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THERMAL EFFECTS RESULTING FROM OCCUPANT BEHAVIOR AND BUILDING OPERATION*

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ABSTRACT

Issues related to occupant activity in passive commercial buildings are being investigated determine their energy impacts. Total building energy analyses are performed to identify the heating, cooling and lighting effects of a variety of occupant requirements and activities identified by Min Kantrowitz Associates (MKA) in their investigation of the buildings in the Passive Commercial Experimental Buildings Program. The analyses utilize thermal performance data collected and compiled by Burt Hill Kosar Rittelman Associates (BHKRA), and supplemental data provided by Architectural Energy Corporation (AEC). The analyses are being performed using the building energy analysis program BLAST+.

The evaluation phase of the Passive Commercial Experimental Buildings Program is described; the interaction of occupancy and thermal/energy evaluation is discussed. The methods used to evaluate tne effect of occupants on daylighting performance in two of the buildings is described and progress on that activity is detailed. Preliminary results of investigations into occupant-related aspects of the use of thermal mass in commercial buildings and analysis plans for further investigation are presented. Additional areas of investigation are identified and discussed.

BACKGROUND

Both in research and in practice, broad assumptions are made about the way occupants will or will not respond to the comfort conditions and control requirements of passive buildings. Far-reaching assumptions are also made with regard to the performance of such passive techniques as roof monitors, thermal mass, radiant heat sources, and the occupant responses to them. Experience gained from the design and construction of buildings and data collected from occupied buildings provide a unique opportunity to evaluate the practical advantages and disadvantages of complex passive technologies and evaluate the assumptions which have been used in the absence of such information.

Thus, evaluation of existing passive commercial buildings results in occupant-related information which is difficult to obtain simply through analysis techniques. It also provides information which can improve building energy analysis techniques. Combining both existing building evaluation and computer building energy analysis can produce a more comprehensive understanding of many issues than is possible through other techniques.

EXPERIMENTAL BUILDINGS PROGRAM

Twenty-three commercial buildings have been designed and, with some exceptions, built with DOE support. These are experimental buildings which push the state of the design art; they incorporate advanced conservation features and passive heating, cooling, and/or lighting strategies. These buildings are being used to better define research needs in the heat transfer, modeling, analysis and design areas. They are also valuable in confirming and/or adjusting many assumptions made during analysis of passive buildings.

The experimental commercial building program has entered the performance evaluation phase. There are two parts of this evaluation:

- o Occupancy effects and occupant satisfaction.
- o Thermal/energy performance.

Data is being collected for each of the 23 projects in the program, most of which are occupied or nearing completion of construction. This data includes information on the design process and the designs themselves. In addition, peformance data is being collected for a 12-month period after occupation; this consists of reports on occupancy schedules and occupant satisfaction as well as meter readings, sub-metering, and, in some projects, specialized automatic monitoring with data acquisition systems.

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+ Building Loads Analysis and System Thermodynamics. BLAST is copyrighted by the Construction Engineering Research Laboratory, U.S. Department of the Army, Champaign, Illinois.

The occupancy portion of the performance evaluation deals with the way in which the occupants interact with the building -- how they influence energy consumption profiles through use patterns and building operation and how the building influences their comfort and productivity. Occupancy is critical to the energy consumption issue; buildings are built to provide a "comfortable" environment and it is imperative to evaluate the projects from this viewpoint.

In addition to its direct value, the occupancy evaluation provides feedback into more traditional energy research projects. When the occupant data is analyzed in conjunction with the energy performance data, a far better understanding of the limitations of existing energy consumption prediction tools can result. These tools necessarily rely on assumptions made by both designers and energy analysts regarding occupancy, thermal control, and comfort requirements. It is important to test how these assumptions translate into uncertainties in predictions of energy use in actual buildings. The current passive commercial buildings program provides the best opportunity to date to evaluate these occupant effects.

