Impacts of Climate Change on the Energy Performance of Buildings in the United States

BY

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ABSTRACT

This study uses computer simulation techniques to assess the impacts of climate change on building energy demand. This analysis allows for the characterization of the potential for reducing the energy use of buildings in a quantitative manner and therefore improving building design. Six cities and five building types representing a range of climates and building occupancies were modeled. Three design strategies for improving energy performance under warmed conditions are compared to a basecase.

The study concludes that annual cooling loads will increase at a much greater rate than heating loads will decrease; The timing, magnitude and duration of short term changes, peaks, is as large a concern as the sheer magnitude of the large annual changes in demand due to Global Warming; new methods of resource acquisition will have to be implemented to respond to the new energy resource demands; and a new set of incremental measures, conservation targets, will have to be developed to support new resources.

The results of the study indicate that research and demonstration of *regional, building unit area weighted, zero energy growth, energy demand targets* should be developed. These regional energy conservation targets should emphasize the saving of *lost opportunity resources* in the design of the most permanent of the building systems, the building's exterior skin geometry, assembly and interiors. The study indicates that the clearest *specific target* for reducing energy use under Global Warming is the design of **windows**. The research, design, and demonstration of windows that act as an integrated lighting system with the electric lighting; admitting daylight, view, and cooling ventilation without admitting sunlight; should be a major thrust for research and development of the 1990's.

1. INTRODUCTION

This study initiates an analysis of the effects of global warming on the energy performance on a population of residential and commercial buildings. Building descriptions as generic building energy demand types were created. The physical characteristics of these building types were based on American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE)90.1P (Proposed-1988) prescriptive *whole-building* energy performance standards. These generic building characteristics define the building's skin and internal energy requirements. This array of heat transfer characteristics forms the basis for the description of a representative range of building energy-use types. These building skin and internal energy-use characteristics were graphed and clustered into larger representative categories of energy use. Clusters representing both commercial and residential occupancies were analyzed. Specific types were chosen to represent each cluster. Representative cities of regional climate zones were chosen to guide the climate specific architectural characteristics of the representative building types.

Building types representing energy use clusters were chosen for computer modeling. *Annual* energy simulation of the representative buildings in the cities representing each climate region was performed by *hourly* simulation software. These simulations indicated changes in energy demand both on an hourly peak and seasonal basis. These energy demand changes provided information which revealed the design strategies that maintain standard comfort ranges while holding energy requirements to a minimum. These design strategies formed a basis from which building design and energy-use was assessed. The computer-based projections of changes in building energy demand were based on the climate change scenarios specified by the Office of Technology Assessment of the U.S. Congress (OTA), and were provided by the Goddard Institute for Space Studies (GISS) through the National Center for Atmospheric Research (NCAR).

This method of assembling a mean set of buildings based on average building characteristics that are representative of a broad range of building types was necessitated by the very limited time frame of the study. These specific expedient methods were chosen so as to produce *conservative* results. That is to say, if a more lengthy and precise study was undertaken, we believe the results would indicate less energy use by the new set of buildings, rather than more energy use. We chose to utilize the newest proposed energy use standard for building construction as the design base line for energy conservative construction. Thus, our results will be indicative of a 1989 code-compliant state-of-the-art, homogeneous building design population. We felt that in the intervening 50 years framed by the study and defined by the GISS climatic scenarios, and given difficulty in predicting design changes and life spans of todays buildings, the code-compliant state-of-the-art building of 1989 would most likely become the standard or mean of 2040. Since the advent of quasi-national building energy codes in the mid-1970's energy use in new buildings has been reduced by more than 50%. The newest standard represents a very energy conservative building as measured against the population of buildings constructed just 20 years ago. If the life span of the total population of buildings increases over the next 50 years, caused by increased costs of construction, the slowing of population growth, etc., the population of buildings could be increasingly dominated by less energy efficient older buildings. The mix of existing building stock and the rate at which new and more energy efficient buildings are constructed, will greatly effect the general results of this study. We have chosen assumptions that defined a population of buildings for analysis that in the year 2040 will be seen as neither state-of-the-art energy conservative or energy glutens

2. METHODS

This section documents the general questions surrounding the energy performance of buildings, the type of methods available for the energy simulation of buildings, classification of climate into regions, and lastly, it describes this study's method of classifying buildings so as to create categories of buildings with similar energy use patterns. The methods, documented in Section 2.0, allow energy-use studies such as this to more easily generalize the results of a limited set of energy simulations to a larger population of buildings of similar use type and in similar climate regions.

2.1. Methods of Simulation

The simulation of the energy performance of buildings requires the analysis of hundreds of interior and exterior building components. It also requires the periodic sampling of their performance over some time interval. This time interval may be as long as several years or as short as a single hour. This type of simulation thus may require the computation of the range of conductive, convective, radiative and evaporative heat transfers within a three dimensional surface of points, within some time sampling, and over the sum of these samples to include a longer term time interval. Depending on the number and range of performance questions, there is an equally wide range of computer-based energy analysis methods and software tools.

The choice of an analysis tool is generally based on the amount of precision required from the results and the amount of time available for producing the simulation. Typically, the more precision required, the more effort that is required in the preparation of the simulation. The most precise methods of simulating the effects of climate on the thermal performance of buildings generally include the use of hourly-based climate data and the use of transient heat transfer equations.

2.1.1. Methods of Simulation Selected

The computer program CALPAS3[1] was chosen as the software tool for the study. It analyses the energy performance of buildings through the use of an hour-by-hour transient thermal network simulation. It has been validated for the accuracy of its results against other computer models and operational buildings. It was the software of choice because of the flexibility of its input format, the wide choice of cities from which to choose simulation points, and the range of output reports which include annual and peak-annual cooling and heating loads, monthly and hourly energy balance reports. CALPAS3 is supported by the Berkeley Solar Group of Berkeley, California. They supplied hourly weather tapes based on our selection of cities and the global warming climate scenarios for doubling the carbon Dioxide levels of the atmosphere (2 x CO2) supplied to the study by the Goddard Institute for Space Studies (GISS) through the National Center for Atmospheric Research (NCAR).

2.1.2. Description of parametric approach-basecase versus warmed strategies

CALPAS3 was used to simulate the performance of a the representative sample of buildings and cities as documented in the Sections 2.2 and 2.3. Parametric analysis provides a set of single-variable-comparison simulations that are similar in all qualities except for one parameter that varies systematically. This limited variance allows for the direct comparison of one scenario to another.

In parametric analysis, a basecase scenario is established as a benchmark from which other scenarios can be compared. In this study, a basecase scenario simulation was run for each building type in each climate. The basecase building for each type was the ASHRAE 90.1P[2] prototype. The basecase climate was taken as the Typical Meteorological Year (TMY) weather tape established by the National Oceanographic Atmospheric Administration (NOAA) for the representative city. The first variable changed against the basecase was the climate. The TMY weather was warmed by the amount specified under the 2 x CO2 climate scenario produced by GISS. The simulation of the basecase buildings under warmed weather was defined as a second basecase scenario from which the study could test for changes in energy performance due to the adaptation of design changes.

