finding variables with fit or misfit between form and context. L. Bruce Archer also gives a nice difinition of the design problem. He suggests that human actions arise from the experience of discontent which exists when "there is a discrepancy between a condition as it is and the condition as he would like it to be."[25] A design problem exists when "the action appropriate to the correction of a particular unsatisfactory condition is not apparent."[26]

According to Archer's definition, the design problem is composed of the human experience of unsatisfactory condition, the intention to correct this condition and the ambiguity of approapriate action to make this correction. Therefore, problem structure is associated with values, existing conditions and objectives.

The nature of the problem plays a critical part in determining the design solution. The purpose of problem structure analysis is to identify the design elements and characteristics of problems and to establish their relationships.It is a stage of translating the physical and abstract concepts into architectural terminology. The design problem has two sources. One is the client's statement of intention. The other is the designer's judgement about the discrepancy between the existing situation and the activities whcih users want to perform.

Alexander says, "We sometimes forget how deeply the nature of an object is determined by the nature of its components."[27] He believes that once one decides the components of an object, there are very few essential changes one can make. Therefore, in constructing a design problem, one most analyze all the components existing and designed.

There are two kinds of components in architectural design. The first are independent variables which are not controlled by the designer. They determine the design situation. The other are the controllable variables which can be changed and manipulated by the designer and contribute to the composition of new conditions. These components which will provide the opportunities for design solution are the basis of problem structure. The variables which are associated with energy problems are:

1. Variables for design planning and programming.
2. Variables for design concept.
3. Variables for constructing buildings.
4. Variables for utilizing solar energy.

I. Variables for design planning and programming in energy design

A. Users' life style

The relationship between lifestyle and energy consumption is best observed in the occupancy of buildings and rooms within buildings. A residential building usually has more rooms than the number of occupants. Some of the spaces may be only used once in a while during the day, such as bedrooms, bathrooms, study rooms, etc.. It is wasteful to heat or air-condition them all the time. By using a time-room table (Fig.6) to find out the occupancy schedule, a designer can establish a system of relationships or organization among them. This schedule can be transformed into space zoning or organization which will affect the maintenance program and energy load. The second intention of studying lifestyle is to discover

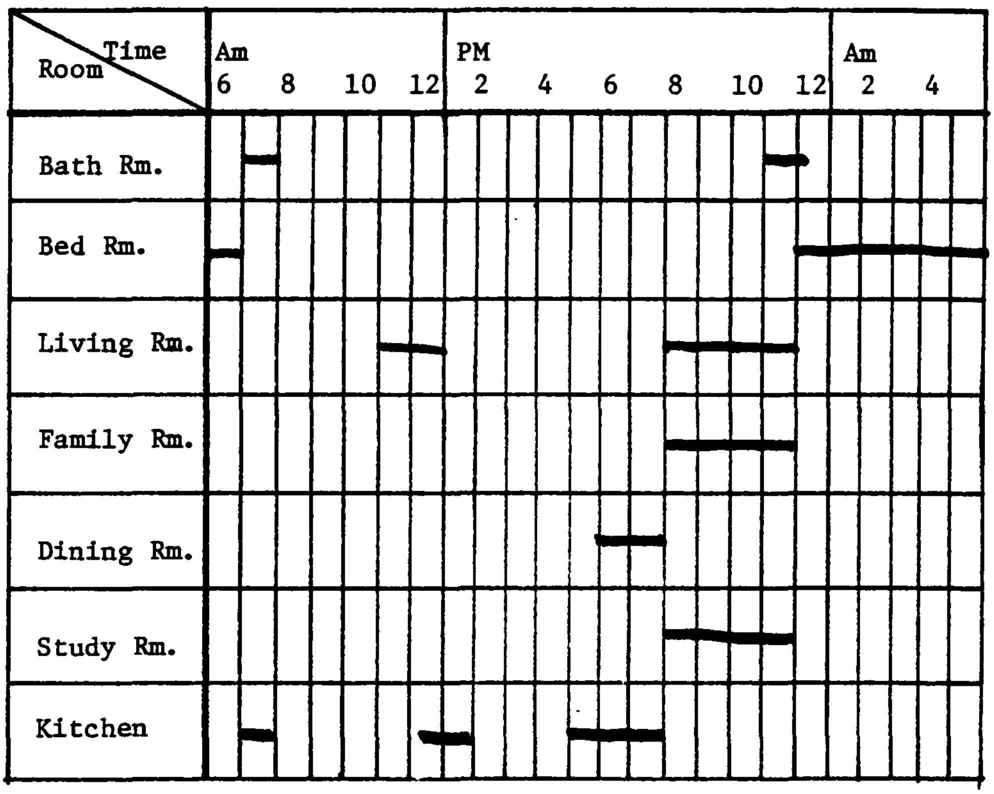


Figure 6. Time-Room Table

the possibility of decreasing the building size and volume using multi-use spaces.

B. Space quantity and quality analysis

The space standard is a major factor that affects energy consumption. The standard varies with activities and users' ages and habits. Carefully considering these backgrounds before design can have a major effect on saving energy. Many examples of poor design can be found around us, such as the War Memorial Gymnasium at Virginia Tech, designed with mechanical conditioning. The function of a gymnasium is to provide for high and intensive activities, requiring high air movement and low vapour pressures. The conditions of the War Memorial Gymnasium show poor response to these requirements. And it wastefully consumes energy to maintain comfort conditions. These shortcomings can be avoided if we have the understanding about proper spatial conditions for designated activities and the attitude of using natural energy for maintenance.

II. Variables for design concept and energy consideration

The variables which are associated with energy in the design stage are:

A. Site planning

The purposes of site planning are to give form to the basic design concepts which are appropriate to optimum human use and enjoyment and to utilization of natural forces on the site. These purposes can be achieved through the site planning process of location of functions and building elements.

The basic functions of residential sites are residential units, access, service, storage, recreation, outdoor living, circulation and solar radiation devices. In site planning the activities are to organize these functions to take place on specific sites and to show the relationship, the interaction and the location of each of these functions.

The typical site planning elements are paving, vegetation, fences, walls and canopies. The placement of these on the site should be planned so as to provide the optimum relationships and more climatic control. The basic concept of the site planning for energy conservation is to manipulate the sun and other climatic factors through site design decisions. Site design includes two considerations. One is to use the characteristics of land form and land materials. The moving of earth to increase, decrease or direct climatic factors is probably the least expensive method of site manipulation. Early in the site design phase, careful calculation on where and how to move and adjust the earth should be made. The topogeaphy and orientation of an earth form determines the amount of solar radiation and air movement. The other is to use and select vegetation. The placement of vegetation is used for solar and wind control.

Site design is not only for energy conservation but also for aesthetic and spatial quality. For instance, site elements can articulate space, enhance visual focus and provide privacy control.

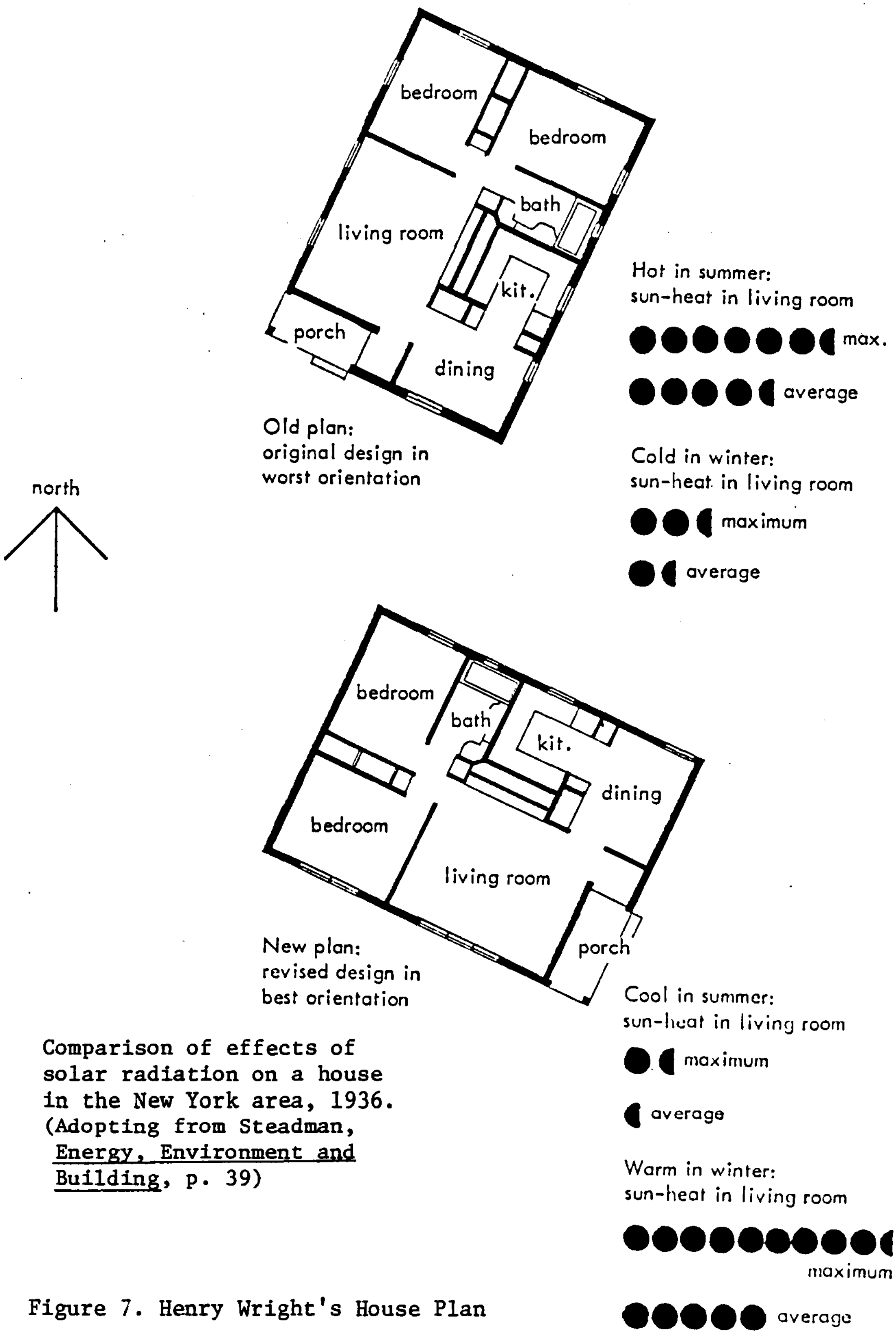
Detailed information about site planning and energy conservation can be found in the book Landscape Planning for Energy Conservation, edited by Environmental Design Press.