The second portion of the performance evaluation program deals with the more traditional energy issues. It is divided into basic evaluation (submetering, and/or simplified automated data acquisition) and advanced performance. The former provides a gross assessment of energy consumption by end use for comparison with existing data on conventional buildings. The latter is intended to determine the extent to which the passive features of the building contribute to its performance.

The extended analysis project described here falls within the advanced performance evaluation area and is directed at (1) joint evaluation of the occupancy and energy data bases, and (2) isolation of the energy impacts of specific design features of selected buildings. The design features selected for study have been identified as potential energy issues by the occupancy studies. The project utilizes energy data measured in the buildings to calibrate a computer model and, where necessary, supplemental data from the building or physical models to better quantify the performance of specific energy subsystems. The calibrated model is then used to examine the energy performance impacts of the design and occupancy issues selected for study.

EXTENDED ANALYSIS PROJECT

Two major thrusts have been selected for the Extended Analysis Project: (1) to analyze the effect of roof monitors on lighting, heating, and cooling, with special consideration to lighting control strategies, both manual and automatic; and (2) to analyze the thermal effects resulting from variation in occupancy and occupant interaction with passive systems, especially as they relate to the presence of thermal mass in the building.

Daylighting Analysis (Roof Monitors)

There are two conflicting schools of thought which pertain to control systems in buildings. One believes that the occupants cannot be trusted to control a passive system according to the strategy laid out by the designer, while an automatic control system will conform to that strategy. The other knows that occupants have a greater feeling of satisfaction when the have more control over their environment. The roof monitor investigation was prompted by a desire to compare the performance of occupant controlled electric lighting with automatically controlled lighting.

This portion of the study is also of interest because roof monitors play a major role in 80% of the passive buildings in the Experimental Buildings Program. A secondary purpose of the study is to comparatively evaluate the design variations appearing in the program. The study can provide considerable direction for future work in a field which is still in the process of identifying the basic potentials of different daylighting approaches.

In the lighting control portion of the study, comparisons will be made of actual operation and alternative manual and automatic control strategies. Instrumentation beyond that for the basic energy performance evaluation is required. Measurement of direct and diffuse solar radiation and electric light status has been planned and carried out by AEC with input from the personnel from the building projects being studied and from LBL. Physical models will be used in conjunction with BLAST to determine energy usage for alternative control strategies. Additional software has been developed to deal specifically with daylighting evaluation. Two projects are involved in this analysis: Community United Methodist Church (Columbia, MO); and Mt. Airy Library (Mt. Airy, NC).

Figure 1 illustrates the method for analysis of lighting control strategies at the two sites. It is always difficult, when dealing with real buildings, to make comparisons with simulations, because comparability of the two is always in question. In order to minimize this problem, as much as possible is held constant for the comparison. In this case, the many possible discrepancies between the actual building and the computer simulation are eliminated by running the computer simulation for all cases. The only differences are the ways in which the lighting schedule input to that simulation is generated.

To evaluate the building in terms of the actual manual control strategy, instrumentation has been installed in each building which will provide hourly information on which lights were on and for how long. This translates directly into electric lighting schedules for each zone, which can be read into a special version of BLAST in order to perform a total energy analysis.

To evaluate the building in terms of various automatic control strategies (or ideal manual controls) requires a more complex procedure. First a "map" must be prepared showing the interior illumination resulting from each of a variety of sky conditions. A physical model has been built for each building. The interior illumination resulting from a grid of about fifty sun positions and intensities, as well as cloudy sky conditions, is recorded. Both direct and diffuse solar radiation is recorded for each of these conditions as well. Further processing produces a series of tables which stores the ratio of illumination at a certain point in the building which results from direct or

diffuse radiation under a given sky condition (clear/cloudy and sun position).