A very limited number of strategies for improving the energy performance of the selected buildings could be tested. It was felt that each strategy should be tested against all building types, in all cities/climate regions under the 2xCO2 climate scenario. The magnitude of the parametric approach defined that each strategy for improving the energy performance would require thirty building energy simulations. The scope of writing the simulations and assessing the resulting data within the time frame of the study limited the number of alternate strategies to be tested to four. The four generic changes in design strategy were chosen.

1. Lowering the lighting power density (LPD) by 50% **(Basecase-50% LPD).** The whole-building average lighting power density for office buildings constructed in the 1960's and early 70's was 4-6 watts per square foot. These maximum allowable levels have been reduced to 1.5-2.0 watts per square foot in the ASHRAE 90.1P standard. Energy utilized directly or indirectly to control lighting can contribute up to a 60% share of an office building's annual energy load. Reducing the lighting power density can be accomplished in several ways. The introduction of the mandatory use of daylight as a primary method of illuminating the interior environment can greatly reduce lighting energy use. This can also introduce other problems such as additional solar overheating and integrating the control of the electric lights with the

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[1] Atkinson, B.A., C.S. Barnaby, A.H. Wexler, and B.A. Wilcox; "Validation of CALPAS3 Computer Simulation Program", Proceedings of the Fourth Annual Meeting of the American Section of the International Solar Energy Society, Passive Systems Division, September, 1981

[2] ASHRAE 90.1P, Section 13 - "Building Energy Cost Method"

daylight. More efficient electric lighting technology is a second way to meet the strategy limits. In regions such as the Pacific Northwest, studies are underway with the Bonneville Power Administration's Energy Edge Commercial Building Design Assistance Program to test the implications of lower lighting power budgets. These demonstration program's indicate that power budgets in the range of half the presently mandated ASHRAE 90.1P standard are demonstrable with present technology.

2. Increasing the building skin's insulation by 50%.**(Basecase+50% Insulation).** In commercial buildings of the south where insulation standards are presently low, this strategy would generally add up to 4" in thickness to the exterior wall with present insulating technology. This could be accomplished fairly simply. In Northern climates, especially in the residential sector, this additional wall thickness would require the institutionalization of whole new methods of construction to accomplish the needed 12" to 24" insulation thickness. Another strategy would be to reduce window area, thus increasing the overall insulation of the skin. This has obvious detrimental effects on the quality of the workplace that would have to be considered. New insulation technologies would have to be explored to accomplish much of this insulation strategy. These technologies would include expanded research in new technology windows with "smart" insulation.

3. Decreasing the sunlight transparence of the windows by 75%. **(Basecase+75% Window Shade).** The simplest way to reduce sunlight penetration is to reduce the amount of window area. The lower limits of this strategy have obvious habitability problems. The addition of dense shading to the windows of building can greatly reduce sunlight penetration and can be accomplished in many ways with existing technology.

4. Combination of reducing lighting, increasing insulation, and decreasing sunlight transparence in the amounts described above.**(Basecase with all Combined Energy Reduction Scenarios)**

The central purpose to these choices was to reduce the cooling loads that were increased due to the warmed climate scenarios. The following Section 3.0 , SIMULATION, documents the results of those parametric simulations.

2.1.3. Implications of Simulation Method

The time frame of this study, 10 weeks, and quality of the available "warmed" weather data, required that that we chose a simple but relatively precise computer tool. These restrictions required that we chose software with a highly modular input structure. Such an input structure describes the building in modules consistent with a standard software spread sheet. This quality enables the person writing the building description to establish a large number of variables, and to change them easily. If the simulation software is written correctly, data input files can be written directly by the spread sheet. This quality is uniquely true of CALPAS3. Therefore, It was chosen as the study's simulation software because it provided the most accurate type of simulation, hourly and transient, as discussed earlier. It was compatible with the modular input structure required by the short time frame of the study, and its weather files could be created within a several week period.

There are several significant limitations to the use of CALPAS3, however. The structure of the programs does not allow the unusual scheduling of internal loads, other changes in dry bulb temperature. We believed that this might have an notable effect of cooling requirements, thus we chose to simulate two cities in the US.DOE Zone 5, Fort Worth , hot and dry, and Charleston, hot and wet.

After choosing the representative cities, the GISS 2xCO2 computer tape climate scenarios were read by a Fortran computer program supplied by NCAR. This program read the GISS weather tape and plotted the dry bulb temperatures on a 15 degree grid of latitude and longitude points across the continental United States. Monthly mean 2xCO2 temperatures of the representative cities were then interpolated from the longitude and latitude grid of GISS/NCAR temperature scenario values. These monthly mean 2xCO2 temperatures were then sent to Berkeley Solar Group (BSG). BSG then modified the Typical Meteorological Year (TMY) computer weather tapes' hourly temperatures for each city based on the GISS/NCAR adjusted mean monthly temperature values.

2.2.4. Implications of Climate Selections

In simplifying the representation of the continental United States to six cities, one must always ask, what was left out? The answer is, when related to all the variables of climate, not just dry bulb temperature, a great deal was left out. This is a very simplified model of climate and therefore general building response. There is an idiosyncratic quality about each one of the city choices. It may be located within a specific climatic region, but it will always be easily differentiated from many of the other cities in the region. It will therefore be very important to follow up on this preliminary study with research on the structure of climate regions, global warming, and the fundamental relationship between these changing regions and energy use in buildings.

Table 2.2.3
Monthly Mean Temperatures for Selected Cities under Present (1xCO2) and Future Warmed(2xCO2) GISS Climate Scenarios

MONTHS	1	2	3	4	5	6	7	8	9	10	11	12
Charleston, SC												
1 x CO2	58.6	58.5	66.2	74.7	80.8	84.6	88.0	86.3	84.3	73.8	67.7	60.6
2 X CO2	66.5	66.5	77.1	83.6	86.8	89.6	95.0	93.3	94.9	81.8	80.7	70.5
Fort Worth, TX												
1 x CO2	44.6	49.5	53.8	63.9	70.8	80.3	86.1	83.7	74.5	67.1	56.7	46.3
2 X CO2	52.3	57.9	64.0	72.0	76.3	87.5	93.0	90.9	80.9	76.0	68.1	57.1
Knoxville, TN												
1 x CO2	37.5	40.0	48.2	59.9	68.1	74.5	77.5	77.2	73.0	59.1	46.9	41.3
2 X CO2	45.5	47.0	59.3	68.4	74.5	81.5	83.5	83.2	84.0	67.7	58.0	49.8
Chicago, IL												
1 x CO2	24.9	26.2	35.1	49.1	60.5	71.8	75.0	74.0	66.4	55.8	42.0	28.7
2 X CO2	35.0	33.7	44.1	57.6	67.0	77.8	81.5	81.0	75.5	62.8	50.0	39.7
Minneapolis, MN												
1 x CO2	10.4	17.7	27.9	47.3	58.0	68.7	73.5	70.8	61.7	50.3	34.2	18.4
2 x CO2	21.0	27.9	37.9	55.8	63.1	74.7	78.5	77.3	72.2	57.3	44.7	29.5
Seattle, WA												
1 x CO2	38.9	42.2	42.9	46.6	53.4	59.0	62.7	63.5	58.7	51.1	46.3	40.3
2 x CO2	47.0	49.7	48.8	52.5	59.6	65.5	69.1	71.4	67.3	57.3	52.1	45.8

