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ABSTRACT

The current emphasis on energy conservation in buildings must be balanced by a careful consideration of how proposed approaches affect building occupants. A headlong rush toward building designs that conserve energy at the expense of the quality of buildings as judged by occupants would be a very shortsighted approach. There must be a continual awareness and sensitivity of the consequences on people when selecting among alternative "technical" options designed as a result of energy conservation needs. We need an increasing understanding of such factors as thermal comfort and illumination needs in buildings, as decisions likely to influence these requirements are made by designers. Another area of concern which should not be overlooked is the interaction of people with their environments. Approaches to energy conservation problems are often defeated by building occupants. Tight seals around doors and windows are useless if doors and windows are kept open, and building occupants have no choice but to turn all of the lights on or off if these are the only control options available to them. Building managers, operators, and occupants have an important, though not well understood, role to play in any energy conservation program. (Author)

DEPARTMENT OF COMMERCE · NATIONAL BUREAU OF STANDARDS

# NBS BUILDING SCIENCE SERIES 88



U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

# Energy Conservation in Buildings—A Human Factors/Systems Viewpoint

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# Energy Conservation in Buildings—A Human Factors/Systems Viewpoint

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# ENERGY CONSERVATION IN BUILDINGS --
## A HUMAN FACTORS/SYSTEMS VIEWPOINT

Arthur I. Rubin

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Another area of concern which should not be overlooked is the interactions of people with their environments. "Hardware" approaches to energy conservation problems are often defeated by building occupants. Tight seals around doors and windows are useless if doors and windows are kept open. Building occupants have no choice but to turn all of the lights on or off if these are the only control options available to them. Building managers, operators and occupants have an important, though not well understood role to play in any energy conservation program. This problem deserves serious attention.

Key Words: Energy conservation; human factors; people in buildings.

## 1. Introduction

Buildings have been identified as being major consumers of energy. Furthermore, a good deal of the energy used in buildings is said to be wasted because of inefficient design and practices. As a result of these factors, it is reasonable to expect that future building designs are likely to be more sensitive to energy usage than those developed in the past. However, it is still necessary to determine how the needs for energy conservation are to be met.

In the past few years, this problem has been addressed repeatedly and with increasing frequency by policy makers, designers and researchers. A number of conferences have addressed this issue; studies have been initiated, and in some instances decisions were made which modified traditional design practices -- (removing light bulbs in Federal office buildings).

Most of these activities were conducted in response to the "crisis" nature of the energy problem. As a result, it should not be too surprising that near term goals have been stressed, questions concerning what should be done to conserve energy have the implications of immediacy (what should be done now?). As a result, many of the proposals which have emerged from such discussions seem to be in the nature of "quick fixes" to problems which might well be more complex than they appear to be. Furthermore, the proposed solutions have implications associated with them which might not have been given the thoughtful consideration that they deserve.

Let us consider some of the suggestions put forward to conserve energy in buildings:

- A frequently mentioned one is to permit buildings to be warmer in the summer and cooler in the winter. The relaxation of environmental criteria will be offset by having occupants modify their dressing habits to suit their own needs for thermal comfort [1][1].

- Another popular approach (which has been put into practice in some instances) is to remove some proportion of the lighting fixtures in buildings thereby reducing energy consumption associated with lighting and cooling [2].

- The reduction of ventilation in buildings is another modification advocated by some people trying to reduce energy usage.

The suggestions mentioned share a number of characteristics.

- They appear to be "engineering" solutions to the problem in their focus on hardware.

- They appear to address short term goals without appropriate consideration to long range implications.

- They are directed toward modifying building design parameters but do not pay sufficient attention to the possible effects on occupants.

All in all these particular suggestions appear designed to rather arbitrarily modify the human based design criteria developed slowly over the years in ways that are likely to compromise the quality of the building environment from the standpoint of building users.

Is the design profession so bankrupt of ideas that some proposed "solutions" to problems of energy conservation require building occupants to "bear the brunt" of building environments which do not conform to present day criteria for acceptable buildings?

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[1] Figures in brackets indicate the literature references at the end of this paper.

It is especially ironic at this time that suggestions are made which may produce building environments which are less acceptable to occupants. Within the past few years there is evidence of an increased awareness by architects of the need to become more responsive to user requirements in building design [3]. This awareness is probably an outgrowth of the increased emphasis of many people throughout the world on environmental quality. Now, as with many environmental problems, a choice is being posed between environmental quality or energy conservation.

Is this either/or choice, a necessary approach?
Does it have to be made immediately?
Our answer to both questions is NO.
Let us first address the question of timing.

