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Parametric Analysis of Energy Impacts on Office Buildings Due to Climate, Physical Type, and Occupancy Characteristics

G.D. Ander **N. Sharabianlou, Ph.D.**
ASHRAE Associate Member

ABSTRACT

Section 25402 of the California Public Resources Code requires the California Energy Commission (CEC) to establish and periodically update energy-efficiency standards for new buildings. Sensitivity analyses were conducted by the Standards Development Office of the CEC for nonresidential buildings. The purpose of this parametric analysis was to determine which variations in building parameters actually have significant energy impacts.

A "generic" building model was developed and implemented in conducting this sensitivity analysis. The generic model was used as an analytical tool in modeling the energy impact of building parameter variations. The parameters that were analyzed can be best described by the three major categories of (1) occupancy type (internal loads), (2) physical type (size and number of stories), and (3) weather. The preliminary analysis was concentrated on office occupancies using engineering assumptions developed by the CEC in conjunction with a five-member Technical Advisory Group and a 34-member Professional Advisory Group representing ASHREA, AIA, IES, and other professional and business organizations.

The conclusions of this study revealed that the generic building model is a valid and valuable tool in analyzing the energy impacts of building parameter variations. Sixteen California climatic zones can be represented by five weather regions. Characteristics of the occupancy of office buildings can be represented by two categories: banks and low-rise offices. Variations in the physical type of office buildings can be represented by three categories: small single-story, medium to large single-story, and medium to large three-story.

INTRODUCTION

Section 25402 of the California Public Resources Code requires the CEC to establish and periodically update energy-efficiency standards for new buildings. This mandate is reinforced and extended by Section 25612, which required the CEC to establish passive solar standards for government buildings in 1982. Section 25402 requires the CEC to establish both performance standards, in Btu per square foot, and prescriptive standards. The standards must be cost-effective when taken in their entirety, when amortized over the economic life of the structure, and when compared to historic practice, i.e.,

Gregg D. Ander, Research Architect, Conservation Division, California Energy Commission, Sacramento, California, M.S. 24; Nader Sharabianlou, Mechanical Engineer, Conservation Division, California Energy Commission, Sacramento, California, M.S. 24,

prior to establishment of statewide energy standards in 1975. In addition, the standards must meet California Environmental Quality Act (CEQA) and State Building Standards Law requirements. Section 25402.1 also requires the CEC to make available compliance materials, including a public domain computer program for compliance with the performance standards, and a design manual.

Nonresidential Building Standards Categorization

The first task in developing energy-efficiency standards for new nonresidential buildings is to determine how the standards should be categorized. Two primary guidelines should be used in determining the categorization: (1) the categories should be based on parameters that have a direct and significant impact on building energy use and (2) the categories should be based on parameters that are normally fixed constraints faced by the building design team, such as investor requirements or site limitations.

Three basic parameters affect the energy use in nonresidential buildings: conditions inside the building, conditions outside the building, and the effect of the building itself. These parameters suggest that the standards should be categorized by

-- Climatic zone (outside conditions)

-- Type of occupancy (inside conditions)

-- Physical type (primarily size and number of stories)

This paper presents the analysis of the energy impacts caused by variation in these three parameters in an attempt to develop categorizations for the new nonresidential standards. The organization of the nonresidential building standards on the basis of the major parameters affecting energy use (occupancy type, physical type, and climatic zone) can be portrayed as the three-dimensional matrix in Fig. 1. Each cell in this matrix represents a potential case for which a separate energy budget may be appropriate. This would result in a maximum number of combinations equal to 22 occupancy types, (offices, retail stores, restaurants, etc.) by 16 climatic zones by 5 physical types (size, number of stories, etc.), or 1760 different energy budgets. However, it is expected that this maximum number of energy budgets will not be necessary because energy use will not vary significantly among many of these cells. This sensitivity analysis is intended to determine the parameters of the cells that vary less than $\pm 5\%$ (the relative accuracy of the analytical tools in predicting energy in actual buildings) and to determine which cells can be grouped into fewer categories on this basis. The present analysis was focused on office occupancy types (shaded area in Fig. 1). The four office occupancy and operation characteristics analyzed in this study resemble the following:

-- Low-rise offices, #1A

-- Banks, #1B

-- Medium-rise offices, #2

-- High-rise offices, #3

A detailed description of the engineering assumptions and operating conditions for these occupancy types can be found in Ref 1.

EXPERIMENTAL DESIGN

Computational experiments were designed from a point within the matrix of occupancy types, climatic zones, and physical types. This starting point--selected to determine a means of reducing the number of energy budgets--was the medium low-rise office building in Climatic Zone 13 (Fresno).

The low-rise office occupancy type has the lowest combined internal loads and will therefore have the greatest variation in energy usage relative to changes in climatic zones. The medium low-rise physical type was chosen because it represents a large portion of new nonresidential building construction. Climatic Zone 13 (Fresno) was chosen because it has substantial winter heating and summer cooling. The sensitivity analysis was centered around this point, analyzing the energy impact of changes in each dimension of the matrix, while holding the other two dimensions constant. For this combination of occupancy type and physical type, the DOE 2.1 building energy analysis computer program was implemented to determine the annual energy consumption per square foot of floor area in each of the 16 climatic zones.[2] This analysis was repeated for all occupancy and physical types identified earlier for offices. It is important to note that the reference point in all three cases was the original point.

TEST PROCEDURES

Climatic Zone

The CEC has established 16 climatic zones that reflect regional differences in weather patterns (i.e., temperature, solar radiation, wind speed) throughout the state of California. However, the energy use in nonresidential buildings tends not to be greatly affected by climate. It is expected that fewer regions, perhaps three to eight, should be established for standards, reflecting those climatic zones for which energy use impact is significantly different. The procedure in analyzing sensitivities due to climatic conditions consisted of holding the occupancy type and physical type constant and completing DOE 2.1 computer analysis to determine the annual energy use per square foot in each of the 16 climatic zones. These results were analyzed to aggregate the climatic zones into regions in which the annual energy use per square foot did not vary by more than $\pm$ 5% within each region. For each of these climatic regions, one location was chosen to represent that region in further analysis.