2.3. Description of Building Types

The commercial building sector of the US economy is very diverse, but not without common characteristics that are generalizable as building types. Buildings with common qualities such as function, physical dimensions, or internal heat generating density become the qualities around which there is a record of building classifications. According to the U.S. DOE, the principal building activity classification system is based upon "...the primary business, commerce, or function carried out by the occupants of a building."[5] This categorization of building types was designed to group buildings into classes which share similar patterns of energy consumption. The definition of "Building Type" rests on the predominance of

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[55] NBECS, Appendix C, p. 163

one activity in a building, as measured by the square footage devoted to that activity. Thus other activities may take place within a building which has a singular classification.

Other methods of classification are in development which determine building-type definition on a more sophisticated level.[6] Such classification relies upon statistical correlations which are more representative of building energy use. This level of sophistication is beyond the scope of our study. However, such a classification system in combination with more detailed computer simulation techniques will prove invaluable in later studies.

Both the US Department of Energy and Department of Housing and Urban Development have proposed classification systems based on the building's primary function or activity associated with the building's occupants. While the US/DOE BEPS study included the widest set of types, it is not supported by the broadest set of building data. The US/HUD NBECS study included the best generic data base, but had the fewest type categories and therefore the mean values often over simplify the range of surveyed buildings. In order to cluster the fullest range of buildings into a limited set of types, this study has chosen to use a composite set of types taken primarily from HUD/NBECS and augmented with USDOE/BEPS data for large clusters of types not easily covered in NBECS.

The residential building sector is more homogeneous than the commercial sector, but the prescriptive standards of construction are not nationally available as they are in the ASHRAE 90.1P standard. The NBECS data base was the best source of building types, again augmented with USDOE BEPS information.

The range of building types that were drawn upon to produce a core of sample buildings included the following:

Commercial Building Types:

1. Health
2. Lodging
3. Large Office
4. General Office
5. Educational
6. Mercantile
7. Assembly
8. Warehouse
9. Food Service

Residential Building Types:

10. High-Rise Multi-Family
11. Low-Rise Multi-Family
12. Single Family Detached
13. Single Family Attached
14. Mobile Home

This group of building types is similar to that used by DOE in its study of commercial and residential building characteristics, as published by the Energy Information Association. Two publications, the *Nonresidential Buildings Energy Consumption Survey* (NBECS)[7], and the *Residential Energy Consumption Survey* (RECS)[8], provide a comprehensive source of building characteristics. The data are grouped to show relationships between particular occupancy categories and the distribution of such occupancies according to location, climate, square footage, age, and a variety of other factors. In order to take advantage of this data source, we organized our building samples into similar classifications.

These building-type designations are based upon the primary function or activity associated with the building's occupants. Following are the U.S. DOE categories and descriptions where applicable. The changes and/or deletions we have made to this classification system are discussed in the next section, 2.3, "Building Data Sources".

D.O.E. Commercial Occupancy Categories[9]:

1. *Assembly* refers to large building used for the gathering of 50 or more persons for social, recreational, or religious activities.
2. *Education Buildings,* house academic or technical instruction. This category includes: Preschool, Elementary, Junior High, Senior High, College or University, Vocational School. Buildings used for other than instructional purposes, such as the Gymnasium or Dormitory buildings found on school campuses, are recorded in the appropriate classifications such as Assembly or Lodging.
3. *Food Sales and Service* buildings
4. *Health Care* buildings house diagnostic and treatment facilities for both in and out-patient care.
5. *Lodging* facilities refer to buildings offering multiple accommodations for long or short-term residents.
6. *Mercantile Sales and Personal Services* buildings are those housing sales and displays of goods or services (excluding food).
8. *Office* buildings are use for general office space, professional offices and administrative offices.
9. *Warehouse* buildings are used for the storage of goods, merchandise, raw mtls., or manufactured products.

DOE Residential Occupancy Categories[10]

1. *Single-Family Detached*
2. *Single-Family Attached*
3. *Building of 2 to 4 Units*
4. *Building of 5 or More Units*
5. *Mobile Home*

Note: DOE residential characteristics were also grouped according to ownership (or rental) status for each type.

2.3.1 Building Data Sources

The NBECS commercial building survey included three building-type categories which are not included in our study. The "Vacant" building category was deemed non-classifiable because the buildings were not described or occupied; "Other" buildings (including Parking Garage, Hangar, Crematorium, Laboratories, etc), were likewise non-classifiable for our purposes; and lastly, a "Residential" classification was not utilized due to its broad scope (included within this category were both multi-family and single-family categories). The residential building types were instead characterized using the RECS data and other sources, as outlined below.

The primary weakness in the DOE building characteristics data relates to the variation of activities and the lack of specificity concerning size-parameters within each classification. The more sophisticated modelling

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[6] Gas Research Institute and Battelle Pacific Northwest Laboratories, "Segmentation of Office Building Sector for Energy Use Analysis," Gas Research Institute, 1988

[7] NBECS, Appendix C, "Building Types", p 163

[8] RECS, Residential Energy Consumption Survey: Housing Characteristics 1984, Energy Information Administration, Office of Energy Markets and End Use, U.S. DOE Washington, DC, (DOE/EIA-031(84)

[9] NBECS Appendix C "Building Types" p. 163

[10] Residential Energy Consumption Survey: Housing Characteristics 1984, Energy Information Administration, Office of Energy Markets and End Use U.S. DOE Washington, DC, (DOE/EIA-031(84)

techniques addressed previously by the Gas Research Institute would reduce the inherent over-simplification.

For our study, it was satisfactory, given the simplifications in the simulation process, to utilize the U.S. DOE characteristics in formulating "average" building types. We utilized a secondary source, *Building Energy Performance Standards Phase III(BEPS)*[2], to augment the DOE characteristics data in two areas: In the case of commercial building types, we created a "Large Office" category using only BEPS data; and, in the case of the Residential category,BEPS data was correlated with DOE residential characteristics data (obtained from RECS), in the development of residential simulation models. The methodology and reasoning are outlined in the next section.