There appears to be substantial agreement among experts that the energy shortage is a real, not a contrived one [4]. As to the scope of the problem there is less of a consensus concerning the dimensions of the problem today and its progression in the near term and long term future [5]. In any event, the research and other programs being devised to deal with energy issues can readily be placed into "short term" and "long term" categories.

For purposes of simplification, we might consider building modifications as typifying a short term approach. Under this heading, options such as increased insulation and adding storm doors and windows are often mentioned.

The longer term options might include an examination of criteria now used in building design, such as illumination levels and ventilation requirements -- with a view toward modifying them in order to conserve energy.

We think that it is premature (at the very least) to down-grade requirements associated with occupant satisfaction as a first step in a program to conserve energy. Rather, in our view, design criteria associated with user requirements ought to be modified "downward" only when other possibilities are not feasible.

We do not mean to infer that such design features as illumination and ventilation criteria should not be examined -- only that any proposed modifications should be considered hypotheses to be tested experimentally. Furthermore, great care has to be taken in determining what response variables are to be measured, how measurements are to be made, and the state-of-the-art associated with making such measurements. For example, modification of ventilation requirements might result in an "odor" problem. Our ability to evaluate the nature and extent of this potential problem is governed by the state-of-the-art of measurement methodology associated with the response of people to odors of various types and concentrations. Unfortunately, the state-of-the-art of performing such measures is quite primitive as compared with that dealing with such factors as illumination and acoustics.

Another consideration which should not be overlooked when examining existing human response based criteria for buildings is the possible cumulative effects of environmental "contaminants." For example, there is considerable evidence that the effects of noise exposure should be considered on a cumulative long term basis if these effects are to be evaluated properly [6]. As a result, studies of odor (using the same example) might have to be extended over a considerable time period rather than perhaps collecting data for a given person in a single day.

Now that we have explored the question of timing, let us consider whether environmental quality must be degraded if energy conservation in buildings is to be achieved.

The remainder of this report is designed to provide a response to this apparent dilemma. In addressing this issue, a number of questions will be explored:

- Criteria to select among alternative design options
- Approaches to energy conservation
  - Hardware
  - Management and Operations
  - Systems/Performance Approach
- Experiences to date - energy conservation and people
- Some current programs
- Recommended research.

It is evident that these topics cover a broad range of subject matter and therefore cannot be treated at any great depth in the present paper. Our goal is a much more modest one -- merely to suggest a few of the factors which might be considered when addressing issues of energy conservation in buildings.

## 2. Criteria Which Can Be Used in Selecting Among Possible Design Options

We have already expressed our belief that the maintenance of the present quality of the environment is an important criterion to consider at the outset. Additional criteria which merit attention are:

- The number and/or type of buildings affected.
- The availability of resources to implement program.
- The initial/long term costs.
- The "difficulty" of implementation.
- The time-lag between implementation and meaningful results.
- The degree of participation by people -- occupants, managers, maintenance personnel.
- The probable degree of acceptance by those responsible for implementation.

### 3. Approaches to Energy Conservation

Even a cursory review of the "literature" recently generated on the topic of energy conservation reveals a preponderant emphasis on the "hardware" aspect of the subject.

### 4. Design and Technology

A sample of the recommendations generated recently by designers, engineers, policy makers and researchers, derived from recent studies and conferences [7-10] are mentioned below:

- Improve the efficiency of energy utilization equipment.
- Reduce heating and cooling loads on buildings.
- Select appropriate equipment to heat and cool buildings.
- Tighten air leakages.
- Optimize the combined use of thermal insulation, heat capacity of building, and glass area.
- Develop and use heat recovery and heat storage techniques.

The topic of building usage, though not dealt with in as much detail as design, has not been disregarded in the reports cited. The following approaches are among those mentioned.

### 5. Management and Operations

- Schedules for turning off lights, fans, heating/cooling systems.
- Automatic timing controls for heat, lighting.
- Scheduling of building usage to concentrate activities.
- Emphasis on need for routine maintenance -- changing, filters, cleaning light fixtures.
- Scheduling of janitorial services to avoid lighting entire building at night for this purpose.
- Training for maintenance and operations people to sensitize them to practices which are wasteful and not conserving of energy.
- Preparation of material (check lists) to be used routinely to identify potential problem areas.
- Turning off lights by individual occupants.

### 6. Systems/Performance Approach

We have mentioned only a small number of the many design and operations procedures recommended as energy conservation measures to be implemented in buildings. Our primary purpose in this review was to suggest that a large variety of approaches are possible -- and that they were not limited to "hardware" solutions. The task then is one of using (or developing) a methodology which facilitates the examination of energy conserving options in a systematic way. Furthermore, many of the options to be considered are closely tied to tasks which might be performed by people.