Physical Type

The second step of the sensitivity analysis was to hold the occupancy type and the climatic zone parameters constant and complete DOE 2.1 computer analysis to determine the annual energy use per square foot for each physical type. Five physical-type combinations were identified for the analysis based on building scale. These five physical types were:

1. Small low-rise (approximately 2500 ft.^{2} (232.26 m^2), a one-story 50-by 50-ft. (15.24-by 15.24-m) model)

2. Medium low-rise (approximately 10 thousand ft.^{2} (929.03 m^2), a one-story 100-by 100-ft. (30.48-by 30.48 m) model)

3. Large low-rise (approximately 40 thousand ft.^{2} (3716.12 m^2), a one-story 200-by 200-ft. (60.98-by 60.98-m) model)

4. Medium high-rise (approximately 10 thousand ft.^{2} (929.03 m^2) per floor, a three-story 100-by 100-ft. (30.48-by 30.48-m) model

5. Large high-rise (approximately 10 thousand ft.^{2} (929.03 m^2) per floor, a three-story 100-by 100-ft. (30.48-by 30.48-m) model)

It is apparent that this sensitivity will involve analyzing the effect of building size and number of stories on energy consumption. The size sensitivity involved analysis of five different sizes of generic building models. These were 50-by 50- (15.2-by 15.2), 75-by 75- (22.86-by 22.86), 100-by 100- (30.48-by 30.48), 200-by 200- (60.96-by 60.96), and 300-by 300-ft. (91.44- by 91.44-m). The stories' sensitivity involved DOE 2.1 simulation of one- and three-story buildings. A one- and a three-story building resemble a low- and a high-rise office, respectively.

Occupancy Type

The last part of this sensitivity analysis was to hold the physical type and climatic zone constant and complete DOE 2.1 computer analysis to determine the annual energy use per square foot for each of the four occupancy types. The results were analyzed to determine if changes of occupancy type result in differences in annual energy use per square foot of greater than ± 5%. The occupancy categories resulting in a less than ± 5% variation in total energy consumption were aggregated. The procedure involved starting with the reference point and analyzing the impact of change in occupancy types on buildings energy consumption. The reference point was consistent with previous analysis and consisted of climatic parameters for Zone 13 (Fresno), single-story physical type (100-by 100-ft.) (30.48-by 30.48-m), and office occupancy type with low-rise office (1A) characteristics.

THEORETICAL CONSIDERATIONS

Generic Building Model

The concept of a "generic" building model was developed for this analysis. The generic model is a square building composed of the five thermal modules shown in Fig. 2. These thermal modules divide the generic building model into the five spaces within a building that may have significant energy use differences. There are four perimeter modules, whose energy use is expected to be affected by the impact of wall and window variations. One perimeter module faces each of the cardinal orientations; the fifth module is an interior module.

The generic building model is a powerful analytical tool. It was developed to minimize the effect of building orientation and configuration on analyzing the cost-effectiveness of alternative energy-saving measures that can be considered for incorporation into the standards. This concept enables one to analyze the energy-use impact of building parameter variations and architectural energy-saving measures on the energy use of each of the thermal modules. It also allows analysis of the energy impact of alternative space-conditioning systems independently for each thermal module and interactively for the building as a whole. Finally, it allows one to recombine the energy budgets determined for each thermal module into any building orientation and configuration for the purpose of setting standards.

Module Selection

Building energy consumption varies by configuration characteristics such as envelope area, construction type, and glazing orientations. These characteristics determine how the building interacts with outdoor conditions (the climate). The five-module orientation for the generic building model was selected for flexibility in modeling interactions of the building envelope and climate. The various areas of the building that interact differently with climate can be investigated independently. Four perimeter modules were selected to isolate the impact of exterior wall and glazing effects for different orientations. An interior module was selected to model areas of a building that are not directly affected by exterior walls. This modeling approach is consistent with the common practice of zoning a building for heating, ventilating, and air-conditioning (HVAC) systems and with design practices to include daylighting. Often a HVAC system designer selects separate systems and controls for perimeter building zones because of the temperature fluctuations near exterior wall and/or windows. A separate system or controls are often designed for the interior zone, where temperature conditions vary much less with climate changes. The five-module building configuration is consistent with this common HVAC design approach.

For daylighting design, the determining factor in establishing a daylight zone was the distance from a fenestration system that can be adequately provided with daylight. The generic building module depth was based on this distance. Quicklite, a daylighting calculation computer program, was used to determine the amount of daylight available for ambient (nontask) purposes at at various distances from the exterior wall. Footcandle levels at various distances from the window were calculated. Based on this analysis and the amount of illuminances for ambient (nontask) spaces suggested by the Illuminating Engineering Society (IES),[3] the depth of daylighting zone was determined.[4] This value was found to be 15 ft. (4.572 m) inward from a window (area source). This finding is consistent with the advice received from the professional energy analysts who served as professional and technical advisory groups for the CEC during the nonresidential standards development program.

Building Envelope and HVAC System Description

A frame construction was selected for the generic building model because it is the most common construction assembly among the representative office buildings. Building envelope features that minimally meet the current California nonresidential prescriptive standards[5] were used for each representative building and for the generic building model. The current standards allow variation in roof and wall insulation levels and glazing amounts but set an overall U-value for the building (heating criteria)[6] and a maximum overall thermal transfer value (OTTV) for the building (cooling criteria).[7]

In meeting the current standards, the insulation levels for the walls and roof were fixed, and the maximum allowable glazing level to meet the standard was determined. The wall and roof insulation level was set at R-11, and maximum glazing levels were calculated for both the heating and the cooling criteria for all climatic zones. Upon inspection, it was determined that 30% of the wall area for the glazing level of the generic building model would comply with current standards in all but two climatic zones (15 and 16). The proposed U-value and OTTV calculated for the generic model were less than the values allowed by the current standards in the three primary climatic zones (Zone 3, Oakland; Zone 7, San Diego; Zone 13, Fresno). This allows the compliance of the generic model in these climatic zones with the current standards.

The exterior wall assembly was modeled to consist of plyscore wood panels, 3½ in. (8.89 cm.) of insulation (R-11), and 5/8 in. (1.59 cm.) gypsum board interior finish.[8] The roof assembly consisted of built-up roofing over ½ in. (1.27 cm.) exterior plywood, 3½ in. (8.89 cm.) of insulation (R-11), a variable airspace, and an acoustical tile ceiling system with recessed flourescent luminaries.[9] The windows used in the generic building model were all fixed, ¼ in. (0.63 cm.) clear glass mounted in aluminum mullions and muntins. No external shading devices were used. Interior drapes with a shading coefficient of 0.70 were assumed half-closed at all times.[10]

The space-conditioning system used for the generic building model is a gas-heating and electric-cooling package unit. This was modeled with the Packaged Single Zone (PSZ) system of DOE 2.1, with a separate system for each thermal module. Efficiencies just meeting the current California Nonresidential Building Standards were used: a heating efficiency of 0.75 and a SEER of 7.5 for cooling.[11]

Occupancy Characteristics

The occupancy type determines the internal load conditions and some building parameters. The small office building (representative building 1A) values were used in the generic building model for the climatic zone and physical-type sensitivity analysis. The height of the conditioned space was 11 ft. (3.35 m) and lightweight furniture of 8 lbs./ft.^{2} (39.14 kg./m^2), covering 40% of the floor area, was also used. The HVAC system was started one hour before occupancy, and the internal load levels and schedules of the 1A building were used. These occupancy characteristics and the internal load schedules are discussed in detail in Ref 1.