2.3.2. Choice of Building Types for Study

Our choice of prototypical buildings was based upon the availability of reliable data concerning the following parameters: Statistical characterization of physical dimensions (mean value parameters); proportion of total building stock (by square footage); geographic distribution of Type (by square footage); climate-zone distribution of Type (by square footage); and, on the availability of current envelope characteristic prescriptions (as formulated by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, ASHRAE, and appropriate government jurisdictions). The shortcoming of this approach is that the buildings represent some minimum standard mean building which may simulate well but does not represent a very believable building in the architectural sense.

The building types 1 through 14 listed in Section 2.3, are U.S. DOE classifications with the following exceptions:

1. The Large Office sector was developed using BEPS data.
2. Classification for Multi-Family Residential groups (Low-Rise and High-Rise) were obtained from BEPS and ASHRAE 90.1P.
3. Single-Family Detached and Attached categories were developed from NBECS, with factors for aspect ratio and number of floors determined using BEPS data.

The reasoning for substitution is as follows: Concerning the Office category, the DOE NBECS classification includes small office buildings and large office buildings in one group. This broad classification is represented in our study as "General Office", and DOE information was averaged to determine characteristics for this building group. However, the NBECS census data indicates that over half of the office building square footage is attributed to buildings having "More Than Three Floors". Table 2.3.1 illustrates the distribution of office building area:

Table 2.3.1 Office Dist. by No. of Floors[11]:

No. of Floors	No. of Buildings	Square Footage	Percent
1	289,000	1,368,000	16.2
2	153,000	1,458,000	17.2
3	81,000	1,295,000	15.3
3 +	52,000	4,333,000	51.3
All Groups	575,000	8,454,000	100.0

We felt it would be useful to model the Large Office sector more accurately. BEPS provided a means for non-arbitrary characterization of this sector.

The BEPS phase III study represents a sensitivity analysis for specific structures. In that study, buildings which were analyzed in an earlier (Phase II) study were grouped by a statistical analysis of their physical characteristics and their energy performance. Mean values for these qualities were compiled. These qualities then became the basis for representative categories of building types . BEPS classifications are similar to NBECS and RECS classifications However, the BEPS categories are based upon the phase II study (and correlation with ASHRAE classifications) and do not represent DOE census data as published in NBECS and RECS. In our study, we utilized the summary listings in the US.DOE. Building Energy Performance Standard. The Large Office Building type characterization utilized Building Data Sheet: Number 25, Large Office Building[12] "mean" values.

In their Multi-Family category, DOE RECS data used two groupings, "2-4 Units" and "5 + Units". To gain a more defined representation of this sector, we utilized the BEPS and ASHRAE classifications- Multi-Family Low-Rise buildings were characterized as residential structures of three floors or less; Multi-Family High-Rise structures were three or more floors BEPS data was used in the definition of the High-Rise category. Small Multi-Family structures were characterized by averaging of the RECS data for buildings with 2-4 units. The RECS values for 5+ Unit buildings were averaged and included for comparison, though the imprecise nature of this classification makes it less reliable for in-depth simulation. It should be noted that the Multi-Family High-Rise classification is given a commercial designation by ASHRAE for the purpose of energy performance criteria.

In modelling the Single-Family residential sector, we relied upon BEPS data to augment RECS statistics for the "Detached" and "Attached" residential classifications. The BEPS study used prototypical building types developed by the National Bureau of Standards and the American Institute of Architects Research Corporation for analysis purposes. As the RECS data contained no information on the number of floors or length to width (aspect ratio) relationships, the BEPS values for these factors were utilized with RECS data (concerning mean square footage) to arrive at specific building simulation models.

With regard to the "Mobile Home" category, several unit sizes are in existence, in widths ranging from 10 to 14 feet. We contacted local mobile home distributors and 14 foot widths were given as a current industry standard. This width was applied to RECS average square footage data to determine the aspect ratio and overall simulation model.

Work needs to be done in characterization of the residential sector for purposes of accurate representation. However, the scale of single-family residential structures, which vary only slightly in comparison with the range of commercial structures, makes the impact of descriptive errors less crucial in the simulation process

Aspect Ratios and Building Orientation

For the purpose of computer simulation, the aspect ratio for commercial buildings was taken to be 1 : 2.5, as prescribed by ASHRAE 90.1P for comparative analysis

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[11] BEPS, Building Energy Performance Standards, Phase III, Energy Information Administration, U.S. D.O.E., Washington DC, DOE/CS/20531--T6 DE83 015066 "The Ehrenkrantz Group" (Draft Copy), P. 170.

[11] Adapted from NBECS Table 5., "Number of Floors, 1983", p.59

[12] BEPS, p 46

TABLE 2.3.2 REGIONAL DISTRIBUTION OF COMMERCIAL BUILDING TYPES[13]

TYPE	ALL BUILDINGS		NORTHEAST		NORTH CENTRAL		SOUTH		WEST	
	NUMBER	SQ.FT.(mil	NUMBER	SQ.FT.(mil)	NUMBER	SQ.FT.(mil	NUMBER	SQ.FT.(mil	NUMBER	SQ.FT.(mil
ALL	3948	52.30	670	11.60	1211	16.10	1493	17.00	574	7.60
ASSEMBLY	457	5.48	61	1.05	149	1.70	202	1.84	45	
EDUCATION	177	6.04	28	1.37	39	1.83	79	2.08	31	0.75
FOOD SERVICE	380	2.05	58	0.39	120	0.72	145	0.62	57	0.32
HEALTH CARE	61	2.28	11	0.50	21	1.02	20	0.57		193.00
LODGING	106	2.24	13	0.42	12	0.67	57	0.80	24	0.35
MERCANTILE	1071	10.43	183	2.04	353	3.22	383	3.84	151	1.33
OFFICE	575	8.45	97	1.77	176	2.18	191	2.90	112	1.60
RESTAURANT	236	2.45	97	1.34	78	0.72	44	0.30	16	0.10
WAREHOUSE	425	6.79	57	1.22	131	2.13	170	2.29	68	1.15
OTHER	179	2.76	20	0.84	50	0.88	87	0.64	22	0.40
VACANT	281	3.34	46	0.66	80	0.94	114	1.17	41	0.57

purposes.[14] To gauge the project's sensitivity to this parameter, we modeled a series of base-case (un-warmed, 1 x CO2) simulations in which the aspect ratios were derived from BEPS building examples. The Phase III building examples provided actual plan configurations. In the case where single buildings were considered representative of the type, we used that building's dimensions for the derivation. In the case where several buildings represented the category, the building proportions were averaged (with long and short dimensions averaged consistently across the range of example buildings).

The BEPS aspect ratio cannot be held as an average value, for there is a wide proportional variation in the shape of many building types; and in fact many of the smaller occupancy groups are not housed within particular facilities as are occupancies such as schools, hospitals and large office buildings. However, given the simplifying assumptions inherent in the energy simulation process (simplifications that are vital in a study of this scope), the use of these aspect ratios provided a method for comparison based upon physical examples. A preliminary analysis of the effects of orientation on the performance of prototype commercial buildings indicated a difference of 5-8% in energy requirements due to elongation of the building plan's aspect ratio on a north/south axis versus east/west axis. the ASHRAE 90.1P Standard proscribed the 2.5:1 aspect ratio and an elongation of orientation along the north/south axis.