The hourly radiation levels (direct and diffuse) are measured at the site, and then combined with the ratio tables to produce a grid of illumination levels inside the building for each hour which should result from the solar conditions. Assuming that these illumination levels are the basis for the automatic control of the electric lighting, different strategies can be applied to the array of illumination levels to generate a schedule of electric lighting which must be added to the daylighting each hour to provide the required minimal lighting level. This electric lighting schedule can then be read into the same special version of BLAST as the manually controlled lighting schedule was.

Except for the electric lighting schedules, all the building and occupant parameters which are so difficult to quantify exactly are treated precisely the same in BLAST for the different manual and automatic control strategies. Baseline BLAST runs are being compared to actual lighting, heating, and cooling energy consumption in order to assure that the computer simulation provides a reasonable characterization of the building energy use. Spot checks will also be taken to assure that the physical modeling of illumination levels accurately reflects the situation inside the building itself.

The combination of physical and computer models allows a variety of daylighting configuration changes to be evaluated as well. Different glazing areas or variations in baffling configurations or interior surface treatments may be investigated.

Occupancy Thermal Analysis

From occupant issues identified by MKA, three areas for evaluation have been determined:

(1) Thermal Mass. Three issues are involved here: the difficulty in recovering from night/weekend setback; the effective comfort resulting from mean radiant and air temperature differences; and the competition for exposure area between thermal mass and acoustic treatments.

(2) Changes to Design Assumptions. Analysis will be done to evaluate the energy effects of changes to occupancy schedules, activity types, and equipment. This study will examine the end use flexibility of passive solar buildings.

(3) Building and Passive System Operation. The two issues here are who has responsibility for operation and how much the level of instruction in the proper operation of the system affects performance. Analysis will determine energy penalties for improper passive system operation.

To the extent possible, generic building descriptions will be used with appropriate variations. If specific situations require, especially in the third case, input descriptions for actual buildings will be used.

Preliminary investigations have been made into the thermal mass questions. Figures 2-5 show preliminary results from this study. Complaints were heard from occupants at several buildings that the buildings stayed cold late into the morning and that the acoustics of some areas left much to be desired. Realizing that these results likely stemmed from excessive mass in the building (lowering the radiant temperature after a night setback in the first case and precluding extensive acoustical treatment in the second), investigations were made into the heating and cooling loads and peaks resulting from variation in thermal mass.

The solid lines on Figures 2-5 represent variation in the amount of thermal mass exposed to the occupied space. The exposed mass took the form of concrete interior walls in a prototype 10,000 square foot office building, described in [1]. The results for all three climates tested (Atlanta, Los Angeles, and New York) show similar tendencies. Heating loads and cooling peaks were not significantly affected. Cooling loads were reduced, as expected, as a result of increased exposed mass. However, heating peaks were substantially increased as mass was added. Heating peaks always occurred as a result of thermostat resets after a night setback. A higher heating peak in such a case implies that it will take longer to raise the radiant temperature to the comfort levels required by the occupants.

The dashed lines represent a similar set of parametrics, but the interior mass added to the building is covered with acoustical treatment (acoustic tile or carpet each represent about R-1.5 insulating value). While this treatment produces more modest cooling load reductions when the mass is added, the advantages of the added mass are still significant. On the other hand, the disadvantages of additional thermal mass in peak heating (and implicitly in morning comfort conditions) are dramatically reduced. Much more work needs to be done, but the preliminary interpretations are that when occupant requirements are considered, (1) the optimum level of thermal mass may be less than those used in many of the experimental buildings, and (2) appropriate acoustic surface treatments may not be mutually exclusive with good energy-conserving design.

In order to investigate methods of reducing the peak heating load, three alternative setback strategies are currently being evaluated: (1) moderating the setback from 57°F to 62°F; (2) setting the thermostat back up to 68°F two hours before occupancy each morning; and (3) gradually increasing the thermostat during the four hours prior to occupancy. If a method of mitigating the mass effect on heating peaks and morning start-up can be found which does not adversely affect consumption, the optimum balance of thermal mass, thermal comfort, acoustic comfort, and energy use would be changed.