B. Building orientation

Building orientation is one of the most effective factors of energy conservation in design. The typical consideration in building orientation are aesthetic values and views, access route, topography, source of noise, solar radiation, the sun's path and wind direction. By orienting building and outdoor activities in certain directions, it is possible to maximize the effects impacted by both sun and wind to raise or lower the temperature or humidity and thus to provide comfort levels naturally, and decrease the use and dependence on energy to artificially heat or cool buildings.

The relative importance and need for added solar radiation and the heat provided by the sun will vary from region to region and from season to season. In a cold region or season, additional solar radiation will be welcomed and needed. The information about the optimum orientation for various building configurations in each of the four climatic region of the United States can be found in the book, Landscape Planning for Energy Conservation.

Henry Wright did a study of the orientation and planning of housing in the New York area in relation to solar radiation in 1936.[28] He recommended that most of the important rooms and large windows be placed on the south and south-west to take advantage of winter sun and that a minimum of windows be introduced on the west-northwest end. A diagram from Wright's report illustrates the vices and virtues of two "before and after" situations where the same plan is turned through 180 degrees to give the optimum orientation which wright recommended. (Fig. 7)



Comparison of effects of
solar radiation on a house
in the New York area, 1936.
(Adopting from Steadman,
Energy, Environment and
Building, p. 39)

Figure 7. Henry Wright's House Plan

For the theoretical study of orientation and design consideration, one can refer to Knowles' book, Energy and Form. Detailed information on building orientation in relation to energy conservation can be found through the books Design with Climate and Man, Climate and Architecture.

C. Space organization

The Space organization decision is one of the most important phases in architectural design. The conventional design consideration of space organization is based on the location of activities and building performance. Space organization is associated with energy conservation in four ways: multi-use spaces, space zoning, buffer zones and air movement.

To combine several functional spaces together will decrease building size and energy load. Space zoning is the grouping of rooms which have the same occupancy schedule in zones. The prupose of zoning is to have separate mechanical systems and operations which will save unnecessary heating and cooling when spaces are not in use. Buffer zoning is the location of service and storage spaces properly in order to increase the building solidity. For example, to place these spaces at the north wall can reduce heat loss in winter, or to place them at the west end can reduce solar impact in summer.

Interior air movement is partially determined by space organization. Two causes of air movement are air pressure and thermal balance effect. Space organization should be carefully arranged in order to have a proper pattern of air movement to transport the heat from the heat source to the proper location. For instance, air movement is needed to move heat from a greenhouse or Tromb wall to the living room in the day and to the bedrooms during the night. Another function of air movement is to provide natural cooling in summer.

Detailed information about air movement and its thermal effect can be found in Givoni's book Man, Climate and Architecture.

D. Building configuration

Building shape and configuration have a direct relation to building energy consumption because the heat transmission through its envelope. Design problèms are considered in several ways. During an underheated period the objectives are to decrease heat loss by minimizing the building surface area and to to increase solar heat gain by maximizing the south facing walls or openings. During an overheated period the need is to decrease solar heat gain by minimizing the sun impact surface.

The climatic factors to consider in determining an optimum shape are solar radiation and wind effect. Based on the solar impact, Olgyay developed the optimum shapes of houses for different climatic regions. His criteria of optimum shape are stated as such: "the rule of the optimum shape is that which loses the minimum amount of outgoing Btu in winter, and accepts the least amount of incoming Btu in summer."[29] The detailed information of it can refer to Olgyay's book, Design with Climate.

E. Underground structure

Energy is wasted by unwanted heating or cooling of the surrounding environment. The major heat loss or gain by a structure occurs in two ways, infiltration and heat transmission. The underground structure can reduce greatly or eliminate infiltration and also reduce heat transmission through the soil insulation effect. At a depth, soil temperatures respond only to seasonal changes and the changes occur after a long time delay. Fig. 8 shows how the amplitude of the mean temperature fluctuation decreases rapidly with depth.[30]

From a real experience of an underground office structure in New Jersy, designed by Malcolm Wells, the peak soil temperature fluctuation is three months after the peak air temperature fluctuation. Therefore, when the winter's coldest temperature hit the underground structure, it will have almost no effect in the spring.

In another experiment, a practical house was modified to place the second floor activities on the lower level which is six feet below ground. It can save energy of 23.1% of the total. If basement construction is not practical, earth can be bermed up to the height of conventional window sills. In this case 13.1% of energy can be saved.

There are some problems with underground struture. The psychological impact of the absence of a view and construction problems related to geology and underground water conditions are the drawbacks. A few studies have proved that psychological impact is insignificant in many situations such as libraries, museums, classrooms, laboratories, etc.. Designers should be encouraged to consider underground construction as an important design solution of energy conservation.

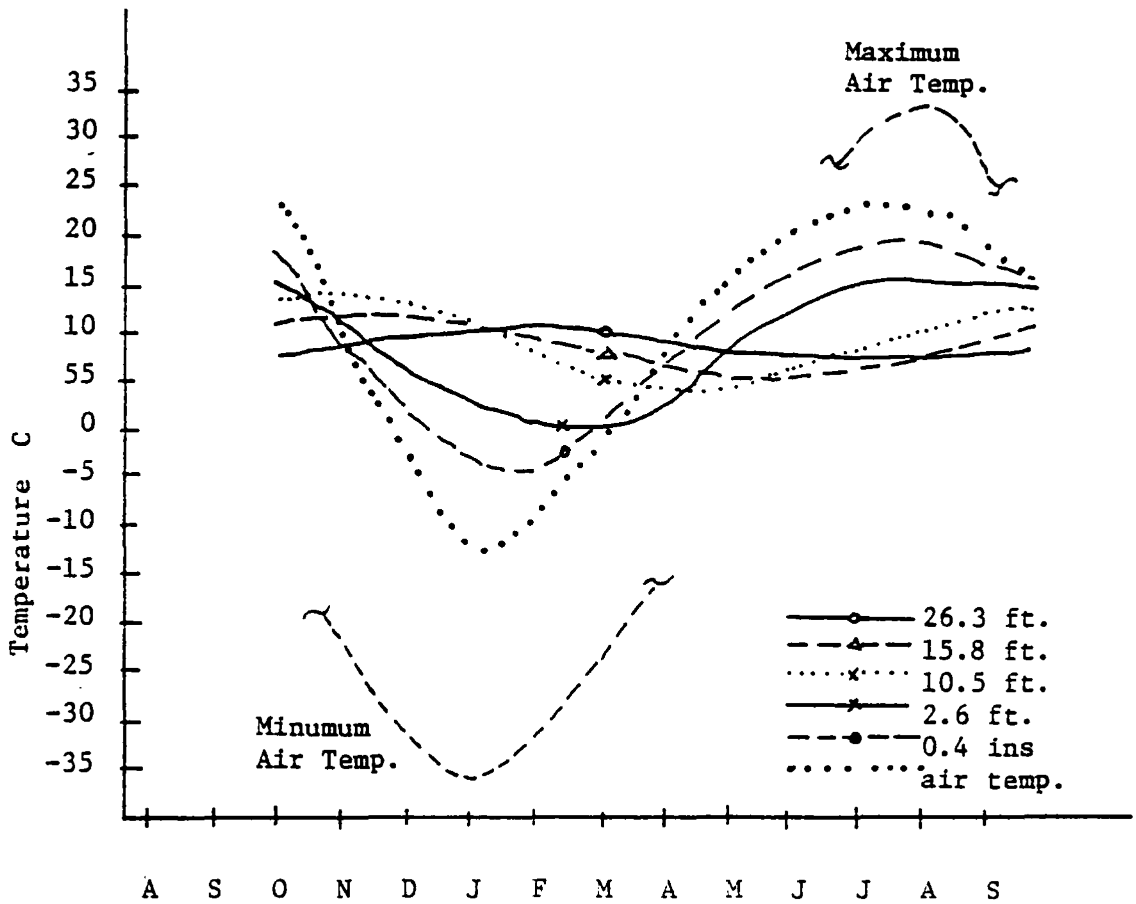


Figure 8. Average monthly temperature variation with soil depth near St. Paul, Minnesota (Data from Reference 30)

F. Building compactness

> " It has always been a matter of architectural faith that the compactness of buildings relates in a general way to initial cost and to a number of other variables such as ease of maintenance, running costs, length of service runs and convenience of circulation. Hence it is believed that all other things being equal, a compact plan is a better solution than a sprawling one." 31

Two simple methods[32] of examining the compactness of buildings have been developed by the Building Performance Research Unit of University of Stratheclyde. One is the ratio between the total useful area and the perimeter. The other is the ratio of mass compactness (the ratio between the area of the curved surface of a hemisphere of volume equal to the volume of the building and the area of the external skin of the building.) These ratios have direct effects on construction cost and energy consumption. Figure 11 shows a theoretical relationship of energy cost and ration of mass compactness.

III. Variables of constructing buildings

The variables of composing a building or buildings which have relation to energy conservation are:

A. Roof and ceiling

The thermal effects of roofs are determined by color, finishes, materials, location of insulation layer, ventilation and protecting devices. Heat transmission through the roof causes both cooling and heating load. In the summer, the heat absorbed by a roof surface works down toward the deck. Indoor heat in winter seeks to flow outward. The method of solving these problems should depend on the climatic conditions. If the summer heat is a big burden, the roof construction will be emphasized in protecting against excessive heat by,

1. reflection of solar radiation by white washing,
2. increase in thermal resistance by layer of insulation materials.
3. shading provided by wooden boards placed one inch above roof surface,
4. cooling by water pond or sprayed roof,
5. combination of those methods.