In the case of the residential building sector, Multi-Family structures are covered by the ASHRAE commercial standard, and used the ASHRAE prescribed 1:2.5 aspect ratios. The other residential categories were modified with a secondary data source as outlined at the beginning of this section, *Choice of Building Types for Study*. We utilized BEPS prototype descriptions to determine aspect ratios for the Single Family Detached and Attached categories. Mobile Home configuration was determined by the application of a standard 14 foot width to DOE average square footage data.Given the range (1-14) of building types, we used the census data available in NBECS and RECS to determine which Types were significant portions of the national building stock. Then physical and energy-use characteristics were used to cluster the range into a manageable number of study samples. This prioritization resulted in a final set of five basic building types which could be simulated for each of our six cities. Computer simulation of energy performance was conducted for each of the five "clustered building types". This set of results simulated under existing weather conditions formed the *base-case* data. The same building types were then simulated using the "warmed climate" data supplied by the Goddard Institute for Space Studies (GISS) through the National Center for Atmospheric Research (NCAR).

2.3.3. Buildings and Building Types by Location and Population Area

In arriving at figures for the distribution of buildings and building types, we utilized the Department of Energy's NBECS and RECS information . From these sources, certain features of this distribution can be noted such as commercial building distribution and the percentage of square footage according to census region:

This data illustrates that the Mercantile sector houses the greatest amount of square footage (19.9% of the commercial total), followed by the Office Building sector (housing 16.2% of the commercial total). Other significant occupancies after these two are:

Table 2.3.3: Metropolitan Status of Building Types[15]

PRINCIPLE ACTIVITY	ALL BUILDINGS		METROPOLITAN		NON-METROPOLITAN	
	SQ.FT.(mil	% of Catagory	SQ.FT.(mil	% of Catagory	SQ.FT.(mil	% of Catagory
ALL	52,325	100.00	37,587	71.80	14,738	29.00
ASSEMBLY	5,483	10.40	3,576	65.20	1,907	35.00
EDUCATION	6,044	11.50	4295	71.00	1,749	29.00
FOOD SERVICE	2,051	3.90	1,300	63.40	751	36.60
HEALTH CARE	2,277	4.30	1,760	7.30	516	22.70
LODGING	2,241	4.20	1,617	72.10	624	27.80
MERCANTILE	10,427	20.00	6,651	63.80	3,776	36.20
OFFICE	8,454	16.10	7,040	83.20	1,414	16.80
RESTAURANT	2,454	4.70	1,912	77.90	542	22.10
WAREHOUSE	6,791	12.70	4,641	68.30	2,150	31.70
OTHER	3,342	6.40	2,518	75.30	824	24.70
VACANT	2,760	5.20	2,275	82.40	485	17.60

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[13] Adapted from NBECS Table 8, p 65

[14] ASHRAE 90.1P. Section 13.7.1, "Orientation and Shape", p 13-8

[15] Adapted from NBECS, Table 9, p 67

Table 2.3.4 Distribution of Commercial Building Types by Climate Zone

COOLING DEGREE DAYS	<2000		<2000		<2000		<2000		>2000	
HEATING DEGREE DAYS	>7000		7000 - 5000		5499 - 4000		4000 & LESS		4000 & LESS	
	SQ.FT.(mil	% Catagory	SQ.FT.(mil	% Catagory	SQ.FT.(mil	% Catagory	SQ.FT.(mil	% Catagory	SQ.FT.(mil	% Catagory
ALL BUILDINGS	5,725	10.90	16,965	32.40	13,793	26.30	7,496	14.30	8,348	16.00
ASSEMBLY	554	10.10	1,760	32.00	1,638	29.90	460	8.40		
EDUCATION	722	11.90	2,055	34.00	1,597	26.40	697	11.50	973	16.00
FOOD	302	14.70	741	36.10	368	17.90	311	15.20	329	16.00
HEALTH CARE	201	8.80	1,213	53.30	272	11.90	400	17.60		
LODGING	146	6.50	728	32.50	537	24.00	292	13.00		
MERCANTILE/SERVICE	1,353	13.00	2,463	23.60	3,485	33.40	1,489	14.30		
OFFICE	728	8.60	2,611	31.00	2,031	24.00	1,348	15.90	1,736	20.50
RESIDENTIAL	342	13.90	973	39.60	970	39.50				
WAREHOUSE	770	11.30	2,080	30.60	1,547	22.70	1,507	22.20	888	13.10
THEATER			1,180	42.80	616	22.30	324	11.70	361	13.10
VACANT	326	9.80	1,160	34.70	731	22.00	596	17.80	528	15.80

Warehouse- 13%; Educational- 11.6%; Assembly- 10.5%.

Together, these five classifications account for 71% of the total square footage in the NBECS data. Though it should be noted that the relative standard errors in the case of the "Mercantile Services" category is 11.5%, and that this data is by its surveyed nature, only approximate.
Table 2.3.2, reveals that of these major building populations, every category shows the greatest amount of square footage to be concentrated in the "South" Census Region.

In addition, Table 2.3.3 shows that an average 65-70% of the commercial building stock is situated within metropolitan zones (83.2% for the office sector).

Another data grouping that is useful in characterizing the commercial building sector is the breakdown of square-footage according to climate-zone location:

Table 2.3.5 Residential Building Stock[17]

TYPE	%	HEATED SQUARE FEET
S.F. DETACHED	73.9%	91.8 Bil. sf
S.F. ATTACHED	5.4%	6.4
M.F. 2-4 UNIT	8.6%	10.7
M.F. 5+UNIT	8.8%	10.9
MOBILE HOME	3.4%	4.2

The data concerning many of the building types for the zone having an annual cooling degree-day summation in excess of 2000 CDD is missing. However, it is significant that 20% of the office sector shows up in this cooling dominated climate. In addition, over 30% of the commercial building stock is designated as being situated in the warmest two of the five zones.

RESIDENTIAL BUILDING TYPES:
From the RECS data, it can be seen that by far, the single family detached dwelling unit houses the greatest percentage of "households".

The RECS data shows a large number of these Single-Family Detached homes (38.7%) as being located in the south while attached single family dwellings such as row-houses tend to predominate in the Northeast region. RECS data shows 45% of the Mobile Home households to be located in the South.