In the second category of occupancy thermal analysis (changes to design assumptions) use pattens which differ from design assumptions have been suggested as the cause of differences between expected and actual performance for some of the experimental buildings projects Three tendencies have been identified across several buildings. Typically, many more people have been using the facilities than was planned by the owner or designer. This puts a strain on many building systems, including the energy systems, particularly cooling equipment. A related change from design assumptions is longer hours of occupancy, ranging from the addition of a half-day on Sunday to

conversion of a 4-hour per night evening school into a 16-hour occupancy schedule. The third tendency is for the use of particular areas to change dramatically from what was initially expected (from day-care to aerobics class, for example), altering the thermal performance of the area in the process. The effects of such changes on energy use will be investigated.

Direct Assistance to Building Occupants

In some cases, specific buildings for which computer simulations have been prepared can benefit by investigations into modifications which are being considered by the building operators. Both of the projects being used for the daylighting investigations have requested simulations to guide them in revising their winter setback strategies. The results should help to minimize the amount of experimentation which has to be done with the buildings themselves.

PROJECT STATUS

The preliminary work has largely been completed. The instrumentation plans have been completed and reviewed. Physical models of the two building projects have been constructed. Special daylighting software has been written to link the physical lighting models and the computer thermal models. The BLAST building descriptions for the prototype office building and two existing buildings have been completed. Analysis of thermal mass and thermostat control issues has begun, and preliminary results have been obtained.

Anticipated accomplishments for this project include:

- o Energy use characterization for various natural lighting control strategies for two buildings naturally lit by roof monitors, providing guidance for preferred strategies to be furtner researched.
- o Thermal/energy characterization of roof monitor daylighting system variations in glazing configuration and internal surface treatment.
- o Evaluation of the thermal/energy and comfort effects of changes to thermal mass levels and surface treatment, changes in the mode of thermostatic control, changes in design assumptions, and changes in the level of dependability of building operation.
- o Direct energy analysis assistance to building projects to improve building performance without extensive/expensive experimentation on the building itself.

The Passive Commercial Buildings Extended Analysis studies are significant in that they directly impact identification of program goals, and that they provide important information to parametric studies. The results of the studies, taken together with other occupant and energy analysis activities, serve as a primary evaluation mechanism for the DoE Passive Commercial Buildings Program.

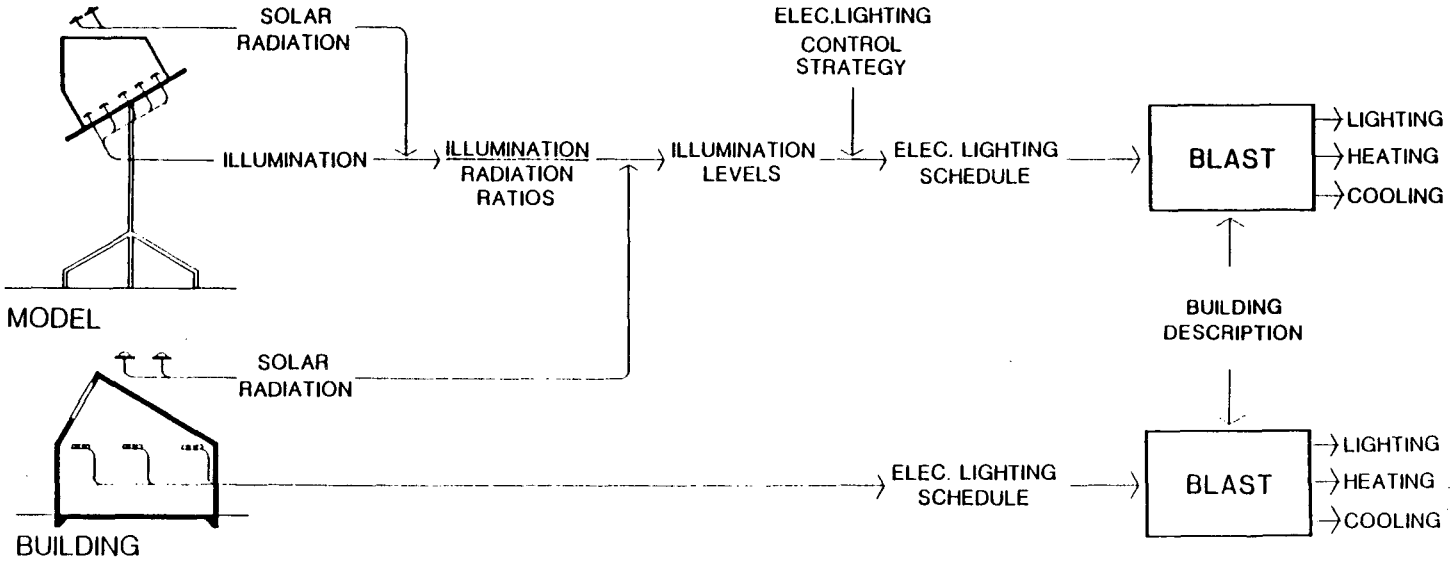
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Figure 1