To protect heat loss in winter, the roof structure will need good insulation and massive materials. The importance of roof design is not only the construction solutions discussed, but also integrating of roofs with passive or active solar design to utilize solar energy efficiently. The basic principles of passive solar design will be discussed in the latter sections.

Ceilings have great effect on the thermal performance of roofs, depending on whether ceilings creat an enclosed air space or a ventilated air space. When the same space is vented to the outdoor air, the ceiling becomes the principal barrier to heat gain and loss. The effect of roof deck can be substantially discounted. The advantage of vented ceiling is to reduce or prevent condensation.

B. Walls

The thermal performance of walls depends on orientation, surface color, thermal resistance and massiveness of the materials and shading devices. To solve the problem of excessive heat, the principle of the air-cooled wall is useful. That is a reduction of the solar heat load by shading and vigourous air movement.[32]

The effect of this design is to reduce the heat gain by shading devices and to creat a chimney effect that tends to keep the temperature on the surface of the wall down to the outside air temperature. Although the sun's heat has less effect on the walls than on the roof (because of the briefer impact of the sun), the wall are important in collecting and storing solar heat in passive design. An example is the Tromb wall which is a wall using massive materials to store solar heat.

Walls are also an important building element that determines spatial and visual qualities. For instance, the invention of curtain wall panels is one of the important features of modern architecture. The size and shape and the arrangement of walls are the major factors in design creation. The ratio of opaque walls to openings is not only relevant to energy consumption but also associated with human psychological effect and aesthetics. The careful consideration of the interrelationship among energy factors, human behaviors and aesthetic values in wall design is an important problem.

C. Windows and glass

The amount of glass area in the building is the most important factor affecting energy conservation. The use of glass and the ratio of glass to opaque wall area in a building has risen dramatically in the age of modern architecture. This trend of using glass, however, makes many of today's windows be mere architectural statements and have little to do with visual requirements or even comfort.[33] "There has been little substantial research on how much and what kinds of glazing are most comfortable but we know that huge expanses of windows donot necessarily improve a room."[34]

Window glass and clear plate glass have very low values of thermal resistance and are almost completely transparent to heat radiation from the sun. Therefore, both heat loss and solar heat gain are the important thermal effects of windows. The extent, type, size, location and orientation of windows determine the transmission of natural light, the design of solar control and amount of heat transmission.

The design problem of the window depends on the design situation: the need of view, lighting and comfort. For energy conservation, the window design should be considered to be a passive soalr device that provides heating in winter and cooling in summer.

The glazing material has an effect on thermal performance of windows. Several types of glass are relevent to energy conservation:

1. Tinted glass is often used to reduce light levels and glare in a building and also can reduce solar transmission.

2. Heat absorbing glass can absorb as much as 45 percent of solar energy. Combined with exterior shading devices, it can reduce solar heat load by 75 percent.

3. Reflective metallic coatings can block any amount of solar heat and light and can increase glass thermal resistance by 26 percent.

4. Double and triple glass can effectively reduce thermal transmission. The thermal resistance of double or triple paned glass is a function of the gap of an insulating air space between them. The thermal performance of glazing is also a function of wind velocity.

Detailed informance on windows and glazing can be found in the book, Energy Conservation and Window Systems, by S. Berman.

D. Solar control

Shading device can effectively reduce solar heat load. They can be divided into two categories: man-made elements such as rooler shade, venetian blind, canvas, overhang, eggcrate (Detailed information can be found in Olgyay's book, Solar Control and Shading Devices, Princeton University), and natural elements such as deciduous and conifer trees (Refers to the book Landscape Planning for Energy Conservation). A method of solar control design developed by Olgyay employs the following procedure:

1. Define the time when shading is needed,
2. Determine the position of the sun when shading is needed,
3. Determine the type and position of a shading device for overheated period,
4. Evaluate the shading device.

E. Ceiling height

Reducing ceiling height has effects both on economy and energy conservation. It permits economy in materials and increase the number of stories in multi-story buildings. The thermal effect on the variation of ceiling height is not significant. At a ceiling temperature of 95 degrees, a four foot reduction in height results in a radiation load increase of 8 Btu/hr or a 2% increase in the overall cooling requirements. But the reduction of height can save a great deal of construction cost and decrease energy load.[35]

The conventional concept about ceiling height is associated with psychological effects, ventilation need and lighting levels. But in South Africa, Richards' theoretical analysis of the factors affecting the determination of ceiling height proved these factors to be insignificant.[36]

1. Adquate overhead clearance in standing position only requires eight feet height.

2. Persons easily become adjusted to a new environment with an initial period of psychological discomfort.

3. The determining factor in natural lighting is the design of window which is not affected by ceiling height.

4. Lowering the ceiling would have very little effect on acoustics.

5. Ventilation is governed by the design of the openings.

This experiemnt suggests that a lower ceiling is acceptable, but the determination of ceiling height is a complex design problem involving social, behavioral and cultural considerations.

F. Material

The selection of building materials affects the building's thermal performance. Two thermal characteristics should be considered in choice of materials. One is thermal resistance and the other is heat capacity. Considering the thermal resistance, there are three types of "insulators". First, air spaces are formed between structural components. Second, surface insulators are primarily intended for use over the surfaces of structure such as coating, fabricated panels, light-weight aggregated concretes and calcium silicate. And third, internal insulators are designed to partially or wholly fill air spaces formed between structural components such as insulation batts, blankets, formglass, fiberglass. Another property of any material is its heat capacity. It is an important characteristic when considering passive solar design.

G. Infiltration and ventilation

Infiltration is one of the major factors in heat loss. With poor fitted windows, infiltration through window cracks can be as much as 100 cubic feet per foot of crack per hour. And a well weather-stripped wood window admits only 25 cubic feet per foot crack per hour. Good weather-stripping can save heat loss up to more than 10% of the total heat load.

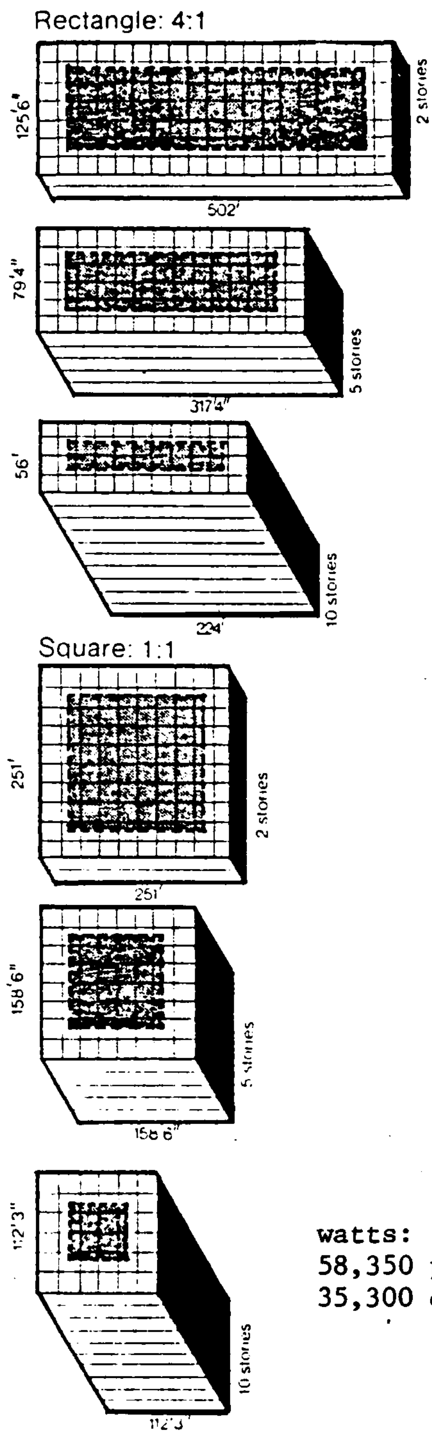
Ventialtion is a benefit for summer cooling, evaporating moisture and providing fresh air. The two basic types of ventilation systems are natural and mechanical. The former is appropriate in small buildings and in houses. Design for natural ventilation must consider several factors: the building site, orientation, internal space organization, window design, etc..

H. Lighting

The two kinds of lighting systems are natural and artificial. Natural lighting design is an important factor of aesthetic and comfort achievements. Large window area is not necessary for these qualities and is contrary to the principles of energy conservation.

The amount of natural light available to building users depends on the site condition, the size and location of the windows and skylights, shape of the building (Fig.9) the position, shape and color of interior partitions, ceiling, floors and furnishings.

Artificial lighting systems consume large amounts of energy. The present standard of lighting is too high and wastes energy. Just reducing foot-candel levels by one-third can reduce the energy



Watts:
35,650 p.
180,304 c.

watts:
5,000 p.
121,740 c.

watts:
75,000 p.
100,000 c.

watts:
28,320 p.
195,360 c.

watts:
43,440 p.
165,120 c.

watts:
58,350 p.
35,300 c.

Assumptions:

126,000 sq. ft.
15 ft. wide Perim.
1 watt/sq. ft. in Perim.
2 watt/sq. ft. in Core

Figure 9. Building Shape and Lighting Analysis (Adopting from A.I.A. Energy Conservation in Building Design p. 89)

consumption of lighting system by as much as 90 percent.[37]

The opportunities for saving energy in lighting design are through:

1. Using high-efficient lamps such as fluorescent lamps,
2. Designing lighting for the task and not for whole room,
3. Separating switching systems.

IV. Solar architectural design

No matter how tight the building envelope is, the heat flow from building cannot be stopped. To maintain a comfort condition requires energy supply. Energy conscious design is different from conventional design in that it utilizes natural energy for supporting building energy needs. Solar architectural design can be divided into three types: active system, passive system and hybrid. The active system requires mechanical devices such as collectors, pumps and pipe systems. The passive system involves designing structure itself as a solar heat collector and storage by using proper materials and placing them at proper locations. The basic principles of passive solar design are to use high heat capacity materials to collect and store soalr energy and to use proper ventilation to transport heat to warm spaces. The entire building or various elements of the building (walls, roofs and windows) will be used as solar components. Because the concept can serve various purposes, (visibility, ventilation, natural illumination as well as heat collection) they become most valuable in building design. Passive solar design involves several design features such as:

A. For passive solar heating:

green house, solar pond, tromb wall, massive floors,

ceiling, solar windows, etc.