The distribution of residential buildings is documented through the U.S. Census Regions and detailed in Table 2.3.6: (in terms of millions of households)

Table 2.3.7 documents the predominate locations of those households with regard to climate. Climate Zones 2, 3, and 4 contain 74% of the households, 15% of the households are within the cooling dominated Zone 5, while 10% of households are in the heating dominated Zone:

Table 2.3.6 Regional Distribution of Housing Stock[18]

TYPE OF HOUSEHOLD	TOTAL NO. OF HSHLDS	HSHLDS NORTH EAST	HSHLDS NORTH CENT	HSHLDS SOUTH	HSHLDS WEST	HSHLDS METRO.	HSHLDS NON-METRO
	(millions)	(millions)	(millions)	(millions)	(millions)	(millions)	(millions)
ALL	86.30	18.30	21.60	29.30	17.10	65.70	20.60
SINGLE-FAM. DET.	53.50	9.10	13.70	20.70	10.00	37.80	15.50
SINGLE-FAM. ATT.	4.10	1.60	0.90	1.10	0.30	3.80	0.30
MULTI-FAM 2-4 UNITS	10.00	3.20	2.80	1.70	2.30	8.90	1.20
MULTI-FAM 5+ UNITS	13.60	3.60	3.10	3.50	3.40	12.60	1.00
MOBILE HOME	5.10	0.70	1.10	2.30	1.00	2.70	2.40

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[16] Adapted from NBECS Table 10, p.67

[17] RECS: Table 17, p.34,

[18] RECS Table 8, P.65

Table 2.3.7 Distribution of Housing Stock[19]

DOE WEATHER ZONE	MILLIONS OF HOUSEHOLDS
ALL ZONES	86.3
1 <2000 CDD & >7000 HDD	9.0
2 <2000 CDD & 5500-7000 HDD	21.5
3 <2000 CDD & 4000-5499 HDD	22.5
4 <2000 CDD & <4000 HDD	20.0
5 >2000 CDD & <4000 HDD	13.3

2.3.4 Building Codes as a Basis for Defining Building Characteristics

Once the range of building-type categories was established, the identification of building surface and internal heat generating characteristics had to be delineated. Current and proposed building code standards became the basis from which assumptions of the mean building characteristics of the selected building types were made. These thermal building characteristics formed the basis for thermal simulation. In determining prototypical energy performance characteristics related to the future U.S. building stock, we used the ASHRAE 90.1 P Proposed American National Standard as a basis for commercial building parameters. In the case of characterization of the residential sector, except for high-rise residential, ASHRAE National Standards for residential energy efficient construction are only now under the earliest states of review. In the absence of an adopted or proposed standard we relied upon the California Title 24 State Residential Building Energy Code[20] as a basis for our assumptions. The California Code bases its prescriptive standards for building components on degree days, thus dry-bulb temperature. Other mitigating factors such as relative humidity, solar radiation, wind speed do not play a significant role in the characterization of the California climate regions. Assessing only the temperature characteristics of the nationally selected locales, we were able to find cities, climate regions, in California that closely corresponded to each of the national cities assessed under this study. Given that the primary climate characteristic assessed under the 2xCO2 scenario was temperature, we felt this method of simplification was well justified. High-Rise Multi-Family structures were described using ASHRAE'S commercial building guidelines. In addition, Mobile Home characteristics were based upon HUD National Standards For those structures [21]

Commercial Building Load Characteristics:
The ASHRAE 90.1 standards determine building envelope characteristics based on a number of factors. The primary factors consist of the climatalogical location; and the nature of internal load levels (the loads generated by lights, equipment and the inhabitants) With a given location and climate zone, the internal load characteristic of the building determines the overall percentage of glazing that will be allowed (this figure is in turn modified by coefficients for shading, thermal mass and daylighting strategies). Thus, building envelope characteristics are dictated by climate, internal load ranges and the aforementioned coefficients. It is beyond the scope of this study to model the full range of modifiers for each specific building, and we have used the ASHRAE standards without such adjustments. ASHRAE provides a flow chart used to determine the commercial building characteristics[22] This methodology allowed for a consistent relationship between a building's internal load generation and its envelope characteristics. At the same time, ASHRAE data was the basis for determination of the original internal load characteristics

Residential Building Load Characteristics:
As there are no adopted national standards for residential energy performance standards, we used the California Title 24 Building Code as our prime source in determining envelope characteristics. The California code is relatively stringent (comparable with the Pacific Northwest's Model Conservation Standards), and that state is unique in having representations of all five climate zones as used in this study and by the D.O.E. in it NBECS and RECS studies.

In our study, we matched the California Title 24 Climate Zone[23] descriptions (there are 16 climate zones described in Title 24) with the base-case climates in our study. This was achieved by comparing the NOAA weather station climate data for California Title-24 zones with the ASHRAE climate zone descriptions.

The match of climates is not perfectly consistent owing to the variation of micro-climates across the continental U.S., however for the purposes of this study it provided a close correlation. As with the ASHRAE commercial standards, we chose the simplest available building categorization, omitting such factors as solar glazing, thermal mass and special HVAC equipment in determining code compliance

2.3.5. The Process of Creating Representative Buildings

In our selection of representative buildings, we relied upon the previously discussed NBECS and RECS as a sources for rudimentary characteristics. The BEPS study was used to modify these values in the case of the Large Office and Residential sectors.

As a starting point, we created simplified buildings using the DOE compiled mean square footage values. We then applied the ASHRAE 90.1P prescribed 1:2.5 aspect ratios (width and length relationship) in the case of commercial buildings; and we utilized BEPS data to determine aspect ratios for the residential sector and the special Large Office category. While the aspect ratio affects the volume-to-surface relationship, its determination was made, primarily to allow for variation of orientation (N-S and E-W), which requires some degree of rectangularity. This variation in orientation allowed us to begin to isolate the effects of solar insolation in the study. In their comparative analysis instructions ASHRAE specifies that the prototype building be oriented with the long dimension facing east and west.

We used ASHRAE prototype values for floor-to-floor heights. The specified heights for commercial buildings are 13 feet; and for Hotel/Motel and Multi-Family

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[19] From RECS, Table 16 p.198

[20] California Title 24, C.A.C., "Energy Conservation Standards for New Buildings of Occupancy R (Residential Buildings) Other than Apartment Houses with Four or More Habitable Stories and Hotels, Sec 2-5351.

21 H.U.D Standard for Mobile Homes 24 CFR Ch. XX (4-1-88 Edition), 3280

[22] From ASHRAE 90.1P (Tables 8A-1 to 8A-30, p.8-35 to 8-64).

[23] California Title 24, C.A.C., "Energy Conservation Standards for New Buildings of Occupancy R (Residential Buildings) Other than Apartment Houses with Four or More Habitable Stories and Hotels, Sec 2-5351.

buildings, 9.5 feet. We used a 9 foot floor to floor height for the Single-Family category.

Building Selections:
Upon completion of the building characterization process, it was necessary to cluster the data so as to narrow the range of types for in-depth simulation. This was done to economize on time due to the limitations of this study. Our goal was to limit the number of building examples such that the final set would be: a) Significant portions of national building stock; b) Representative of the range of energy-load characteristics; and, a final factor in prioritizing the range involved c) The degree to which satisfactory representation could be achieved for occupancy scheduling and internal load characterization.