Ventilation was calculated using the new ASHRAE Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality."[12] The current standard ventilation rates are based on the old ASHRAE Standard 62-73.[13]

SUMMARY OF RESULTS

The results of the parametric analysis conducted in this study are summarized in this section as follows:

1. The climatic zone sensitivity analysis showed that the 16 climatic zones can be grouped into five climatic regions. The building energy use between climatic zones in each region did not differ significantly. These five Nonresidential Climatic Regions (NCR) are A--desert, B--valley, C--south coast, D--north coast, and E--mountain.

2. The physical-type sensitivity analysis showed that the five physical types can be combined into two or three types. Two size categories are necessary: small (under 10 thousand ft.^{2}) (929.03 m^2) and medium-to-large (10 thousand ft.^{2} (929.03 m^2) and larger). The two physical-type categories recommended are small single-story and medium to large single-story. The third physical-type category recommended is a medium to large three-story.

3. The occupancy-type sensitivity analysis illustrated that the occupancy and operation characteristics of the low-rise office buildings (type 1A) can be used to approximate the characteristics of medium- and high-rise offices. However, occupancy characteristics of bank buildings (type 1B) differed significantly from these and should be considered separately.

DISCUSSION OF RESULTS

Sensitivity Due to Climate

The purpose of the climatic zone sensitivity analysis was to determine when the difference in energy use between nonresidential buildings located in different climatic zones is insignificant. Fewer than 16 climatic zones were expected to be needed for categorizing nonresidential building standards. To this end, analysis to compare climatic zones was performed using the generic building model described earlier for the single-story physical type and office occupancy type with representative building 1A (low-rise office)characteristics.

Two types of weather data on computer tapes were used to represent the 16 climatic zones for this analysis. In 12 climatic zones, weather data in the new Typical Meteorological Year (TMY) format were used. In the other four climatic zones, the type of data developed for the original California thermal zones were used, because none of the newer formats of weather data are available for weather observation stations within these climatic zones (2, 9, 10, and 15).

The results of the DOE 2.1 runs using the generic building model with low-rise office occupancy characteristics for climatic zones 1 through 16 are presented in Tab. 1. These were grouped into Nonresidential Climatic Regions (NCR)[14] using the following procedures. The primary criterion was a $\pm$ 5% variation from the average total building energy within a proposed climatic region. Fan, cooling, heating, and lighting energy comprise the total energy analyzed. Climatic zones were first grouped by total energy use. The average total building energy consumption was then calculated, and the percent variation of the extremes from the average was determined. If the whole building variation was less than $\pm$ 5%, the grouping was considered acceptable. If the variation was greater than $\pm$ 5%, a new grouping was tried. The results for climatic groupings are presented in Tab. 2. The average total budget for each group and the variations within the groups are shown in the final column. Tab. 2 also shows that the heating requirements for Zone 16 are significantly different from all other climatic zones. Therefore, it is proposed that Zone 16 be considered a separate region (Region E).

A similar check was applied to the variation in modular budgets for each end use in each proposed climatic region. This was done to check the reasonableness of groupings that were based on the whole building model. The modular budgets showed that these regional groupings are reasonable as well. The energy used within a group did not vary more than $\pm$ 5 kBtu/ft.^{2}-yr. (1.8 w/m^2) on a modular basis. In most cases, the percent variation was also within $\pm$ 5% from the group average.[15] In most cases, on a modular basis the groups had less variation than on a whole building basis. This further substantiated the validity of the resulting five climatic regions. These five nonresidential climatic regions (NCR) can be described by: (A) desert area, (B) central valley, (C) southern coastal, (D) northern coastal, and (E) mountain areas.

Sensitivity Due to Physical Type

The second step of the sensitivity analysis was to evaluate the possibility of using fewer than five physical types in developing the energy budgets. In this analysis, the occupancy-type characteristics and the climatic zone were held constant, and variations in physical-type characteristics were modeled using DOE 2.1. Five physical-type combinations were identified and described earlier for the analysis based on building scale.

Changes in building size may cause differences in energy consumption, because of the changes in the relationship between the proportional area of the interior and perimeter modules within the building. In the perimeter modules of the building, heat losses and gains occur through the walls, ceilings, and floors. In the interior module, gains and losses occur through the ceilings and floors only. As size changes, the perimeter modules decrease in proportion to total floor area, while the interior module increases. The size sensitivity analysis investigated the magnitude of energy use variations due to building size changes in three different climatic zones. The results will be used to determine if the new building standards should be categorized by the size of the building.

The number of stories can be important in determining space-conditioning energy requirements, because different floors in a building have different amounts of wall, ceiling, and floor area exposed to ambient conditions. The stories sensitivity analysis will investigate the magnitude of energy use variation due to number of stories within climatic zones. The results will be used to determine if the new standards should be categorized by the number of stories in the building.

Sensitivity Due to Size. A building-size sensitivity analysis was conducted to determine the effects of different generic model sizes. The three sizes of the five physical types identified for the analysis are small (50- by 50-ft.)(15.24- by 15.24-m), medium (100- by 100-ft.)(30.48- by 30.48-m), and large (200- by 200-ft.)(60.69- by 60.69-m). The one-story generic building was modeled on DOE 2.1 for these three sizes using the weather tape for the representative zones of each of the three major climatic regions. Two additional sizes, 75- by 75-ft. (22.86- by 22.86-m) model to check the variation between the 50-ft. (15.24-m) and 100-ft. (30.48-m) square buildings and a 300- by 300-ft. (91.44- by 91.44-m) model to check the variation due to a very large building were also modeled. The results of this analysis are illustrated in Tab. 3. Figure 3 also displays the variation in total and modular energy consumption versus floor area of these buildings in climatic zone 13 (Fresno). The energy use of the 50- by 50-ft. (15.24- by 15.24-m) building varies significantly from the 100- by 100-ft. (30.48- by 30.48-m) generic building. The energy usage for the other buildings was within the $\pm$ 10% range in all three climatic zones. The variation of the 50- by 50-ft. (15.24-by 15.24-m) model from the 100- by 100-ft. (30.48-by 30.48-m) model places it outside the group; the energy use of the other four sizes is within $\pm$ 5% from the new group average when the 50-ft. (15.24-m) size is removed from the group. Thus, the 100- by 100-ft. (30.48- by 30.48-m) model was overall a good representation of the large buildings. Furthermore, the comparison of modular results illustrated that the results of a 50- by 50-ft (15.24- by 15.24-m) building vary by more than $\pm$ 5% from those of a 100- by 100-ft. (30.48- by 30.48-m) building. However, the modular results of the other four building sizes vary much less from the energy use of the corresponding 100- by 100-ft. (30.48- by 30.48-m) building modules. This variation in energy usage ranges between + 4 and - 6%.

Table 4 illustrates perimeter and interior energy use variations for all these buildings in Climatic Zone 13 (Fresno).