B. For passive solar cooling

solar chimney, massive roofs and walls, solar pond, etc.

The greenhouse serves as a secondary skin, effectively raising the temperature in the winter and lowering in the summer (if plants and shading devices are properly used) and as a passive solar collector. The design of a greenhouse should notice several rules:[38]

1. A south facing greenhouse makes the best passive solar collector.
2. The wall between the greenhouse and the residential spaces must be insulated to control heat flow and to prevent overheating.
3. Wall surfaces directly exposed to the sun should be dark-coloured.
4. Insulated shutters allow the greenhouse to retain the heat collected after the sun has gone down.
5. The distance from the exterior wall of the greenhouse to another object on the landscape should be at least 2½ times the height of the wall.

A solar pond can provide both effects of heating and coolign. The arrangement of a solar pond to be integral with the building structure would be an interesting design solution.

The tromb wall and massive roofs, floors and ceilings are based on the principle of using high heat capacity materials to collect and store solar heat. A carefully designed vantilation system can transport heat from them and effectively warm the building. When using windows as solar collectors, it is necessary to calculate the heat gain and loss through windows and to provide insulation devices to have efficient performance.

A solar chimeny increases ventilstion for cooling in the summer, because air movement follows the thermal rule (Refers to Givoni's book Man, Climate and Architecture, ch.13)

V. Energy problems and other environmental factors

The approach to energy problems should not ignore other environmental factors, spatial performance or aesthetic values. Spatial performance is associated with physical conditions of spaces and space size and shape. These factors have relation to energy and visual environments. The optimum spatial performance is "that which permits the designated activities to be carried out with maximum facility and with the minimum consumption of resources."[39] The integrating of energy factors with spatial performance is necessary to achieve this optimum solution.

Appropriate arrangements of building elements to compensate natural factors is often an acceptible criterion for aesthetic value. Therefore, energy design doesn't conflict with aesthetics. Many masterpieces of architectural design possess great aesthetic achievement by reason of their proper response to natural forces.

The construction of a design problem needs to consider of three environmental subsystems simultaneously. For example, if a designer plans to apply a tromb wall in his design to collect soalr heat, then several questions arise:

A. About energy:

1. What is the optimum orientation of the tromb wall?

2. Where is the proper location to place it?

3. What is the relationship among tromb wall, windows and the building structure?

4. What is the capacity of heating that can be supplied by it?

5. What should be the pattern of ventilation in order to transport the heat?

B. About spatial performance:

1. Does the tromb wall block the view?

2. Does it affect activity?

C. About aesthetic values:

1. How is the outlook and its relation to the building?

2. How can the shape and size be improved that can have better "form"?

3. Is there any other solution which can have the same thermal effect but better "form"?

By asking such questions, design concepts would be generated which would integrate energy factors into design solutions.

4.3. Developing Energy Design Criteria

Malcolm Wells of New Jersey, an architect and conservationist, developed a rating system for evaluating building performance and its effects against natural environments. There are fifteen items in his consideration. His rating gives a wilderness a 100 percent score on each item. Thus a wilderness scores a high total of 1500. He found that a typical modern building obtains a positive rate only on the item of 'provides human habitation' and its total score is minus 1025. A compatible design should at least rate a positive score.[40]

In considering energy conservation, a designer will be most interested in several of these criteria: use and storage of solar energy, human habitation, maintenance, natural resources and aesthetics. These criteria are associated with four design forces. For instance, the use and storage of solar energy and maintenance are relevant to energy, human habitation is associated with activity and spatial standards, and the rest can refer to the site conditions. Based on this concept, energy design criteria can be established:

A. The first criterion is the standard of spatial conditions.

U.S. General Service Administration has suggested a set of design criteria for office buildings. It is also useful for residential and commercial building design:

1. Humidity	20% in winter, 65% in summer
2. Temperature	68 degrees in winter, 78 degrees in summer
3. Air movement	refers to ASHRAE recommendation
4. Ventilation	5 cfm/capita
5. Illumination	desk tops 50 csi
	lounge 12-18 raw foot candles
	kitchen 50 raw foot candles
	toilet 20 raw foot candles

B. The second design criterion is the building structure standard.

The ASHRAE Standard 90-75, Energy Conservation in New Building Design, has suggested a standard of building structure in terms of insulation. As indicated in the document, this standrad is to provide design requirements which are directed toward the design of building envelope with adeguate thermal resistance, low air leakage and selection of mechanical, electrical, service and illumination systems and requirements which will improve utilization of energy in new building. The criteria of the ASHRAE Standard is a minimum requirement. Good energy design should go beyond that.

C. The third criterion is associated with solar energy design.

It is generally true that the sun provides more energy than we need. The only problem is how we can use it economically. This criterion is established with two categories: energy collection for underheated periods, and solar control during overheated periods.

D. The fourth criterion is the concept of energy budgets.

Energy budgets attempt to conserve energy in building by setting a specific amount of energy that a building would be permitted to consume. An advantage of this approach is that it permits great flexibility for how specific building material, components and subsystems are integrated into the final building. The largest task ahead with this concept is establishing the budgets since the energy consumption in a building is affected by many factors including building type, size, location and operating practices.[41] Two states, Ohio and California, have considered to adopte this concept in their legislations.

4.4. Investigating Sub-solutions

In the energy design method, one step ahead of synthesis of design alternatives is the investigation of sub-solutions. The problem of each of the three environments involved in design considerations have different characteristics. To fully understand them and to investigate sub-solutions is necessary to avoid oversight. The opportunities for energy conservation are based on several design consideration:

1. Orientation and siting,
2. Building shape,
3. Envelore design,
4. Solar control,
5. Radiation of glazed area and glazing material,
6. Exposure to the wind,
7. Thermal mass or earth roof,
8. Internal and external insulation,
9. Solar energy collection,
10. High-efficient building systems,
11. Natural lighting,
12, Multi-use occupancy,
13. Minimum requirements of spatial standard.

The following lists will provide some energy conservation opportunities for a residential building.

A. At the planning stage:

1. Several rooms grouped as a buffer and located at the north wall reduces heat loss.

2. Increased density of occupants reduces overall size of the building.

3. Lowering ceiling height reduces the exposed surface area and the enclosed volume.

4. Grouping spaces which have similiar function or occupancy schedule can provide easy control of building systems.

B. At the design stage:

1. Ponds, water fountains reduce ambient air temperature.

2. Shade walls and paved areas reduce indoor and outdoor temperature difference.

3. Utilize sloping site to partially bury building or use earth berms to reduce infiltration and heat transmission.

4. Select site that allows optimum orientation and configuration to minimize energy consumption.

5. Locate building on site to induce air flow.

6. Locate building to minimize wind effects on external surfaces.

7. Use tree for solar control and wind break.

8. Plan building configuration and wall arrangements to provide self-shading and wind break.

9. Locate entrance on downward from wind and provide wind break.

10. Orient building to have the greatest heat gain in the winter.

C. At the construction stage:

1. Use high insulation materials.

2. Avoid cracks and joints to reduce infiltration.

3. Provide textured finish to external surface to increase external film coefficiency.

4. Use proper colours for finishes.

5. Reduce infiltration by:
   reducing building height,
   using impermeable exterior surface material,
   providing good weather-stripping,
   providing wind break.

6. Improve window thermal performance by:
   Using double glazing and proper solar control devices,
   Using operable thermal shutters to decreas the heat loss.

4.5. A Systematic Process of Developing Alternative Solutions

The developing of alternative solutions is a stage of design creation. The creation usually can be achieved through four sources (or means) analogous, typological, pragmatic and syntactic design. These activities operate in designers' mind as "black box" or "glass box".[42] No matter how they operate, the careful analysis of the problem and the associated factors will enhance the design creation. The energy conscious design considers natural forces as equal important as huamn factors in the design approaches. As discussed in the previous sections, the natural forces include the site conditions and the climatic factors. They will determine the design problems, provide opportunities of design solutions and evaluate alternatives. These considerations will be proceeded parallel to the conventional design concerns of human factors and technological solutions. Figure 10 shows a general diagram of this approach. This method will provide a flexible application for the conventional designers in considering energy conservation. The critical parts of this approach, however, will be the analysis of problem structure and the developing alternative solutions. These steps integrate energy factors with other environmental considerations and creat an optimum solution.