For purposes of clustering data, each building was described in terms of Internal-Load Factor versus Envelope-Load Coefficient. The Envelope-Load Coefficient represents the combined effects of skin loads and infiltration for each simulation model. The Internal-Load Factor represents the sum of internal loads (people, lights and equipment) as determined from ASHRAE 90.1P. The Internal-Load Factor was represented both in terms of the (daily) Averaged Hourly, and the Maximum Hourly summation of internal loading. The two graphs are reproduced as Figures 2.11 and 2.12.

While both graphs are useful in comparison of simulation models, Figure 2.12 showing occupied hourly values was more critical in terms of our building prioritization. This figure is representative of projected actual values for internal loads (unlike the average hourly figures). It pinpoints the magnitude of internal loading that could be expected in a generally light-weight building constructed of contemporary materials. Working from this graph, with reference to the graph of average values, the following simulation set was defined:

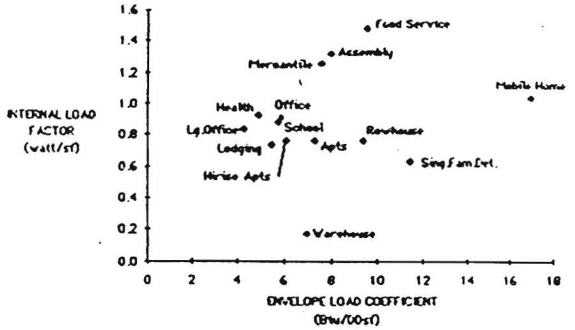

Fig. 2.11. 24 Hour-Average, Building Load Factors-By Building Type

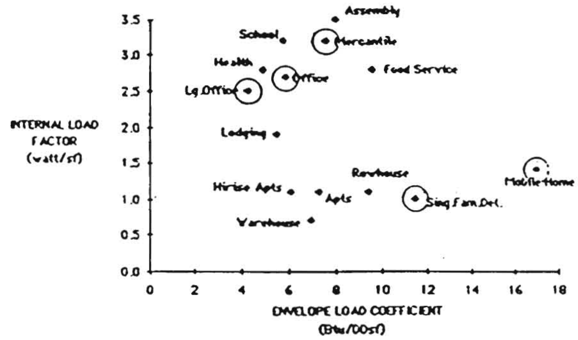

Fig. 2.12. Occupied Hourly, Building Load Factors-By Building Type

BUILDINGS CHOSEN FOR SIMULATION:

1. Mercantile
2. General Office
3. Large Office
4. Single Family Detached
5. Mobile Home

REASONS FOR CHOICES MADE:
Simulated Building Types
1. *Mercantile* was chosen because of its significance in building stock. It represents 20% of the total commercial square footage according to Table 2.3.3. In addition, it represents the high range of internal loading as illustrated in Figure 2.12.

2. *General Office* was chosen as a representative of the mid-level range of internal loads combined with low Envelope-Load Coefficient. According to Table 2.3.3 this category is the second highest in proportion of commercial building stock, representing 16.1% of the total.

3. *Large Office* was chosen as a subset of the General Office sector. While its Internal-Load Factor is less than the general sector, its very low Envelope-Load Coefficient makes this building type one of the boundary points in the data-spread. In addition, offices of more than 3 floors constitute more than 50% of the category square footage (Table 2.3.1). The actual DOE census distribution of this sector is indeterminate. However, the magnitude of internal loads prevalent in this building type gave its performance added weight in prioritizing simulation choices.

4. The Single *Family Detached* building type constitutes a large proportion of residential square footage (73.9% from Table 2.3.5). While it does not represent the most central value for the low Internal-Load Factor cluster in Figure 2.12, its significance in terms of residential representation made it a prime choice.

5. *Mobile Home* was selected due to its character as an extreme data point (Figure 2.12). It was relatively easy to model. In addition, the character of housing market forces have the potential for increasing this sector's representation in the residential building stock (It now constitutes 3.4% of total square footage, Table 2.3.5). Again it should be noted that HUD standards were used in determining the building's characteristics rather than the California State Title 24 Energy Code, as with the other residential prototypes. The HUD standard is a much less stringent energy standard. Therefore, a direct comparison to other residential types should be done with caution.

Building Types Not Simulated:
- *Health Care* was discarded due to the difficulty in determination of accurate internal load scheduling. In average load values, it is closely associated with the modelled Office categories.

- *Lodging* was discarded for its non-significance in the national building stock (4.2% of total commercial square footage, Table 2.3.3). In addition, modelling accurate occupation schedules was difficult due to the nature of use, and unpredictability of that use.

- *Food Service* was discarded primarily for its modelling difficulties, and for its relative non-significance in building square footage (at 3.9% it was the lowest proportion of building stock, Table 2.3.3). However, it represents an energy-intensive occupancy, and given more intensive simulation techniques (accounting for process loads), it would be useful to model this sector in future studies.

- *Assembly* was discarded to to the unreliable characterization of the building occupancy classification. DOE's broad designation included open-air structures and a large variation of building sizes. Reliable occupancy scheduling was impossible to determine for this category in a study of this scope. Future disaggregation of uses such as theater would be possible.

- The *Educational* category showed high internal loads, and in our data, was clustered with the Mercantile category. Its proportion of total building stock (11.5%, Table 2.3.3) is significant. For reasons of modeling economy, it was decided to model Mercantile as the representative of that range.

- *Warehouse* constituted an overly broad category- some DOE building examples were refrigerated, some were not. Reliable scheduling of internal loading was not possible.

- The *Multi-Family* and *Rowhouse* classifications were clustered near the Single-Family Detached category in our data graphs. For the purposes of modeling economy, we discarded these options in favor of the more significant Detached category, and the more unique Mobile Home category.

2.3.6. Implications of Building Type Selections

The building types selected represent clusters of mean building characteristics. The Gas Research Institute[24] method of clustering buildings by energy end-use, fuel type and physical building characteristics goes considerably farther in creating a more homogeneously clustered class of buildings. The heterogeneous aspects of the building type classification system used in this study should be assessed carefully before conclusions are drawn for buildings too distant from the cluster. This would be true for building types like lodging buildings. More analysis of this classification and other out-lying types should done. Secondly, the building types simulated in each city were homogeneous in construction. In reality there would be a wide mix of construction types, varying in assembly type, depending on the time in which they were constructed. Using state-of-the-art building codes to characterize building assembly is a straight forward method for assembling a cross section of generic buildings for analysis. This is especially true within the time frame of the study. Further analysis should be undertaken to assess the mix of construction types and therefore energy demand characteristics in the time limits of the climate scenarios.