On the basis of these results for modules, it can be concluded that medium to large buildings (10 thousand ft.^{2} (929.03 m^2) and larger) can be grouped into one category represented by the modules of the 100- by 100-ft. (30.48- by 30.48-m) generic building. A second group, less than 10 thousand ft.^{2} (929.03 m^2) will also be required for setting energy budgets; this group can be represented by the modules of the 50- by 50-ft. (15.24- by 15.24-m) generic building.

Sensitivity Due to Building Stories. The energy impacts of variations in the number of stories in multistory buildings were also analyzed. This was done by comparing the energy per square foot of each story of each of the following physical types:

1. Medium high-rise (10 thousand ft.^{2})(929.03 m^2) per floor, a 3-story 100- by 100-ft. (30.48- by 30.48-m) model),

2. Medium low-rise (10 thousand ft.^{2})(929.03 m^2) per floor, a 1-story 100- by 100-ft. (30.48- by 30.48-m) model),

3. Large high-rise (40 thousand ft.^{2})(3716.12 m^2) per floor, a 3-story 200- by 200-ft. (60.98- by 60.98-m) model), and

4. Large low-rise (40 thousand ft.^{2})(3716.12 m^2) per floor, a 1-story 200- by 200-ft. (60.98- by 60.98-m) model).

A three-story model was used for the multistory to analyze the three types of spaces in a multistory building: ground floor, middle floors, and top floor. A similar analysis of the energy impact due to the number of stories was not completed for small buildings (50- by 50-ft.)(15.24- by 15.24-m) because this building size is not commonly built in a multistory configuration.

The energy use of the two multistory buildings was compared to the energy use of the two single-story buildings of the same size to determine if the number of stories has an impact on energy use for each floor. The energy use of the single-story was compared to the energy use of each floor of the multistory and to the total multistory energy use. Energy use of the floors of the multistory was compared to energy use of its other floors as well. The analysis was done for the three climatic zones used in the building-size analysis: Zone 13 (Fresno), Zone 7 (San Diego), and Zone 3 (Oakland).

The results of these DOE 2.1 computer runs for the comparison of the 100- by 100-ft. (30.48- by 30.48-m) single-story and multistory buildings in Fresno are illustrated in Tab. 5. In the second column, the notations "ground," "middle," and "upper" represent the ground, middle, and upper floors of the building respectively, while the numbers to the left of these notations represent the number of stories of the building. The notation "3-total" means the average energy use for the entire three-story building. The variations for each comparison are shown in the final column of this table. Variations were calculated using the first building/floor combination of each pair as the base. For example, in 1-ground vs. 3-ground, 1-ground is the base. A greater than $\pm$ 5% variation from the base indicates a significantly different energy impact between the pairs of floors. Identical patterns were obtained for the other two climatic zones also.[16] Using the $\pm$ 5% criteria to determine if the difference in energy use between pairs in a proposed grouping is significant, the following groupings can be made. Based on this energy-use comparison, the middle and upper stories can form one category, the total three-story building can form another category with any of the stories, the total three-story building and the one-story building can form another category, and the one-story building and the ground floor of the three-story building can form the final category. The energy use is significantly different for the second and third floors as compared to the ground floor or to the one-story building. These results occur in all three climatic zones.

The results of the same analysis for the 200- by 200-ft. (60.98- by 60.98-m) building in Fresno are listed in Tab. 6. Identical patterns were observed for climatic zones 3 and 7. The results were the same as those obtained for the 100- by 100-ft. (30.48- by 30.48-m) building analysis, except the one-story building varies slightly more than the ± 5% from the three-story total building in Climatic Zone 3.[17]

On a module comparison of energy use, there is no significant difference between the same module on different floors and the module representing the total building. The same groupings are made on the module basis as on the whole building basis, that is, the one-story building with the ground floor of the three-story building, the middle story with the upper story, both upper stories with the total three-story building, and the one-story building with the three-story building. These groupings are closer on a module basis than on a whole building basis, and these patterns were consistently observed for 100- by 100-ft. (30.48- by 30.48-m) as well as for 200- by 200-ft. (60.98- by 60.98-m) buildings.[18]

In summary, the results of this analysis show that:

1. Using the energy budgets for the single-story building is acceptable for modeling the energy budgets of the multistory building in virtually all cases.

2. Using the energy budgets for the single-story building is acceptable for modeling the energy budgets for the ground floor of multistory buildings.

3. Using the energy budgets for the middle floor of a multistory building is acceptable for modeling the energy budgets for the upper floor of the total building.

4. Using the energy budgets for either the middle or the upper floor of a multistory building are acceptable for modeling the energy budgets for the total building.

A single-story building model could be used to analyze both single- and multistory buildings. In only one case was a significant energy difference noted between the single-story and three-story models. This occurred for the 200- by 200-ft. (60.98- by 60.98-m) building in Climatic Zone 3. Alternatively, a two-story building model could be used to analyze both single-story and multistory situations. The ground floor would represent either a one-story building or the ground floor of a multistory building. The second floor would represent all middle floors and the upper floor of a multistory building. However, some conservation measures may have a different impact on the upper floor than on the middle floors--for example, daylighting using a skylight. When these measures are used, the energy use in a middle floor may vary significantly from that in an upper floor. A three-story model would allow such differences to be analyzed, so in some cases, a three-story building may be the best model.

As the number of "middle" stories increases, the total building energy use (an average of the energy use by floor) approaches the energy use of the typical middle floor. On very high rises, more than 10 stories, the middle floor of the three-story generic building model would best represent the energy usage of the total building and could be used instead of the three-story model.

Sensitivity Due to Occupancy Type

The purpose of this step of the analysis was to determine if the occupancy characteristics of the four representative office building types, i.e., 1A (low-rise office building), 1B (low-rise bank building), 2 (midrise office building), and 3 (high-rise office building), can be combined into one generic occupancy type (on the basis that the energy use differences caused by these occupancy characteristics are less than ± 5%). The occupancy characteristics of these representative buildings are quite similar. As shown in Tab. 7, there is minor variation in operating characteristics, such as square feet per occupant, thermostat settings, and ventilation rates, and there is major variation in lighting and internal load schedules.

These four occupancy types represent four slices of the three-dimensional matrix of Fig. 1. They were studied using the generic base building model, assuming the medium-sized, single-story physical type. Comparisons were undertaken for the three major climatic zone groups identified in the climatic zone sensitivity analysis: Zone 13 (Fresno), Zone 7 (San Diego), and Zone 3 (Oakland). The results of the whole building analysis for each of the four representative buildings in each climatic zone are illustrated in Tab. 8. This table shows that occupancy types 1A, 2, and 3 have very similar total energy use on a per-square-foot basis within each climatic zone.