The complexity and size of the problem, the need to consider from many and varied approaches the importance of the "human factor" and the ability to clearly define an objective -- energy conservation in buildings -- are all characteristics of problems which have been successfully attacked in the past using systems analytic procedures. Furthermore, the performance approach to design seems to be an ideal vehicle to employ when formulating an attack on the problem. A review of the recommendations made earlier indicates that a number of options are specified in performance terms (as opposed to prescriptive) e.g. eliminate wasteful practices; optimize the use of thermal insulation, heat capacity of buildings, glass area.

The first benefit available from a systems approach is the need to provide an overview of the problem. Without such a comprehensive scheme it is possible for designers, engineers and policy makers to pursue individual piecemeal solutions without taking into account the possible interactions between their approaches or determining whether more fruitful paths might be pursued -- viable alternatives might not even be considered.

### 7. Systems Analysis and Human Factors (Ergonomics)

A major strength of the systems analysis procedure is that it can be used for the identification of tasks which can readily be performed by people. As a result, the designer can consider the tradeoffs associated with automated systems, manually operated systems and perhaps most important of all -- systems combining man and "machines*". It is the contention here that many of the energy conserving schemes with high potential for payoff fall in this category. Consequently, the remainder of this paper will be concerned with this subject.

*The use of the word machines is used in the sense of the ability to control an important aspect of the environment, e.g., modifying the position of a venetian blind, varying the illumination on a task surface, changing the setting of a thermostat.

Table 1

Example: Analysis of some man/machine design tradeoffs in the control of the thermal environment of a room

| System Requirements | Temperature Sensing | Evaluation | Control Options | Feedback |
|---|---|---|---|---|
| Man | Sensations of warmth, cold. | Deciding whether any action is necessary, and, if so, what should be done. | Change thermostat setting, activate fan, Open (or close) window | Sensation of comfort, discomfort |
| Options | | | | |
| Machine | Sensor capable of detecting a range of temperatures with specified tolerances | Go/no go decision based on design factors | Activate (or deactivate) fan and heating system | Same as Temperature Sensing |

8. Interactions Between Man and the Built Environment

The interactions between people and buildings were explored by the author of the present paper during a roundtable discussion conducted in May 1972 [12]. Unfortunately, the understanding of the subject is no better today that it was at that time.

It is difficult to answer with any degree of certainty, a question concerning the importance of the role of the people who actually use buildings in any overall program of energy conservation. The absence of a body of directly applicable empirical data compels us to make assumptions based largely on opinions, attitudes and generalizations from subject areas which appear to be relevant to the present one. Obviously, our assumption is Yes, the activities of people in buildings are important determinants of energy usage and therefore should be carefully considered as a factor when programs associated with energy conservation in buildings are being formulated.

*See tables 2, 3 (pages 13, 14)

Let us first consider the design phase of buildings in some detail to identify some of the effects of design decision on energy related activities of people in buildings.

### 8.1 Building Design

One of the major design decisions impacting energy usage by people in buildings concerns the control systems available.

- Are controls to be centalized or decentralized?
- Are they to be operated manually, automatically or by a system combining both operations?
- What criteria are used to select among alternative options?

Design options can be reformulated in terms of the degree of control (flexibility) available in a given space and a determination of how this control is to be exercised. A variety of possible approaches are available ranging from totally automatic systems to those which place heavy reliance upon people.

Let us consider an example where the design goal has been to make effective use of natural and artificial sources of illumination in an energy conserving design. One proposed approach to the solution of this problem is the use of a computer to control both artificial illumination and the amount of daylight permitted to enter a room, depending on the amount and characteristics of daylight available. This system is a fully automatic one. At the other extreme is an approach which provides occupants with individually controlled task lighting and the opportunity to control the daylight entering a room, possibly by making adjustments on venetian blinds. A system which combines aspects of the two mentioned previously might consist of two sets of controls associated with artificial illumination. Assuming a large office, one switch could be a primary one -- governing all of the overhead lighting, while a secondary switch would control the lights positioned near windows. In this way, when sufficient daylight is available, the indoor illumination can be controlled on a selective basis.

Still another intermediate approach might be based on a timing system which may be controlled manually or automatically. For instance, all office lights might be turned out at the end of a working day. Anyone who works "after hours" would have to turn on the lights in his own space.

Although we have only dealt with the example of lighting, it is evident that analagous systems are possible when dealing with the thermal environment.

Another aspect of environmental flexibility is in terms of the permanence of design features, i.e., how difficult and/or costly would it be to make changes in the initial design?