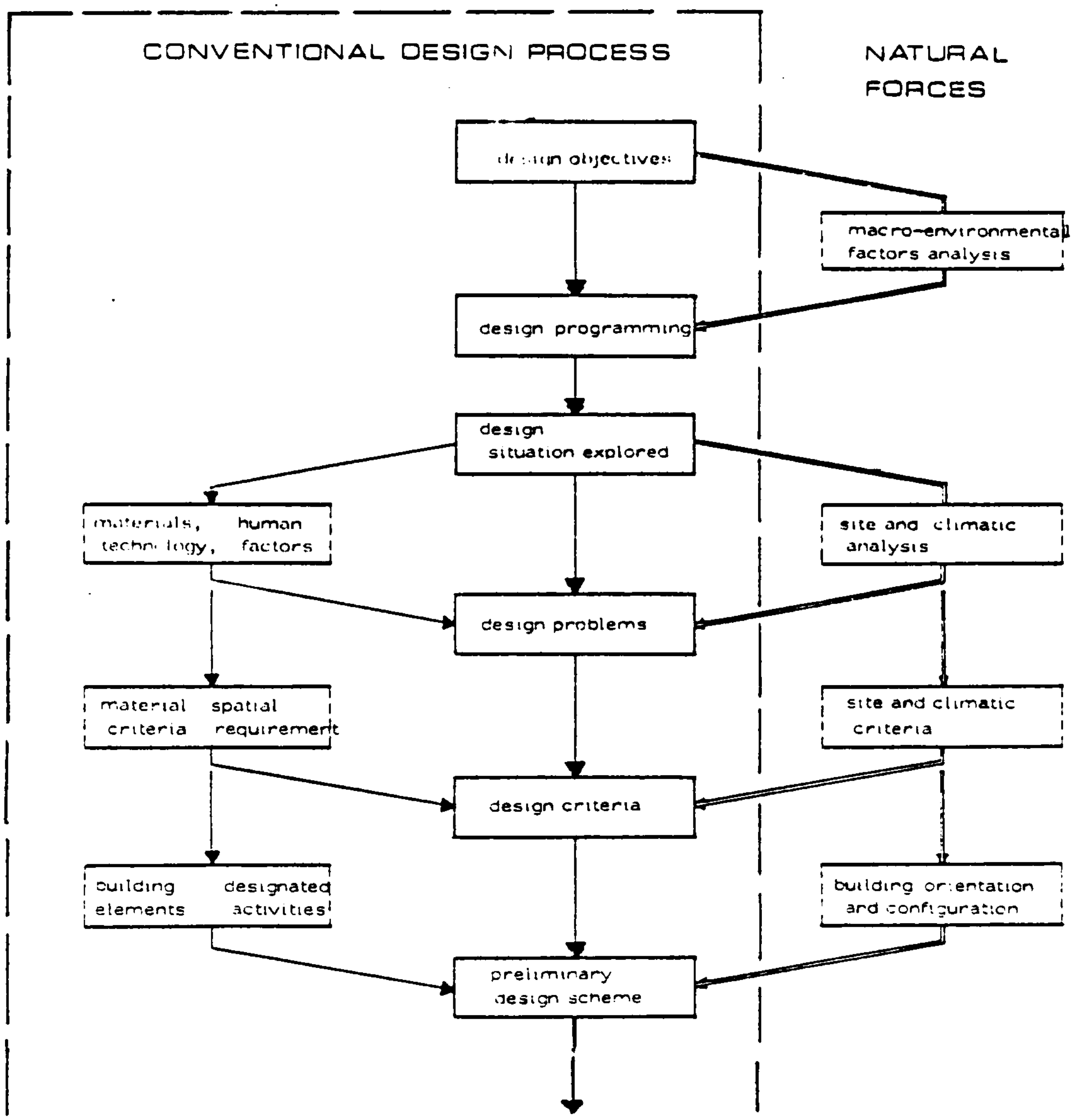


Figure 10. A Systematic Process of Developing Energy Solutions (Adopting from Prof. Robert Chiang, Christopher Gordon and Paul Kao, "Active Architecture")

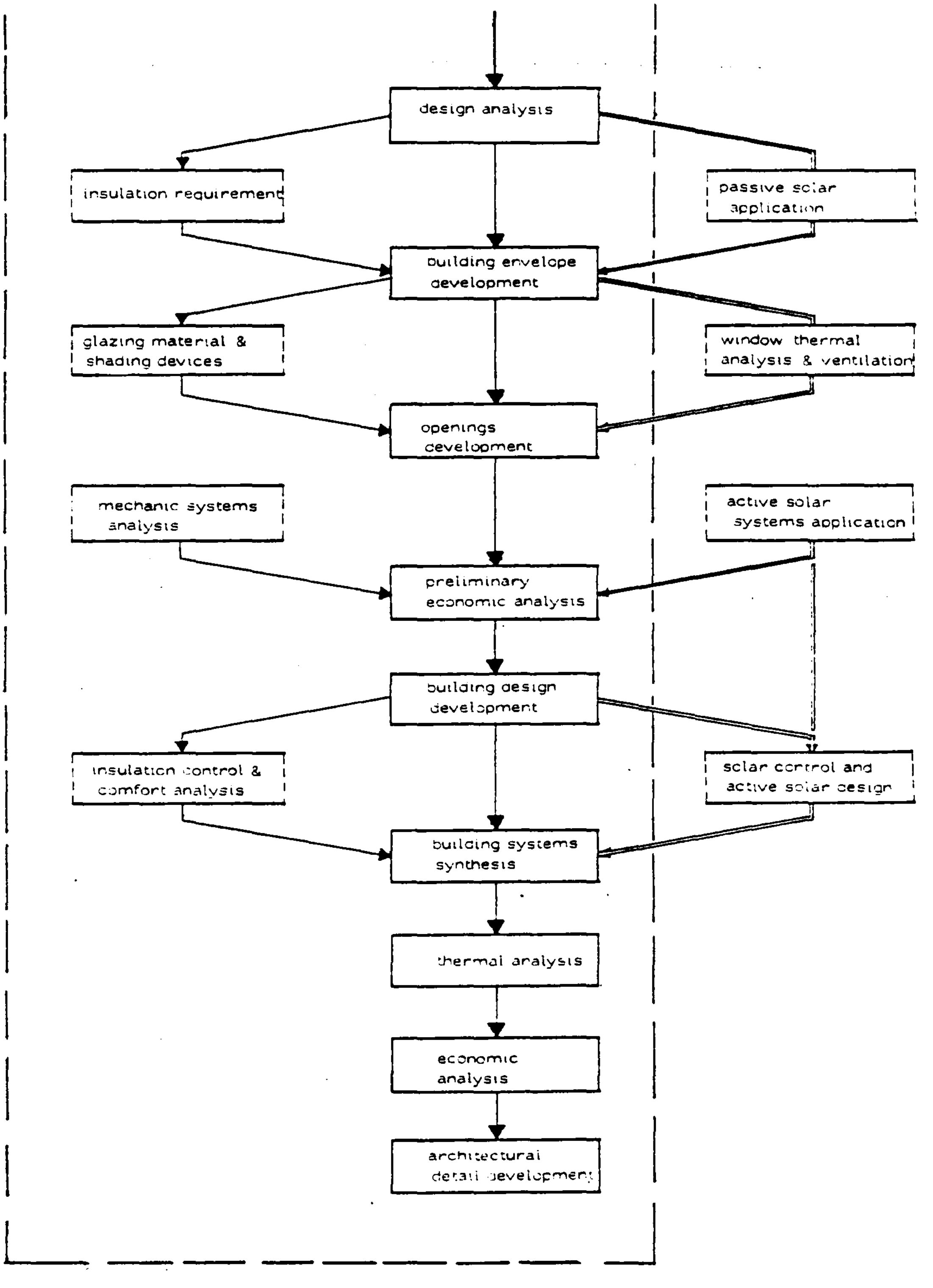


Figure 10. A systematic Process of Developing Energy Solutions (Adopting from Prof. Robert Chiang, Christopher Gordon and Paul Kao, "Active Architecture")

CHAPTER FIVE

EVALUATION OF ENERGY CONSCIOUS DESIGN

5.0. Evaluation and Decision-making

Designing can be viewed as a decision process.[43] It consists of two distinct phases:

1. The development of alternative solutions, and
2. The selection among them.

The former, which is composed of exploring the design situation, analyzing the design problem and developing alternative solutions, has been discussed in the previous chapter. These activities are the primary concerns in designing. However, each of them in turn involves a process of decision-making itself. The process of decision-making is similiar to the process of thinking. John Dewey proposed a five-step procedures of thinking:[44]

1. The occurrence of a difficulty,
2. Definition of the difficulty,
3. Occurrence of a suggested explanation or possible solution,
4. The rational elaboration of an idea,
5. Corroboration of an idea and formation of a concluding belief.

This process explains that every action involves a sequence of thinking and decision. Design activities are composed of several mental actions. Thus, a designer would already make a series of decisions in his mind before a solution is reached. Thus, he often neglected the need and the importance of the evaluation. Although this negligence wouldn't cause much difference in a simple action; the complexity of energy conscious design as is proposed in this thesis would require careful evaluation at all stages in order to achieve an optimum solution.

Barclay suggests that decision-making starts from the statement of the problem, converges through decision criteria and finally leads to a set of recommendations.[45] The establishment of decision criteria, which is critical for decision-making, has two sources: the probability and the desirability of the outcome.[46] The former is determined by the prediction system and the latter is dependent upon the value systems of the designer and the users. The significant features in decision-making are the data, predicting system, value system, criteria and recommendation.

The decision criteria of energy conscious design include three environmental factors: the energy, the spatial performance and the aesthetics. The energy criteria are based on the amount of building energy load. (See section 4.3.) The criteria of the spatial performance are associated with the quality and quantity of spaces and their organization. The aesthetic criteria are non-quantitative value and are often difficult to make an evaluation rationally on it.

5.1. Strategy of the Energy Evaluation

Before discussing the details of selecting from design alternatives based on these three criteria, it is necessary to understand how a designer approaches his problem. Generally, there are two modes of operation that are applied by an architectural designer in his problem-solving. The first type emphasizes the inside of the building envelope and its spatial performance. It primarily concerns itself with functional requirements and space organization, and is therefore called the 'functional appraoch.' This appraoch is ussually adopted in function oriented design problems such as hospital design or industrial buildings. The second mode is called 'environmental approach', which incorporates the environmental factors and their effects on architectural arrangements in the design process. It is ususlly applied to an urban development which has close relationship with its surroundings or a site with a distinct characteristic such as waterfall or steep slope.

Typological and pragmatic designs are associated with the functional appraoch. Analogous and syntactic design are a part of the environmental approach. These activities can be percieved as the actions of the dynamic balance between human activities and the environments. Each of them however, has different emphasis and concerns.

Thomas W. Maver proposes a decision-making mechanism which is based on the interaction between activity system and environmental system, and which also takes account of the analysis of cost and benefit.[47] This evaluation model follows "a series of simultaneous evaluation" of spatial performance and cost of maintenance. Maver considers that design synthesis is based on users requirements; evaluation can thus be approached in terms of performance and cost. The former may include the variety of activity and space standards for these activities while the latter is comprised of the cost of construction and maintenance.

Since both the change of the mode of design approach and the means of design creation dictate different concerns, the strategy of design evaluation may also be varied. For example, the analogous design might consider the building form and aesthetic value as a major factor of decision-making. Nevertheless, Maver's two evaluation criteria, i.e., performance and cost, should be considered in any design situation.

The cost of maintenance which also means the need of energy supply, is an important basis of energy evaluation. An evaluation program of energy design needs to analyze the aesthetic criteria and the spatial performance in terms of energy load.