Occupancy 1B is significantly different. If representative building occupancies 1A, 2, and 3 are grouped as shown in Tab. 9, there is very little difference in energy use per square foot. The last column in this table shows that the energy use variation is within $\pm$ 5%; thus these three occupancies should be combined in each of the three climatic zones. A further check shows that the variation in each end use among the three occupancies in each of the three climatic zones also is much less than $\pm$ 5 kBtu/ft.^{2} (1.8 W/m^2) on a module basis, the representative buildings 1A, 2, and 3 would also form one category and the representative building 1B another category.

In summary, this analysis shows that the occupancy characteristics of representative buildings 1A (low-rise office building), 2 (midrise office building), and 3 (high-rise office building) should be combined into one occupancy type. The occupancy characteristics of representative building 1A can be used to represent the group. Representative building 1B (low-rise bank building) should not be included in this group because its energy usage differs significantly from the group average. Representative building 1B energy usage will be compared to other groupings of the remaining occupancies in future sensitivity analyses.

CONCLUSIONS

The conclusions of this parametric analysis can be summarized as follows:

1. The generic building model proved to be a powerful and a valid analytical tool in analyzing the effects of construction and orientation simultaneously with the impact of occupancy, physical type, and climatic zone variations.

2. The 16 California climatic zones can be grouped into five climatic regions, each representing several climatic zones where no significant difference in energy consumption of office buildings can be expected. These five regions are: A--desert, B--valley, C--south coast, D--north coast, and E--mountain areas. Utilizing these five regions instead of the original 16 climatic zones in analyzing the cost-effectiveness of the energy-conserving measures will greatly simplify the analysis.

3. The physical-type sensitivity analysis showed that the five physical types should be combined into two or three. Two size categories are necessary: Small (under 10 thousand ft.^{2})(929.03 m^2) and medium to large (10 thousand ft.^{2} (929.03 m^2) and larger. For medium to large buildings, only one category may be needed for both single-story and multistory, which could be modeled using a single-story generic building model. However, it may be more appropriate to retain both a single-story and a multistory category to reflect differences caused by particular conservation measures. If so, both small and medium to large size categories could be represented by a two-story generic building model. A three-story model may be needed if significant differences between the energy use of the middle and upper

stories occur with some conservation measures. The two physical type categories recommended are small single-story and medium to large single-story. The third physical type category recommended is a medium to large three-story.

4. Four office occupancy characteristics studied can be reduced to only two: low-rise office occupancy (1A) and the bank occupancies (1B). No significant differences between the occupancy characteristics of the low-rise, midrise, and high-rise office buildings were found. However, analysis of the bank occupancy characteristics (1B) illustrated significant variation from the others (1A, 2, and 3).

5. The original nonresidential building standards matrix (Fig. 1) for office buildings can be reduced substantially based on the results of this study. The original number of combinations was 16 by 5 by 4, or 320 combinations. This represents 320 potential energy-use categories for 16 climatic zones, five physical types, and four occupancy characteristics. This number is reduced to 5 by 3 by 2, or 30 categories, representing five climatic regions, three physical types, and two occupancy characteristics.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the following staff members: Ted Rauh, G. William Pennington, John Schade, Mickey Horn, Fred Berryman, Al Deterville, Cynthia Helmich, Bruce Maeda, and Jim Kelly.

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TABLE 1
Climatic Zone Comparison (Whole Building)
(100- by 100- by 11-ft.* Single-Story Building--Occupancy 1A)

Original Climatic Zone (RCZ)	Fan (F)	Cooling (C)	Heating (H)	(F)+(C)+(H)	Lighting	Total
	kBtu**/ft.^{2}-yr.[a]	kBtu/ft.^{2}-yr.[a]	kBtu/ft.^{2}-yr.[b]	kBtu/ft.^{2}-yr.[a]	kBtu/ft.^{2}-yr.[c]	kBtu/ft.^{2}-yr.
1	12.5	29.7	8.7	50.8	147.2	198.0
2	15.2	52.2	7.8	75.2	147.2	222.4
3	12.7	37.4	6.6	56.8	147.2	204.0
4	13.9	44.4	6.3	64.6	147.2	211.8
5	16.1	45.1	6.8	68.0	147.2	215.2
6	14.4	54.5	6.0	74.8	147.2	222.0
7	14.2	52.7	4.9	71.8	147.2	219.0
8	14.5	55.0	5.4	74.9	147.2	222.1
9	14.9	59.1	5.3	79.3	147.2	226.5
10	15.8	62.2	6.3	84.2	147.2	231.5
11	17.3	64.1	7.8	89.2	147.2	236.4
12	15.8	56.0	7.3	79.1	147.2	226.3
13	17.6	61.0	7.1	85.7	147.2	232.9
14	17.3	76.5	6.3	100.1	147.2	247.3
15	16.8	93.0	5.0	114.8	147.2	262.0
16	14.9	40.2	12.5	67.5	147.2	214.7

[a] Source energy at 10,239 Btu/KW.h
[b] Gas heating
[c] Includes 147.2 kBtu/ft.^{2}-yr of source for lighting

* Multiply ft. by 0.3048 to obtain meter
** Multiply kBtu/ft.^{2}-yr by 0.36 to obtain W/m^2

TABLE 2
Climatic Zone Comparison (Whole Building by NCR)
(100- by 100- by 11-ft.* Single-Story Building--Occupancy 1A)

Proposed Climatic Region (NCR)	Original Climatic Zone (RCZ)	Fan (F) kBtu**/ft.²-yr.[a]	Cooling (C) kBtu/ft.²-yr.[a]	Heating (H) kBtu/ft.²-yr.[b]	(F)+(C)+(H) kBtu/ft.²-yr.[a]	Total kBtu/ft.²-yr.[c]	Var. from Group Avg. (%)
Desert (A)	15	16.8	93.0	5.0	114.8	262.0	+2.9 to -3.0
	14	17.3	76.5	6.3	100.1	247.3	
Valley (B)	11	17.3	64.1	7.8	89.2	236.4	+3.0 to -3.0
	13	17.6	61.0	7.1	85.7	232.9	
	10	15.8	62.2	6.3	84.2	231.5	
	9	14.9	59.1	5.3	79.3	226.5	
	12	15.8	56.0	7.3	79.1	226.3	
	2	15.2	52.2	7.8	75.5	222.4	
South coast (C)	8	14.5	55.0	5.4	74.9	222.1	+1.2 to -2.0
	6	14.4	54.5	6.0	74.8	222.0	
	7	14.2	52.7	4.9	71.8	219.0	
	5	16.1	45.1	6.8	68.0	215.2	
North coast (D)	4	13.9	44.4	6.3	64.6	211.8	+3.5 to -3.2
	3	12.7	37.4	6.6	56.8	204.0	
	1	12.5	29.7	8.7	50.8	198.0	
Mountain (E)	16	14.9	40.2	12.5	67.5	214.7	

[a] Source energy @ 10,329 Btu/kW.h
[b] Gas heating
[c] Includes source lighting energy