### 8.2 Permanence of Design Features

If we again consider the fully automated lighting system described above, it is evident that any flexibility to be provided will have to be "programmed" in advance -- not only in terms of the computer itself but with respect to the design features capable of being controlled by the computer. The permanence (or modifiability) of design features can extend to many aspects of design -- addition of controls (lighting, heating/cooling), "hardware" (light fixtures, air conditioning units), modification of spaces (partitions), manipulation of building features (ability to open windows), etc.

Perhaps the strongest argument for advocating flexible designs -- those capable of being readily modified -- is the current state of knowledge concerned with energy conservation in buildings. It is evident that the more uncertain we are about the relationship between the design and operations of buildings and energy conservation, the greater the need to enable modifications to be made in the future when more information is available.

The maintenance of a building and its elements and subsystems may be considered a link between design and operations. In the previous listing of energy conservation recommendations, the need for appropriate maintenance procedures was noted. However, anyone who has had any experience performing "routine" maintenance knows that there is a close relationship between the difficulty of this task and the willingness to undertake this activity at periodic intervals. The major decisions governing routine maintenance are made by the designer. The question is: what are the impacts of such decisions on energy conservation? For example, in the purchase of luminaires, how much time and effort should be placed on the need to clean them periodically? What trade-offs are associated with this activity?

With respect to modifying the environment as well as performing maintenance functions, the activities which are required range from the complex to the simple. As noted earlier, mechanical equipment must be "tuned" properly if it is to perform efficiently. Trained personnel are required to accomplish this task. In contrast, such activities as turning on lights can be performed by any building occupant.

In summarizing the points made in the paper cited earlier [11], the energy related problems associated with people and buildings has at least two distinct components:

- Determining what people can and should do to save energy in buildings.
- Devising methods which are effective in encouraging people to perform the desired activities.

## 9. Building Operators/Occupants and Energy Conservation

The consideration of energy conservation in buildings from a systems analysis viewpoint including human factors appears to be a very logical, though neglected, approach. One of the primary benefits to be derived is likely to be a vastly increased number of design options available -- primarily because of the flexibility of people. In the "classical" human factors literature [13,14] when man is considered as part of a complex system, strengths and weaknesses have been carefully assessed. Among the advantages that man has when compared with machines is versatility, flexibility and adaptability. That is, people can perform a wide variety of functions and are capable of adjusting rapidly to unforeseen circumstances when required. These abilities were the primary reasons for having manned lunar space flights.

In dealing with the interactions of people and buildings we will consider both occupants and operators/managers, without making any distinctions between them. (Although an exploration of this subject area is thought to be necessary when devising energy conservation programs).

The fact that people are so versatile enables designers to devise energy conserving systems which do not have to be in the either/or category -- fully automated or manual. Instead, based on tradeoffs associated with costs for example, combined man/machine systems might provide optimal solutions. Again, daylight control provides an illustration. Systems have been devised which automatically control the amount of daylight penetrating a building -- perhaps the control might be more cost-effective if it were manual rather than computer based. Similarly, the assignment and design of control functions to "man" or "machine" should be reviewed from the standpoint of energy related tradeoffs before a solution is devised.

Our discussion thus far has been primarily concered with design and energy conservation in the context of the activities of people in buildings which are related to these issues. We have not considered the day-to-day operations of buildings and will not have the opportunity to do so in any detail because such a discussion will increase the length of the present paper substantially beyond the established guidelines. The treatment of the subject will be limited to a listing of some of the frequently cited activities which merit study:

- Use of thermostats.
- Identification of energy wasteful practices.
- Use of energy intensive appliances (freezers).
- Use of lighting controls.
- Opening of doors and windows.
- Control of light, heat, ventilation during times of occupany and vacancy.
- Devising appropriate maintenance procedures.

A number of these issues are currently explored in an experimental program being jointly performed in Twin Rivers, New Jersey by Princeton University and the National Bureau of Standards. (A more detailed treatment of this investigation is provided in another research paper appearing in this symposium.) This study is of special relevance to the present paper since the initial findings of a program designed to retrofit buildings for energy conservation purposes, highlighted the importance of understanding the interactions of people with the buildings. The "hardware" modifications included under the retrofit study could not be readily related to energy usage in buildings without a better understanding of the "human factors" components.

10. Encouragement of Energy Conservation Practices Among Building Users

If we conclude that the actions of people are a critical determinant of energy conservation in buildings, we are still faced with the task of attaining the necessary cooperation from those whose actions are required. This is by no means an easy objective to accomplish -- but deserves research attention just as serious as that accorded to the solution of technological problems. In this instances (as was the case of the day-to-day operations of buildings) there will be no attempt to do more than mention a number of topics which should be investigated. The reason is the same -- the subject is a very complex one and merits a detailed examination.