5.2. Existing Programs of the Energy Evaluation

Several methods have been designed as an aid in the evaluation of building thermal performance. First, the "National Bureau of Standard Load Determination Program" (NBSLD) is capable of simulating the dynamic thermal behavior of a building. The input includes data on weather, building and operating schedule, and the output is in the form of a daily, weekly, monthly or yearly heat loss and gain, indoor temperature, and the relative humidity of each building space or zone.[48]

This program is capable of analyzing the theraml performance of each individual space and simulating different conditions of operating standard in terms of energy load. However, it is bassically an engineering approach to energy conservation. The engineering approach, searching for energy conservation solutions by mechanical means and construction methods, is not easy to apply by a designer in design evaluation.

The second energy evaluation program worth mentioning is the UWENSOL program which is developed at the University of Washington in Seattle.[49] This program is designed to help designer to evaluate the energy efficiencies of alternative building designs. It responses to a need for a simulation program that can analyze "the dynamic thermal response of building resulting from multiple and var heat production or the room to room heat transfer localized sources."[50] The UWENSOL has been used as a a project of mental health care facilities in the state of W. In this project, the program was applied to evaluate the design alte. natives in terms of energy load. The evaluation followed the following procedure:

1. To identify the thermal performance of alternatives by:
   a. establishing common materials for the building envelope,
   b. using similiar occupancy and equipment use schedule,
   c. maintaining a fixed air temperature of 75 degrees inside the buildings.

2. After identifying the best scheme in terms of thermal performance, then to further evaluate the building material of it to control heat flow by comparing the effects of variation of the thickness and quantity of the massiveness of envelope.

The UWENSOL has an advantage over the NBSLD in that it includes the 'Shapefactor'[51] in the evaluation of the thermal performance of design schemes and it provides designers the basis of comparing building shapes in terms of thermal effects. However, a design scheme of good thermal performance is not necessarily a laudable design solution judging from other criteria. The UWENSOL has a weakness that it would discard other alternatives without first comparing the environmental factors and their effects on thermal performance.

5.3. Suggestions for Energy Evaluation

A three-stage evaluation model incorporating the depth of the designer's concern in energy problems is outlined as a contribution to energy conscious environmental design.

I. The first stage is considered a mandatory requirement for any designer. As discussed in section 4.3., there is an increasing concern on the part of public and the legislature about the minimum standard of building insulation and energy load. The ASHRAE Standard 90-75 and the concept of energy budget have been adopted in the building codes of several states. These standards will be viewed as the threshold of design acceptibility and architectural design must fulfill these requirements. The method of design evaluation in this stage are:

1. The designer is required to calculate the U (or R) values of walls, roofs and floors in order to satisfy the insulation requirements of building codes (Refers to the ASHRAE Standard 90-75).
2. If legislation adopts the concept of energy budget, a designer is then required to estimate the building energy loads. This estimation can follow the conventional method of calculation heating and cooling load.

II. The second stage is the economic evaluation. The reduction of energy loads means also the reduction of the maintenance cost. The cost of maintenance is one of the design criteria of Maver's evaluation mechanism. Having had fulfilled the requirements of the first stage, it is appropriate to advance the analysis of energy load of design alternatives by conservation techniques. These energy load reduction techniques include the use of vegetation, window shading devices, insulation materials, earth berms, etc.. The analysis of cost-and-benefit and payback period will provide the designers with a frame of reference in the effectiveness of these features. Conventional thermal calculation methods are appropriate in this analysis.

III. The third stage is the evaluation of energy conscious design. The first two methods respect the conventional attitude of architectural design. They provide modifiers for conventional design solutions in order to improve energy efficiency. These methods however donot incorporate natural forces in the design synthesis involving primarily building performance and human factors. Energy conscious design involves active concern about natural forces. Its evaluation program therefore, should cover not only the building construction standards but also the environmental factors such as site conditions, human activities and aesthetic values. In order to achieve an effective evaluation program several characteristics have to be considered:

1. The program should be easily understood and communicated to non-technically trained designers.
2. It should be capable of analyzing the natural forces and their effects on building performance and energy conservation.
3. It should be capable of analyzing the spatial performance and aesthetic criteria in terms of their thermal effects.
4. It should be capable of analyzing the thermal effects of building components.

An apparent difficulty of this program is the establishment of appropriate relationships between energy consumption and the non-quantitative variables in the areas of human factors and aesthetic values.

Energy criteria can obviously be expressed in terms of quantity of energy required. Spatial performance involves the physical and non-physical elements such as the level of lighting, room temperature, humidity, the accomodated activities, the integration of social or cultural spaces and the potential of flexibility. The Building Performance Research Unit of the University of Strathclyde has suggested a concept of building compactness, (which is associated with space size and shape) as an index for evaluating spatial performance in terms of the costs of maintenance and construction. [52] This concept could be a possible solution in bridging the gap between energy criteria and building performance criteria.

The aesthetic criteria is by far the most difficult to evaluate in terms of energy design. However, the elements of aesthetic appreciation are the three dimensional form and its relationship with the total context. The building form can be analyzed in terms of building components such as roofs, walls and openings. The calcualtion of thermal effects of these components will certainly provide the designer a useful reference in making decisions about aesthetic value.

CHAPTER SIX

CONCLUSION

6.0. The Pre-technological Design Approach

The Industrial Revolution was the boundary between human attitudes toward the natural environments, "to adapt" or "to overcome". Before the modern technology was available to provide the convenient means for compensating the natural forces, the ancient builders had to carefully consider these forces and their effects on human habitation. The Eskimo Igloo, the Pueblo Indians' houses and the Japanese traditional house were the examples of human adaptation to natural. These design solutions were accomplished through designers' efforts of incorporating activities and thoughts of communities with natural environments. These actions maintained a harmony relationship between human and nature. Figure 11 shows a design approach of pre-technology .

6.1. The Post-technological Design Approach

The modern technology provides human beings with mechanical powers which extend human ability to control the natural environments. These powers broke the balanced relationship between human and the nature. The using of natural energy, however, not only improves the living standards but also extends the range of human activities. The amount of natural energy consumption has become an index of achievements of civilization. The higher energy consumption, the more progressive of civilization. This trend altered designers' concerns and attitudes about natural environ-

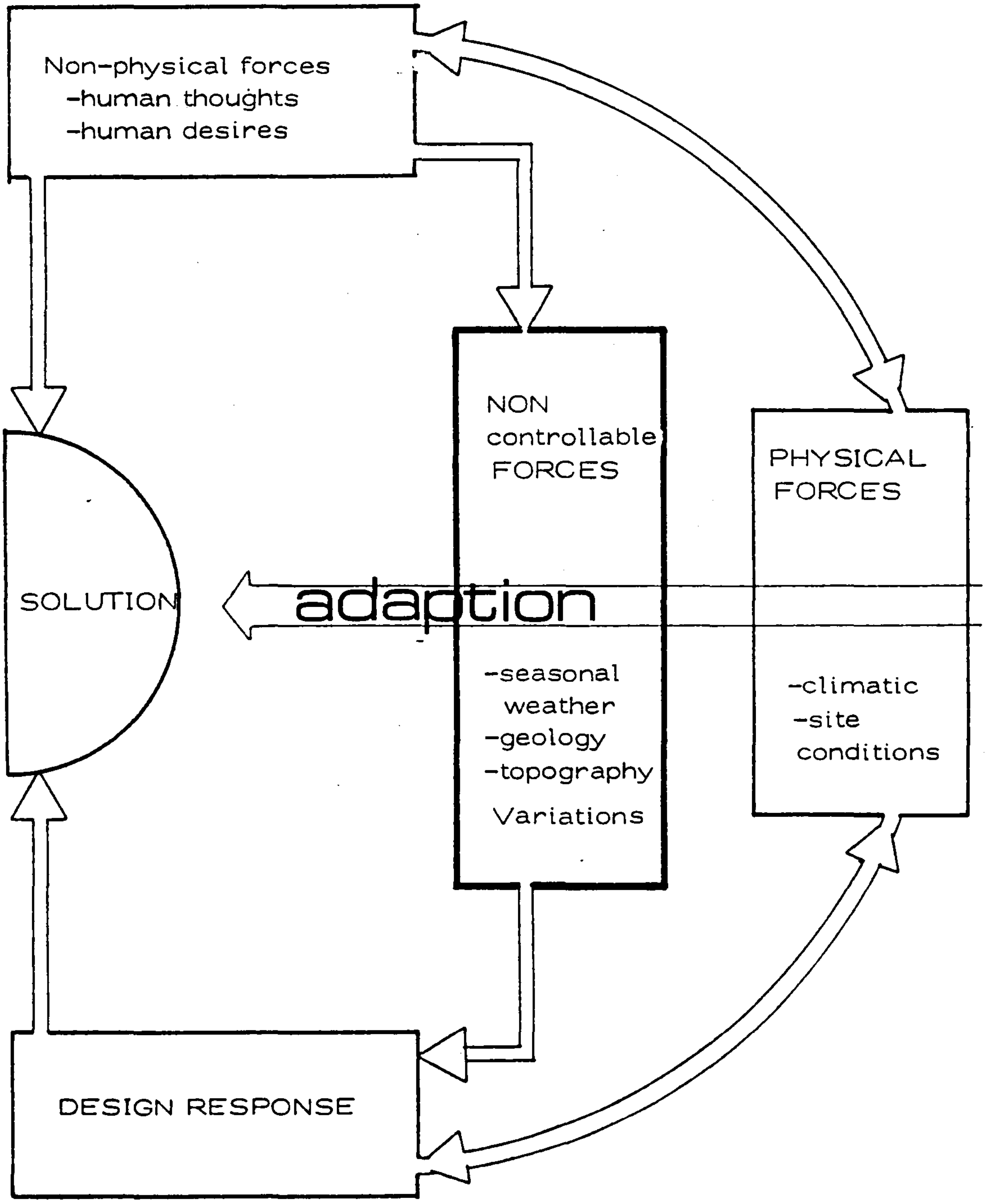


Figure 11. Pre-technological Design Approach
(Adopting from Prof. Robert Chiang, Christopher Gordon and Paul Kao, "Active Architecture")

ments. The present design actions intend to use natural energy and resources to overcome the natural environment (Fig. 12). These actions have induced serious environmental problems and energy crisis. To solve these problems is an urgent need for the future survival of human civilization.