* Multiply ft. by 0.3048 to obtain meter
** Multiply kBtu/ft.²-yr by 0.36 to obtain W/m²

TABLE 3
Building Size Comparison for Whole Building
(Generic Building--Occupancy 1A) (Five Sizes)

Original Climatic Zone (RCZ)	Building Size (ft)*	Fan (F) kBtu**/ft.^{2}-yr.[a]	Cooling (C) kBtu/ft.^{2}-yr.[a]	Heating (H) kBtu/ft.^{2}-yr.[b]	(F)+(C)+(H) kBtu/ft.^{2}-yr.[a]	Total kBtu/ft.^{2}-yr.[c]	Var. from Base (%)[d]
13	50 by 50	27.1	87.4	21.7	136.2	283.5	+22.4
	75 by 75	20.8	67.4	12.0	100.2	247.5	+ 6.9
(Fresno)	100 by 100	17.7	58.7	8.0	84.4	231.6	-
	200 by 200	13.3	48.7	4.1	66.1	213.4	- 7.9
	300 by 300	11.7	45.9	3.2	60.8	208.1	-10.1
7	50 by 50	20.7	75.6	17.0	113.3	260.6	+20.2
	75 by 75	16.2	45.1	19.7	81.0	228.2	+ 5.3
(San Diego)	100 by 100	14.1	50.3	5.2	69.6	216.8	-
	200 by 200	10.9	42.3	9.6	62.8	210.3	- 3.0
	300 by 300	9.9	40.2	1.5	51.6	198.9	- 8.3
3	50 by 50	18.1	51.0	20.5	89.6	236.8	+17.6
	75 by 75	14.3	23.5	26.2	64.0	211.2	+ 4.9
(Oakland)	100 by 100	12.5	34.3	7.3	54.1	201.4	-
	200 by 200	9.8	29.1	3.6	42.5	189.7	- 5.8
	300 by 300	8.9	27.7	2.8	39.4	186.7	- 7.3

[a] Source energy @ 10,239 Btu/kW.h
[b] Gas heating
[c] Includes source lighting energy
[d] Base for comparison is the 100- by 100-ft whole building

* Multiply ft. by 0.3048 to obtain meter
** Multiply kBtu/ft.^{2}-yr. by 0.36 to obtain W/m^2

TABLE 4
Building Size Comparison by Module
(Generic building--Occupancy 1A) (Climatic Zone 13)

Module	Building Size (ft)*	Fan (F) kBtu**/ft.²-yr.[a]	Cooling (C) kBtu/ft.²-yr.[a]	Heating (H) kBtu/ft.²-yr.[b]	(F)+(C)+(H) kBtu/ft.²-yr.[a]	Total kBtu/ft.²-yr.[c]	Var. from Base (%)
North	50 by 50	23.7	70.6	22.4	116.7	264.0	+11.4
	75 by 75	21.3	61.6	15.7	98.6	245.9	+ 3.8
	100 by 100	20.3	56.9	12.6	89.8	236.9	-
	200 by 200	18.9	52.9	8.9	80.7	228.1	- 3.7
	300 by 300	18.5	51.6	7.9	78.0	225.4	- 4.9
East	50 by 50	26.5	86.0	21.2	133.7	281.0	+11.2
	75 by 75	24.0	75.9	14.5	114.4	261.7	+ 3.6
	100 by 100	23.0	70.8	11.7	105.5	252.7	-
	200 by 200	21.6	66.5	8.1	96.2	243.6	- 3.6
	300 by 300	21.2	65.0	7.0	93.2	240.6	- 4.8
South	50 by 50	28.6	101.6	21.0	151.2	298.5	+11.9
	75 by 75	25.8	89.6	14.1	129.5	276.8	+ 3.8
	100 by 100	24.7	83.6	11.2	119.5	266.7	-
	200 by 200	23.2	78.4	7.6	109.2	256.4	- 3.9
	300 by 300	22.7	76.6	6.6	105.9	253.2	- 5.1
West	50 by 50	8.2	51.8	21.9	81.9	229.2	+14.8
	75 by 75	8.6	39.7	7.1	55.4	202.7	+ 1.5
	100 by 100	8.8	39.4	4.2	52.4	199.7	-
	200 by 200	8.9	39.7	2.6	51.2	198.5	- .6
	300 by 300	8.8	40.1	2.3	51.2	198.5	- .6
Interior	50 by 50	28.6	101.6	21.0	151.2	298.5	+11.9
	75 by 75	25.8	89.6	14.1	129.5	276.8	+ 3.8
	100 by 100	24.7	83.6	11.2	119.5	266.7	-
	200 by 200	23.2	78.4	7.6	109.2	256.4	- 3.9
	300 by 300	22.7	76.6	6.6	105.9	253.2	- 5.1

[a] Source energy @ 10,239 Btu/kW.h
[b] Gas heating
[c] Includes source lighting energy
[d] Base for comparison is the 100- by 100-ft

* Multiply ft. by 0.3048 to obtain meter
** Multiply kBtu/ft.²-yr. by 0.36 to obtain W/m²

TABLE 5
Building Stories Comparison (Whole Building)
(100- by 100- by 11-ft* Floors--Occupancy 1A)

Original Climatic Zone (RCZ)	No. Stories Floor	Fan (F) kBtu**/ft.^{2}-yr.[a]	Cooling (C) kBtu/ft.^{2}-yr.[a]	Heating (H) kBtu/ft.^{2}-yr.[b]	(F)+(C)+(H) kBtu/ft.^{2}-yr.[a]	Total kBtu/ft.^{2}-yr.[c]	Var. from Base (%)
13 (Fresno)	1-Ground (d)	17.6	61.0	7.1	85.7	232.9	
	3-Ground	16.3	61.4	5.8	83.6	230.8	-1.2
	1-Ground (d)	17.6	61.0	7.1	85.7	232.9	
	3-Middle	19.2	73.0	5.4	97.6	244.9	+5.2
	1-Ground (d)	17.6	61.0	7.1	85.7	232.9	
	3-Upper	20.7	74.5	6.1	101.3	248.5	+6.7
	1-Ground (d)	17.6	61.0	7.1	85.7	232.9	
	3-Total	18.7	69.7	5.8	94.2	241.4	+3.6
	3-Ground (d)	16.3	61.4	5.8	83.6	230.8	
	3-Middle	19.2	73.0	5.4	97.6	244.9	+6.1
	3-Ground (d)	16.3	61.4	5.8	83.6	230.8	
	3-Upper	20.7	74.5	6.1	101.3	248.5	+7.7
	3-Ground (d)	16.3	61.4	5.8	83.6	230.8	
	3-Total	18.7	69.7	5.8	94.2	241.4	+4.6
	3-Middle (d)	19.2	73.0	5.4	97.6	244.9	
	3-Upper	20.7	74.5	6.1	101.3	248.5	+1.5
	3-Middle (d)	19.2	73.0	5.4	97.6	244.9	
	3-Total	18.7	69.7	5.8	94.2	241.4	-1.4