Figure 2

Annual Heating Load

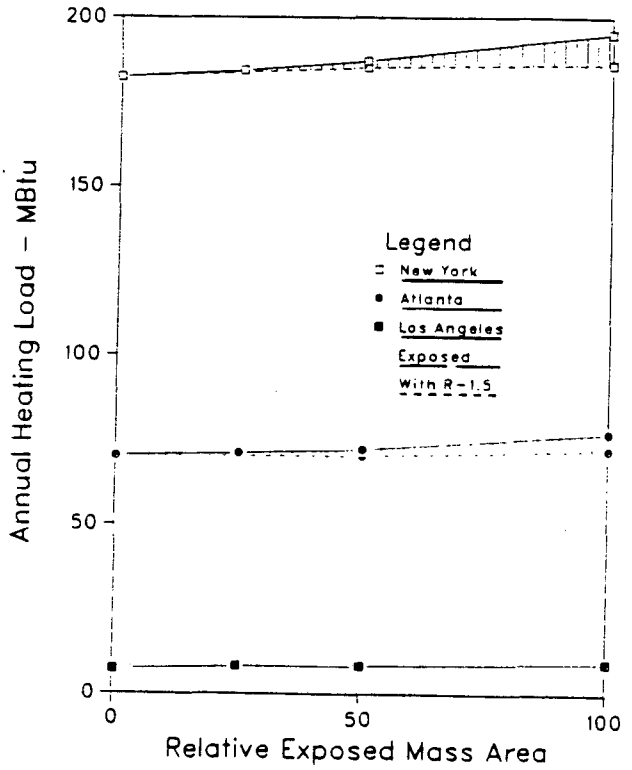


Figure 3

Annual Cooling Load

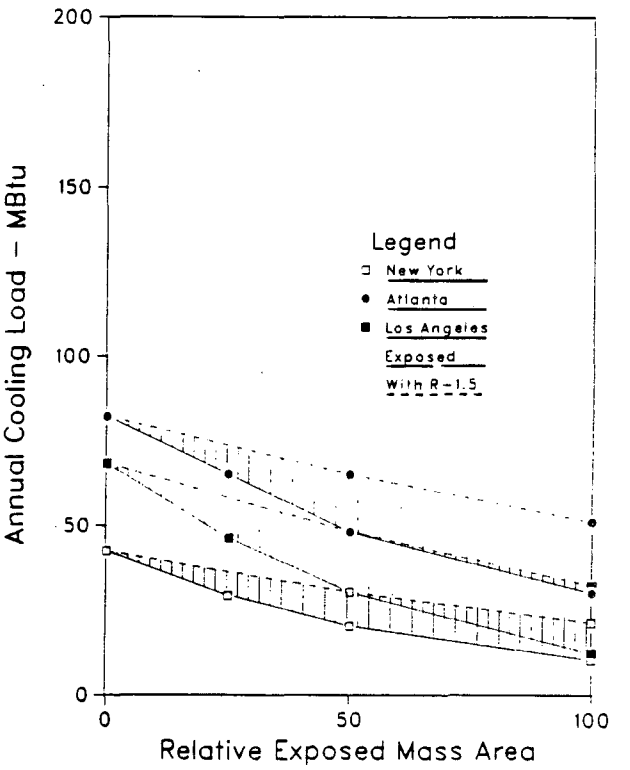


Figure 4

Heating Peak