6.2. The Future Prospect

The energy crisis didn't really begin with the oil embargo of 1972 but started with human manners of using energy, e.g. the burning of the precious and finite fossil energy for heating spaces and unnecessary traveling. Architectural design is a humanistic action. The design Profession is influenced and supported by technologies and communities. Modern technology and civilization are founded on the supplies of natural energy and resources. The energy crisis, therefore, will alter the activities and organizations of future communities. For example, the present structure of suburb, which is dependent on the vast using of motor vehicles, will need fundamental changes in order to save energy. These changes are not to be achieved by slowing down the present activities or by returning the civilization to the pre-technological status. Thus, the pre-technological design approach is not applicable to future needs. The future design consideration should include the environmental factors of:

-- Human

-- Nature

-- Energy

-- Technology

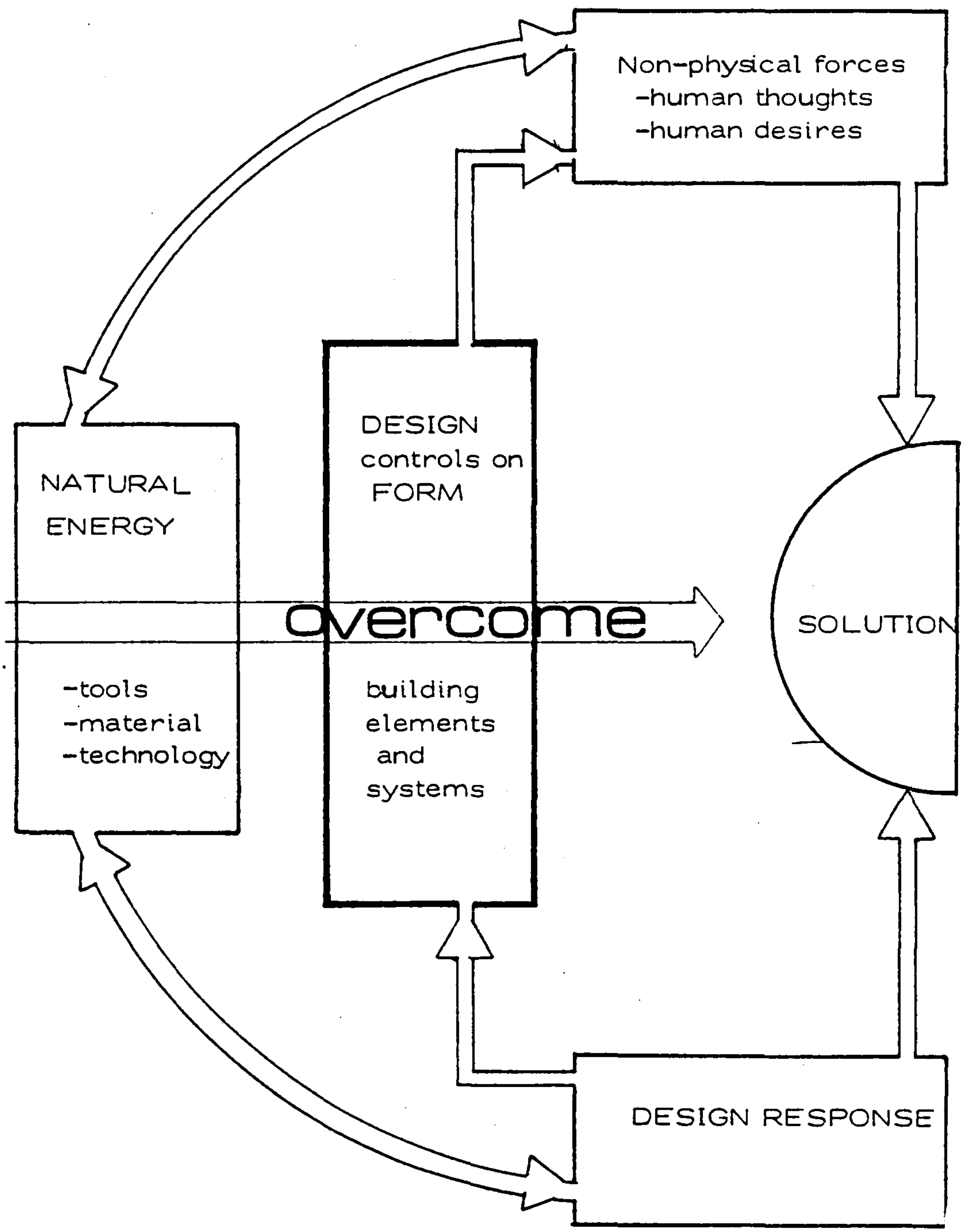


Figure 12. Post-technological Design Approach
(Adopting from Prof. Robert Chiang, Christopher Gordon and Paul Kao, "Active Architecture")

This design is required to incorporate the application of technology and the action of adaptation to the natural environment. The purpose of this approach aims at a human-and-nature balanced environment which will effectively and efficiently utilize natural forces to support human activities. The application of technology to architectural design leads to the use of high efficient active systems and to draw solar energy or other natural powers into buildings. The action of adaptation to the natural environment intends to avoid negative influences of the nature on human habitation and to take advantage of its positive effects passively.

This thesis has developed a general approach of designing with energy. The total design approach (Fig. 13), as is proposed in this thesis, intends to induce an innovation of attitudes and methods of the architectural design profession. This innovation would be achieved through:

1. Understanding the economic purpose for architectural consideration related to the cost of maintenance and energy conservation.

2. Identifying the significance of natural forces and elements and their relationships to human habitation.

3. Incorporating physical/non-physical and human/natural factors into problem structure and design solutions.

4. Evaluating design alternatives through the simultaneous considerations of energy, natural and human criteria in order to achieve optimum and humanistic solution.

One of the greatest problems in this innovation is the lack of sufficient knowledge of interactions among natural, human and energy systems. Also, the attitudes of communities are not ready to accept

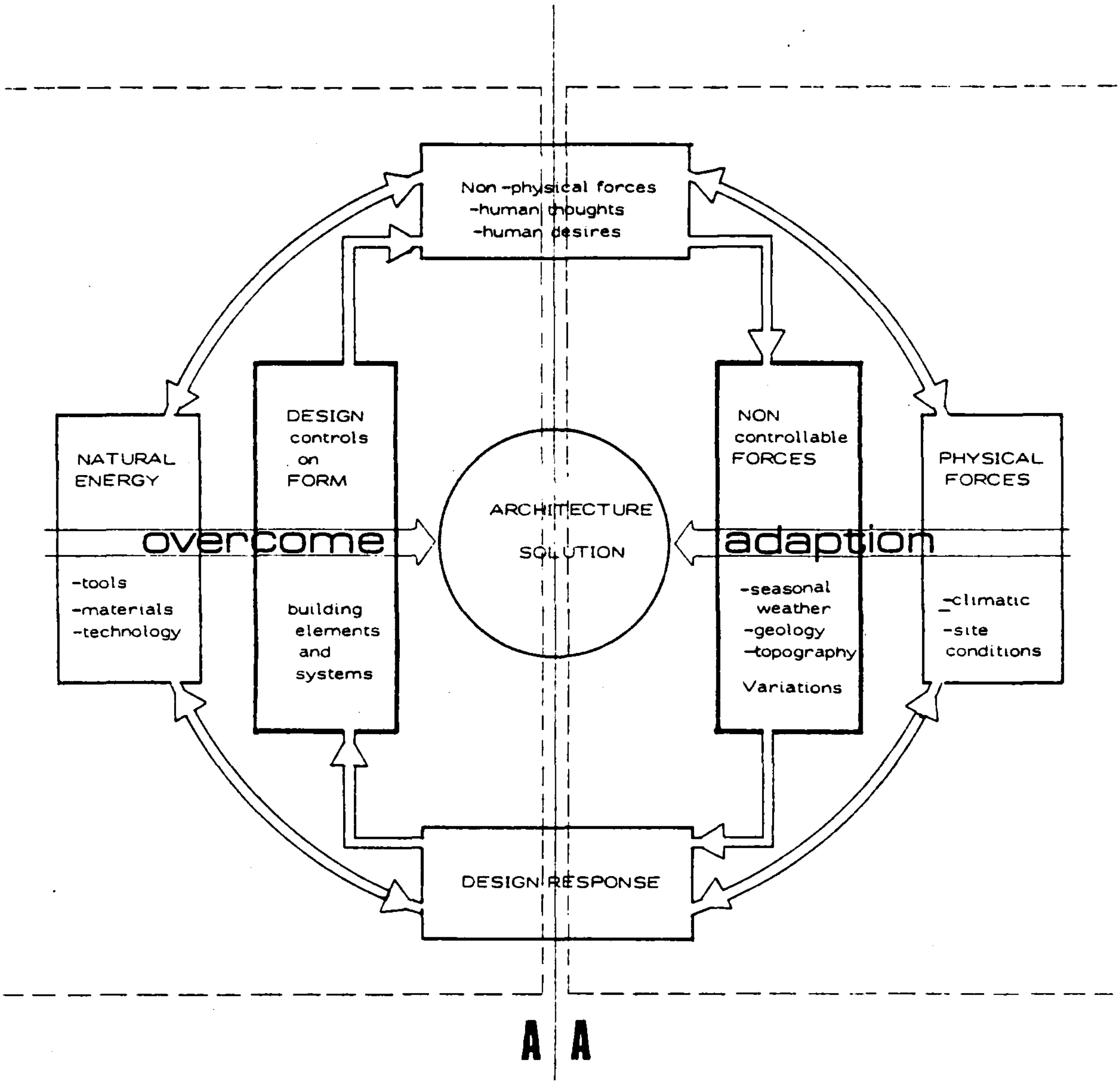


Figure 13. Total Design Approach
(Adopting from Prof. Robert Chiang, Christopher Gordon and Paul Kao, "Active Architecture")

a new life-style which is necessary to support a profession's innovation. To solve these problems, further research should proceed to address to these topical areas:

1. Community education of energy-conscious habitation.
2. The knowledge of the interactions among energy, human activities and other environmental factors.
3. The technologies of utilizing solar energy and other natural forces in support of human habitation.
4. An energy evaluation program for selecting optimum solutions.