[a] Source energy @ 10,239 Btu/kW.h
[b] Gas heating
[c] Includes 147.2 kBtu/ft.^{2}-yr source energy for lighting all floors
[d] Base for comparison

* Multiply ft. by 0.3048 to obtain meter
** Multiply kBtu/ft.^{2}-yr. by 0.36 to obtain W/m^2

TABLE 6
Building Stories Comparison (Whole Building)
(100- by 100- by 11-ft* Floors--Occupancy 1A)

Original Climatic Zone (RCZ)	No. Stories Floor	Fan (F) kBtu**/ft.^{2}-yr.[a]	Cooling (C) kBtu/ft.^{2}-yr.[a]	Heating (H) kBtu/ft.^{2}-yr.[b]	(F)+(C)+(H) kBtu/ft.^{2}-yr.[a]	Total kBtu/ft.^{2}-yr.[c]	Var. from Base (%)
13	1-Ground (d)	13.1	52.7	3.0	68.8	216.1	
	3-Ground	11.6	51.4	1.8	64.8	212.0	-1.9
(Fresno)							
	1-Ground (d)	13.1	52.7	3.0	68.8	216.1	
	3-Middle	13.4	60.2	1.6	75.3	222.5	+2.9
	1-Ground (d)	13.1	52.7	3.0	68.8	216.1	
	3-Upper	15.2	62.9	2.3	80.5	227.8	+5.1
	1-Ground (d)	13.1	52.7	3.0	68.8	216.1	
	3-Total	13.4	58.2	1.9	73.5	220.8	+2.2
	3-Ground (d)	11.6	51.4	1.8	64.8	212.0	
	3-Middle	13.4	60.3	1.6	75.3	222.5	+5.0
	3-Ground (d)	11.6	51.4	1.8	64.8	212.0	
	3-Upper	15.2	62.9	2.3	80.5	227.8	+7.5
	3-Ground (d)	11.6	51.4	1.8	64.8	212.0	
	3-Total	13.4	58.2	1.9	73.5	222.8	+4.2
	3-Middle (d)	13.4	60.2	1.6	75.3	222.5	
	3-Upper	15.2	62.9	2.3	80.5	227.8	+2.4
	3-Middle (d)	13.4	60.2	1.6	75.3	222.5	
	3-Total	13.4	58.2	1.9	73.5	220.8	-0.8

[a] Source energy @ 10,239 Btu/kW.h
[b] Gas heating
[c] Includes 147.3 kBtu/ft.^{2}-yr source energy for lighting all floors
[d] Base for comparison

* Multiply ft. by 0.3048 to obtain meter
** Multiply kBtu/ft.^{2}-yr. by 0.36 to obtain W/m^2

TABLE 7
Occupancy Characteristics of the Representative Office Building

Building	Occupants			Lights	Recept.	Hot H_2O	Hours HVAC Operated		Temperature		Infil-tration	Vent
	Ft^2/person[a]	Sensible (Btu/h)[b]	Latent (Btu/h)[b]	(W/ft^2)[c]	(W/ft^2)[c]	(Btu/person)[d]	M-F	S-S	sum/win occup.[c]	sum/win unoccup.		(CFM/ft^2)[f]
1A Low-rise office	250	230	190	3.1	0.5	64	7-24	Off	78/70	Off	.164	.11
1B Bank	250	230	190	2.44	0.5	64	8-20	Off	78/70	Off	.164	.13
2 Mid-rise office	250	250	200	3.2	0.5	64	8-21	Off	78/70	Off	.164	.11
3 High-rise office	250	250	200	3.11	0.5	64	8-21	Off	78/70	Off	.164	.11

a Multiply ft^2/person by 0.0929 to obtain m^2/person
b Multiply Btu/h by 3.413 to obtain W.
c Multiply W/ft^2 by 10.76 to obtain W/m^2
d Multiply Btu/person by 1.055 to obtain KJ/person
e Use 5/19 (^oF-32) to obtain ^oC
f Multiply CFM/ft^2 by 0.0051 to obtain $m^3/s\text{-}m^2$

TABLE 8
Occupancy Comparison (Whole Building)
(100- by 100- by 11-ft.* Single-Story Building)

Original climatic zone (RCZ)	Occupancy group	Fan (F)	Cooling (C)	Heating (H)	(F)+(C)+(H)	Total
		kBtu** / ft.^{2}-yr.[a]	kBtu / ft.^{2}-yr.[a]	kBtu / ft.^{2}-yr.[b]	kBtu / ft.^{2}-yr.[a]	kBtu / ft.^{2}-yr.[c]
3	1A	11.8	31.1	7.3	50.2	172.1
	1B	10.4	22.6	10.6	43.6	134.6
(Oakland)	2	11.9	31.1	8.3	51.3	168.8
	3	11.6	30.3	8.3	50.2	164.6
7	1A	13.2	45.9	5.2	64.2	186.1
	1B	12.0	37.3	6.6	55.9	146.8
(San Diego)	2	13.2	45.1	5.7	64.2	181.7
	3	13.2	44.2	5.7	63.2	177.5
13	1A	16.7	53.9	7.9	78.5	200.3
	1B	15.2	43.9	10.8	69.9	160.8
(Fresno)	2	16.7	53.2	8.6	78.5	196.1
	3	16.5	52.3	8.7	77.6	192.0

[a] Source energy @ 10,239 Btu/kW.h
[b] Gas heating
[c] Includes source lighting energy as follows:

* Multiply ft. by 0.3048 to obtain meter
** Muliply kBtu/ft.^{2}-yr. by 0.36 to obtain W/m^2

Occ-1A 121.8 kBtu/ft.^{2}-yr for N,E,S,W, module and 121.9 kBtu/ft.^{2}-yr for interior module

Occ-1B 90.8 kBtu/ft.^{2}-yr for N,E,S,W, module and 90.9 kBtu/ft.^{2}-yr for interior module

Occ-2 117.5 kBtu/ft.^{2}-yr for N,E,S,W, module and 117.6 kBtu/ft.^{2}-yr for interior module

Occ-3 114.3 kBtu/ft.^{2}-yr for N,E,S,W, module and 114.3 kBtu/ft.^{2}-yr for interior module

TABLE 9
Occupancy Comparison (Whole Building)
(100- by 100- by 11-ft.* Single-Story Building)