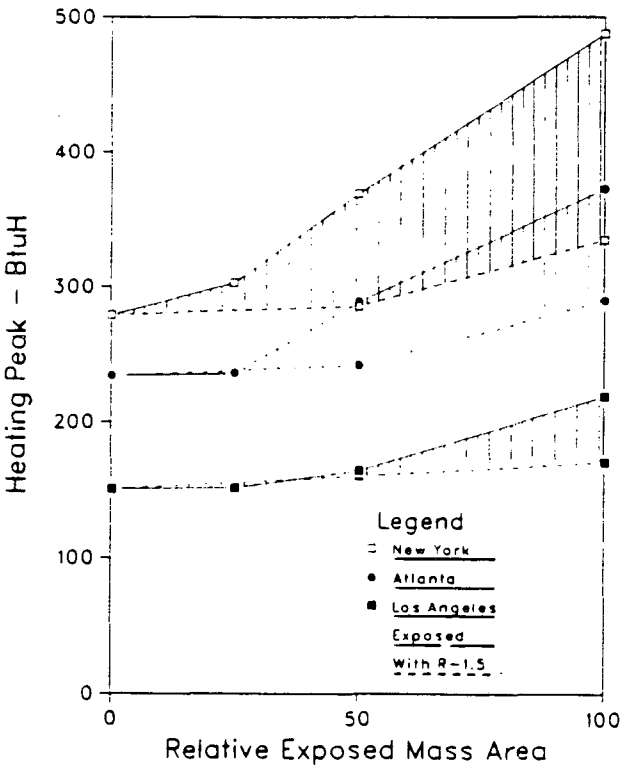
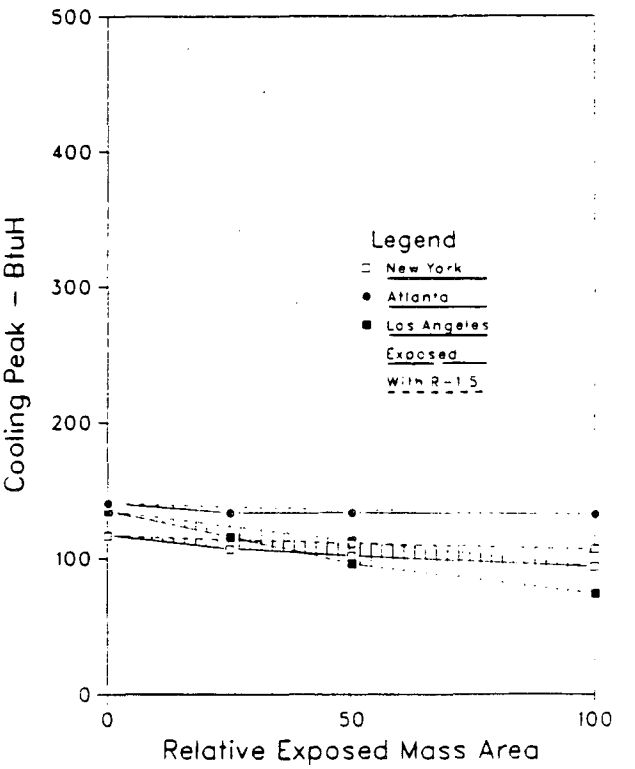


Figure 5

Cooling Peak



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