REFERENCES CITED

[1] American Institute of Architects Research Corporation, A Notation of Energy Efficient Building by 1990, p. 2

[2] Lee Schipper, "Raising the Productivity of Energy Utilization", Annual Review of Energy Vol. 1, 1976, p. 455

[3] AIA, op. cit. p. 3

[4,5,] ibid. p.3

[6] National Solar Heating and Cooling Information Center, Passive Design Ideas for the Energy Conscious Architect, p.1-2

[7] Knowles, R.L., Energy and Form, p.

[8] ibid. p.

[9] ibid.

[10] Givoni, B., Man, Climate and Architecture, p.280

[11] Caudill, W., A Bucket of Oil, p. 13

[12] Alexander, C., "Form a Set of Forces to a Form," in The Man-made Object, ed. Keepes, G.

[13] Broadbent, G., Design in Arhcitecture, ch. 2

[14] Alexander, C., Notes on the Synthesis of Form, p.1

[15] ibid. p.8

[16] Thornley, D.G., "Design Method in Architectural Education," in Conference on Design Method, (London 1962), ed. Jones, C. and Thornley, D.G., p. 51

[17] Broadbent, op.cit., p. 291

[18] Jones, C., Design Method. p. 81

[19] Broadbent, op. cit., p.293

[20] Environmental Design Press, Landscape Planning for Energy Conservation, p.70

[21] Givoni, B., op. cit. ch. 17

[22] ibid. p. 280

[23] Olgyay, V., Design with Climate, p.17

[24] ibis., p.17

[25] Archer, B., "An Overview of the Structure of the Design Process," in Emerging Methods in Environmental Design and Planning, ed. Moore, G.T., p.285

[26] ibid.,p.286

[27] Alexander, C., "The Determination of Components for an Indian Village," in Jones and Thornley, op. cit., p.83

[28] Steadman, P., Energy, Environment and Building, p.39

[29] Olgyay, op. cit., p.87

[30] The Earth Covered Building (Proceedings and Notes of a Conference Held in Ft, Worth, Texas), p. 92

31 Building Performance Research Unit, School of Architecture, University of Strathclyde, Building Performance, p. 115

[32] Steadman, P., op. cit., p. 31

[33] AIA, Energy Conservation in Building Design, p. 37

[34] ibid. p. 37

[35] Givoni, B., op. cit.,

[36] ibid.,

[37] AIA, <u>Energy Conservation in Building Design</u>, p. 87

[38] Nat'l Solar Heating & Cooling Information Center, <u>op. cit</u>.

[39] Building Performance Research Unit, <u>op. cit</u>., p. 60

[40] Total Environmental Action, <u>Solar Energy House Design in four Climates</u>, p. 3

[41] AIA, <u>Evaluating Legislation for Energy Conservation in Building</u>.

[42] Jones, C., "The State of the Art in Design Method," in Moore (ed.), <u>op. cit</u>., p. 5

[43] Barclay, G.J., "Design Processes and Decision Theory,"

[44] Broadbent, <u>op.cit</u>., p.179

[45] Barclay, <u>op. cit</u>.,

[46] Bross, I.D.J., <u>Design for Decision</u>

[47] Maver, T.W., "Appraisal in the Building Design Process," in Moore (ed.), <u>op. cit</u>. p. 195

[48] Kruger, P., "Computer Simulation and Actual Results of an Energy Conservation Program," ASHRAE J. Oct. 1974

[49] Herroagen, and others, "The Evaluation of Passived Controlled Alternative Building Design by the Thermal Simulation Computer Program UWENSOL," (The 1978 Philadophia Second National Solar Conference)

[50] <u>ibid</u>.

[51] <u>ibid</u>.

[52] Building Performance Research Unit, <u>op. cit</u>.

BIBLIOGRAPHY

A. Background Information

American Institute of Architects Research Corporation, A Notation of Energy Efficient Building by 1990, Washington, D.C. A.I.A.

A.I. A. Research Corporation, Energy and Built Environment: A Gap in Current Strategy, Washington, D.C., A.I.A.,

A.I.A. Research Corporation, House Beautiful Regional Climatic Guide, Washington, D.C., A.I.A.,

Aronin, J.E., Climate and Architecture, New York: Reinhold, 1953

American Society of Heating, Refrigerating and Air-conditioning Engineers, ASHRAE Handbook 1977 Fundamentals, New York: ASHRAE, 1977

Banham, R., The Architecture of Well Tempered Environment, Chicago: University of Chicago Press, 1969

Caudill, W.W., A Bucket of Oil, Boston: Cahners, 1974

Fitch,J.M., American Building, The Environmental Forces that Shape It, Boston: Houghton Mifflin, 1969

Gandin, L.S., Environmental Factors in the Heating of Building, New York: Wiley, 1975

Geiger, R. The Climate Near the Ground, Cambridge: Harvard University Press, 1965

Knowles, R.L., Energy and Form, Cambridge, M.I.T. Press, 1974

B. Design Method

A.I.A., Emerging Techniques, Washington, D.C.; A,I.A.

Broadbent, G., Design in Architecture, London: Wiley, 1973

Broadbent, G., Design Method in Architecture, New York: Wittenborn, 1969

Bross, I.D.J., Design for Decision, New York: Macmillan, 1953

Jones, C. and Thornley, D.G., ed. Conference on Design Methods, New York, Macmillan, 1963

Gregory, S.A., The Design Method, London: Plenum, 1966

Jones, C.J., Design Method, London: Wiley, 1970

Moore, G,T., ed. Emerging Methods in Environmental Design and Planning, Cambridge: M.I.T. Press, 1970

Mize, J.H. and Cox, J.G., Essential of Simultation,

C. Conservation Strategy and Techniques

A.I.A., Energy Conservation in Building Design, Washington,D.C.: A.I.A., 1974

Berman, S., Energy Conservation and Window System, Springfield, Va.: National Technical Information Service,

Givoni, B., Man, Climate and Architecture, London: Applied Science Publishers, 1969

Goodland, R., Building and the Environment, Millbrook, N.Y.: Gary Arboretum of the N.Y. Botanical Garden, 1976

Griffin, C.W., Energy Conservation in Building, Washington, D.C.: Construction Specification Institute, 1974

Oakley, D., Tropical House, London: Batsford, 1961

Olgyay, V., Design with Climate, Princeton, N.J.: Princeton University Press, 1969

Roger, S., Thermal Design of Building, New York: Wiley, 1964

Sherratt, A.F.C., ed. Energy Conservation and Energy Management in Building, London: Applied Science Publishers, 1976

Steadman, P., Energy, Environment and Building, Cambridge, England: The University Press, 1975

Ouroboros East, University of Minnesota

The Use of Earth Covered Building (Proceedings of 1975 Conference held in Ft. Worth, Texas), National Science Foundation

D. Solar Design

Anderson, S., Solar Energy in Building Design, New York: Mcgraw-Hill, 1977

Solar Architecture, (1975 Proceeding) A.S.C./ A.I.A. Forum

Barker, E.M., and Watson, D., Design Criteria for Solar-heated Building, Guilford, Conn.: Sunworks, 1975

Daniels, S.F. Direct Use of the Sun's Energy, New Haven: Yale University Press,

Giffels Asso. Solar Energy and Housing, Washington, D.C.:A.I.A., 1975

Dept. of Housing and Urban Development, Solar Dwelling Concept,

Krenz, J.H., Energy Conversion and Utilization, Boston: Allyn and Bacon, 1976

Meinel, A,B., and Meinel, M.P., Applied Solar Energy; An Introduction, Mass.: Addison-Wesley Publishing Co., 1976

National Research Council, Solar Radiation Considerations in Building and Design

National Solar Heating and Cooling Information Center, Passive Design Ideas for the Energy Conscious Architect, Rockville, MD., 1977

Total Environmental Action, Solar Energy Home Design,

Trane Co. Trane Solar Table Manual,

E. Article

Barclay, G.J., "Design Process and Decision Theory", The Teaching of Architecture, ed. Marcus Whiffen, Washington, D.C. A.I.A., 1964

Coggins, J.L., "An effective Energy Audit the Flow Sheet Approach" ASHRAE J. June, 1976

Fanger, P.O., "Calculation of Thermal Comfort," ASHRAE J.

Fleming, W.S., "Energy Conservation Outlook and State of Art," ASHRAE J. March, 1973

Herroagen, D.R. and Others, "Evaluation of Passive Controlled, Alternative Building by the Thermal Simulation Computer Program UWENSOL" From 1978 Philadophia Second National Solar Conference.

Hill, J.E. and Kusuda, T., Manchester's New Federal Building an Energy COnservation Project, ASHRAE J. August, 1975

Kruger, P., "Computer Simulation and Actual Results of an Energy Conservation Program," ASHRAE J. October, 1974

Marples, D.L., "The Decision of Engineering Design" Ire Transactions on Engineering Management, June, 1961

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A NOTATION OF ENERGY CONSCIOUS DESIGN

-- An Architecture Approach to Energy Conservation

By

Paul Tien Kao

(Abstract)

The energy crisis begins with human manners of using natural energy and his attitude toward the natural environment. The most effective actions of energy conservation in building design do not lie in engineering oriented solutions but are in the effort in designing with nature. Based on this belief, this thesis intends to investigate the potential of energy conservation in building and its relationship with architectural design.

The purpose of this thesis is to develop a systematic method for designers to deal with energy problems. This method incorporates natural forces with human factors and aesthetic values in a systematic design approach of (1) exploring design situation, (2) analyzing the problem structure, (3) identifying design criteria, (4) investigating sub-solutions, (5) developing alternative solutions, and (6) evaluating and decision-making. Although it is an articulated approach, enough flexibility has been built in it so that the conventional designers may apply it in their design works. Nevertheless, it is believed that the greater benefit of this method can be achieved through a holistic attention to the proposed process.