Original climatic Zone (RCZ)	Occupancy group	Fan (F)	Cooling (C)	Heating (H)	(F)+(C)+(H)	Total	
		kBtu** / ft.^{2}-yr.[a]	kBtu / ft.^{2}-yr.[a]	kBtu / ft.^{2}-yr.[b]	kBtu / ft.^{2}-yr.[a]	kBtu / ft.^{2}-yr.[c]	Var. from Group Avg. (%)
3	1A	11.8	31.1	7.3	50.2	172.1	+2.1
(Oakland)	2	11.9	31.1	8.3	51.3	168.8	to
	3	11.6	30.3	8.3	50.2	164.6	-2.3
7	1A	13.2	45.9	5.2	64.2	186.1	+2.4
(San Diego)	2	13.2	45.1	5.7	64.2	181.7	to
	3	13.2	44.2	5.7	63.2	177.5	-2.4
13	1A	16.7	53.9	7.9	78.5	200.3	+2.1
(Fresno)	2	16.7	53.2	8.6	78.5	196.1	to
	3	16.5	52.3	8.7	77.6	192.0	-2.1

[a] Source energy @ 10,239 Btu/kW.h
[b] Gas heating
[c] Includes source lighting energy as follows:

* Multiply ft. by 0.3048 to obtain meter
** Multiply kBtu/ft.^{2}-yr. by 0.36 to obtain W/m^2

Occ-1A 121.8 kBtu/ft.^{2}-yr for N,E,S,W, module and 121.9 kBtu/ft.^{2}-yr for interior module

Occ-2 117.5 kBtu/ft.^{2}-yr for N,E,S,W, module and 117.6 kBtu/ft.^{2}-yr for interior module

Occ-3 114.3 kBtu/ft.^{2}-yr for N,E,S,W, module and 114.3 kBtu/ft.^{2}-yr for interior module

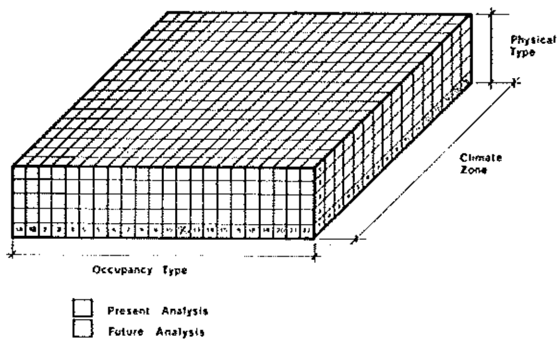

Figure 1. Sensitivity Analysis Matrix

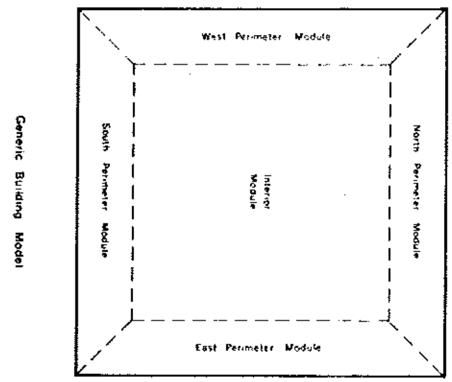

Figure 2. Generic Building Model

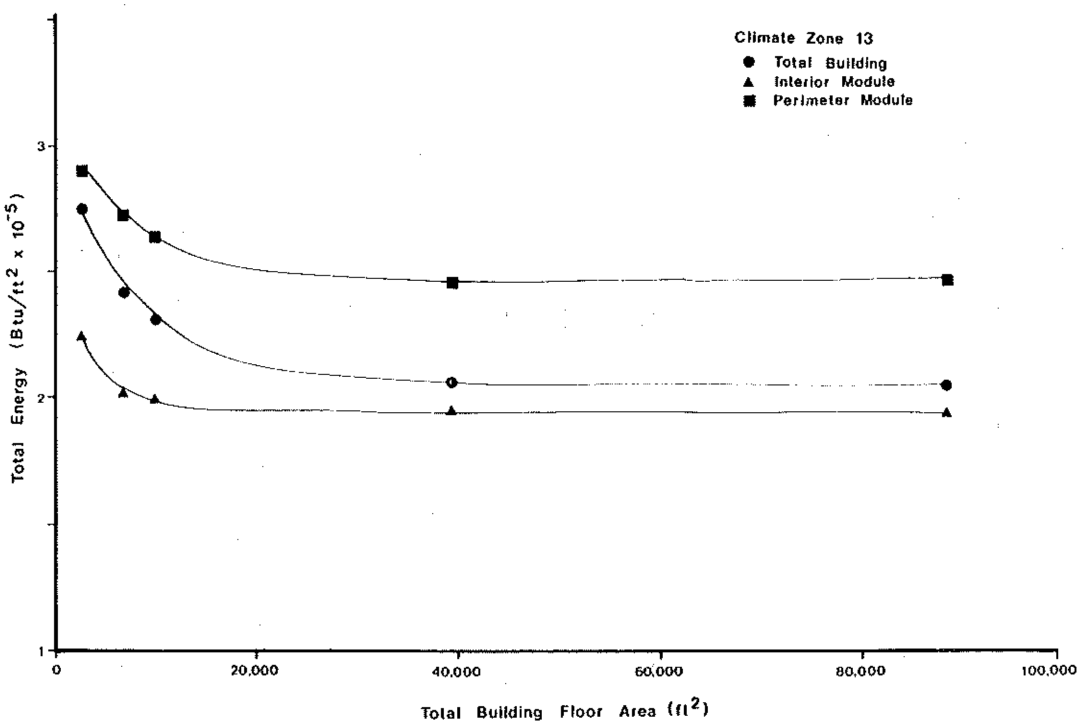

Figure 3. Plot of Energy Consumption vs. Floor Area

Discussion

L. Crow, Loren W. Crow Consultants, Inc., Denver, CO: As an author of the original selection and justification of the 16 climatic zones in California, except for the mountainous areas, when it was illustrated that each of the zones differed from another zone by 2 to 3°F for either mean winter or mean summer temperatures, I submit that Mother Nature will probably not agree to a heat redefinition, that the real differences will not continue to be measured, and that we now have equivalency within only five areas. The determination of similarity within 5 percent ranges in convenient and was appropriately used in your analytical tests. Will the commission staff continue to inform the users which zones are in the higher, lower, or near the middle of the 5 percent range groupings?

Ander: The California Energy Commission reduced California's 16 climate zones into 5 climate regions for the development of energy standards and the interent sensitivity analysis required for this project. This reduction was performed and described in this paper. It is important to note however, that final energy budgets (kBtu/ft^2.yr.) will be for all 16 climate zones.

G.B. Baruey, Portland Cement Association, Skokie, IL: The California residential energy standards recognize the benefits of thermal mass and allow for lower levels of wall insulation when thermal mass is contained within the building envelope. Is thermal mass being considered in any of the 22 commercial occupancies in your present study? If so, how does thermal mass impact the performance of these buildings?

G. Ander: The California Energy Commission recognizes the benefits of thermal mass for commercial buildings. Perscriptive requirements will reflect the conservation measures which can be traded off for other measures including mass. Actual energy budgets using mass are expected to be finalized in the spring of 1983.