- Highlighting the importance and need for energy conservation (an energy conserving ethic).
- Specifying the relationships between activities and energy usage.
- Specifying the relationship between energy usage and monetary costs.
- Determining means for "rewarding" energy conserving activities.
- Determining what type of feedback information is required, how to provide such information, and how frequently it should be provided.

11. Conclusion

Energy conservation in buildings is a relatively new concern among building designers, operators and users -- as well as for policy makers whose decisions might well determine the quality of a "generation" of buildings. Before making firm "hardware" design recommendations which in some instances will sacrifice the quality of buildings (based on current criteria) to be used for many years, other options ought to be carefully explored. A systems analytic approach should be employed to identify these options -- which should take into account the capabilities of building users to play a major role in energy conservation programs. Furthermore, the need to perform research on this topic should receive far greater attention than has been the case in the past where its importance has been noted and then ignored. The systems/human factors approach is likely to greatly increase the number and type of design possibilities that merit consideration and increase the design alternatives available to modify built environments during the lifetimes of buildings. This flexibility would provide the opportunity to respond to new information, technology and other developments which might impact the current "energy crisis" situation.

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Table 2

LEVELS OF ANALYSIS AND SOME RELATED TECHNIQUES

| Level of Analysis | Purpose | Applicable Technique |
|---|---|---|
| System | To determine effectiveness of system in performing a specified mission | Operations-research methods |
| Subsystem | To determine best way of meeting a specified requirement of the mission | System analysis<br>Integration matrix |
| Function | To determine best combination of components required to make up subsystem | Man-machine system analysis<br>Function analysis |
| Task | To determine best allocation of man's capabilities to perform required functions | Task analysis<br>Time-line analysis<br>Logic models<br>Information theory |
| Subtask | To determine best method of utilizing man's capabilities to perform the assigned tasks | Operator load analysis<br>Operator sequence diagrams<br>Decision theory<br>Information-flow analysis |
| Element | To determine best method of utilizing man's capabilities to perform assigned subtasks | Time-and-motion analysis<br>Elemental task analysis |

Table 3

MAN VS. MACHINE

| Man Excels In | Machines Excel In |
|---|---|
| Detection of certain forms of very low energy levels | Monitoring (both men and machines) |
| Sensitivity to an extremely wide variety of stimuli | Performing routine, repetitive, or very precise operations |
| Perceiving patterns and making generalizations about them | Responding very quickly to control signals |
| Detecting signals in high noise levels | Exerting great force, smoothly and with precision |
| Ability to store large amounts of information for long periods -- and recalling relevant facts of appropriate moments | Storing and recalling large amounts of information in short time-periods |
| Ability to exercise judgment where events cannot be completely defined | Performing complex and rapid computation with high accuracy |
| Improvising and adopting flexible procedures | Sensitivity to stimuli beyond the range of human sensitivity (infrared, radio waves, etc.) |
| Ability to react to unexpected low-probability events | Doing many different things at one time |
| Applying originality in solving problems -- i.e., alternate solutions | Deductive processes |
| Ability to profit from experience and alter course of action | Insensitivity to extraneous factors |
| Ability to perform fine manipulation, especially where misalignment appears unexpectedly | Ability to repeat operations very rapidly, continuous, and precisely the same way over a long period |
| Ability to continue to perform even when overloaded | Operating in environments which are hostile to man or beyond human tolerance |
| Ability to reason inductively | |

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Another area of concern which should not be overlooked is the interactions of people with their environments. "Hardware" approaches to energy conservation problems are often defeated by building occupants. Tight seals around doors and windows are useless if doors and windows are kept open. Building occupants have no choice but to turn all of the lights on or off if these are the only control options available to them. Building managers, operators and occupants have an important, though not well understood role to play in any energy conservation program. This problem deserves serious attention.


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Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems Short numerical tables Issued quarterly Annual subscription Domestic, $9.00; Foreign, $11 25.

DIMENSIONS/NBS (formerly Technical News Bulletin)—This monthly magazine is published to inform scientists, engineers, businessmen, industry, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on the work at NBS. The magazine highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, it reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing.

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National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated Developed under a world-wide program coordinated by NBS. Program under authority of National Standard Data Act (Public Law 90-396).

NOTE: At present the principal publication outlet for these data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St N W, Wash. D. C. 20056.

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## BIBLIOGRAPHIC SUBSCRIPTION SERVICES

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