Table 2.3.8 Summary of Physical Characteristics for Commercial Building Types

Type of Occupancy	L (ft)	W (ft)	Footprint Area (sf)	No. Flrs	Gross Flr Area (sf)	Flr-Flr Height (f)	Occupied Internal Gains Lights (watt/sf)	Occupied Internal Gains Equipment (watt/st)	Occupied Internal Gains People	Infiltration + Ventilation (sf/occ)
Health	307	123	37,761	3.2	120,835	13	1.5	1.0	200	0.101
Lodging	230	92	21,160	3.1	65,596	13	1.4	0.3	250	0.186
Office	192	77	14,784	3.0	44,352	13	1.7	0.8	275	0.125
Large Office	221	88	19,448	8.6	167,253	13	1.5	0.8	275	0.083
School	292	117	34,164	2.3	78,577	13	1.8	0.5	75	0.207
Mercantile	156	62	9,672	1.8	17,410	13	2.8	0.3	300	0.1467
Assembly	173	69	11,937	2.2	26,261	13	1.9	0.3	50	0.642
Warehouse	200	80	16,000	1.9	30,400	13	0.6	0.1	15,000	0.08
Food Serv.	116	46	5,336	1.7	9,071	13	2.0	0.1	100	0.412

Table 2.3.9 Summary of Climate-Dependent Building Characteristics for Commercial Building Types

City	DEGREE-DAYS					OCCUPIED INTERNAL LOAD RANGE					
						0-1.5 w/SF		1.5-3.0 w/SF		3.0-3.5 w/SF	
	Heating	Cooling	U-Value Floor	U-Value Roof	U-Value Glazing	U-Value Wall	% Glazing[1]	U-Value Wall	% Glazing	U-Value Wall	% Glazing
Charleston, SC	2194	2005	0.13	0.08	0.60	0.180	19	0.180	15	0.180	12
Ft. Worth, TX	2354	2448	0.11	0.06	0.60	0.150	19	0.150	15	0.150	12
Knoxville, TN	3818	1514	0.08	0.07	0.60	0.190	16	0.190	13	0.190	11
Seattle, WA	5281	106	0.06	0.07	0.60	0.096	24	0.09	22	0.096	21
Chicago, ILL	6151	1015	0.05	0.05	0.60	0.080	21	0.080	19	0.080	18
Minneapolis, MN	8060	773	0.04	0.05	0.60	0.069	19	0.069	18	0.069	17

Table 2.3.10 Summary of Physical Characteristics for Residential Building Types

Type of Occupancy	L (ft)	W (ft)	Footprint Area (sf)	No. Flrs	Gross Flr Ar. (sf)	Flr-Flr Height (f)	Occupied Internal Gains Lights (watt/sf)	Occupied Internal Gains Equipment (watt/st)	Infiltration People (sf/occ)	Infiltration + Ventilation (Avg.Ac/hr)
Sg. Fam.Det	45	30	1,350	1.0	1,350	9.5	0.6	0.2	375	0.75
Row House	39	21	819	2.0	1,638	9.5	0.7	0.2	225	0.75
Lwrse Apts	248	75	18,600	2.8	52,080	9.5	0.7	0.2	225	0.75
Hghrse Apts	148	59	8,732	10.5	91,686	9.5	0.7	0.2	225	0.75
Mble Hm	50	14	700	1.0	700	9.5	1.0	0.2	200	0.75

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[24] Gas Research Institute and Battelle Pacific Northwest Laboratories, "Segmentation of Office Building Sector for Energy Use Analysis," Gas Research Institute, 1988

Table 2.3.11. Summary of Climate-Dependent Building Characteristics for Residential Building Types

City	DEGREE-DAYS						
	Heating	Cooling	U-Value Floor	U-Value Roof	U-Value Glazing	U-Value Wall	% Glazing[1]
Charleston, SC	2194	2005	0.053	0.033	0.65	0.053	14
Ft. Worth, TX	2354	2448	0.053	0.033	0.65	0.053	14
Knoxville, TN	3818	1514	0.053	0.033	0.65	0.053	14
Seattle, WA	5281	106	0.053	0.026	0.65	0.053	16
Chicago, ILL	6151	1015	0.053	0.026	0.65	0.053	16
Minneapolis, MN	8060	773	0.053	0.026	0.65	0.053	16

3. ENERGY SIMULATION RESULTS

Computer simulations of the five representative building types, in six cities, under six different physical or environmental parameters, indicates that generally, buildings will require a great deal more energy both annually and during cooling peak demand periods under the globally warmed conditions of this study's simulations. The timing, quantity and quality of their increased energy demands varies by climatic region and building type. A typological approach to the analysis based on building type and climate region provides the clearest results. As with the Section 2.0, The Methods of Characterizing Buildings, we will classify the results by describing the needs of buildings whose energy needs are:

> Dominated by the cooling requirements generated by their internal sources of heat - most often commercial buildings - Internal Load Dominated Buildings
>
> Dominated by the exterior climatic conditions. If its hot outside, they need cooling and if its cold outside they require heating. These buildings have few internal sources of heat and therefore their energy needs more directly correspond to the exterior climatic conditions. These buildings are most often residential buildings and are referred to as - Skin Load Dominated Buildings.

3.1. Internal Load Dominated Buildings

Three building types were simulated to represent the performance of the range of internal load dominated buildings:

- Mercantile/Retail
- Small Office Buildings
- Large Office Buildings

MERCANTILE/RETAIL - The retail building as a representative of the Internal Load Dominated Building category represents the largest portion of the commercial sector of buildings, and had the second highest level of internal heat generation while it was occupied. It was second only to Assembly buildings, a much more inconsistently categorized set of buildings with a much smaller proportion of the population of commercial buildings.

Cooling was the predominate thermal energy load for the basecase building in all six cities' 1 x CO2 (non-warmed) climate . Thus, with the 2 x CO2 (warmed) climate, the cooling requirements become even more dominant. In the hot or warm climates of the south and southeast, the annual cooling demands increase between 35% and 45%. In the cooler climates of the north, annual cooling demands increase from 40% to 75%. The predominant cooling load varies with climate region. In cooler climates, the heat generated from electric lights is a dominant load, while in hotter climates, the effects of the extremely hot exterior temperatures and heat gain from sunlight dominate the cooling requirements. In all cases, a combination of reducing the internal gains from lighting, the addition of building insulation and the reduction of heat gains from the sun can bring the cooling requirements of the building type back to present levels.

SMALL and LARGE OFFICE - Office buildings were chosen as a simulation type because of their thermal similarity to the majority of other commercial building types. Secondly, they directly represent the second largest proportion of commercial buildings.

Similar to the Retail type, cooling was the predominant thermal energy load for the base case building in all six cities' 1 x CO2 (non-warmed) climate . Thus, with the 2 x CO2 (warmed) climate, the cooling requirements become even more dominant. In the hot or warm climates of the south and southeast, the annual cooling demands increase between 35% and 45%. In the cooler climates of the north, annual cooling demands increase from 40% to 75%. The predominant cooling load varies with climate region. In cooler climates, the heat generated from electric lights and the heat gained from solar radiation are dominant loads, while in hotter climates, the thermal effects of interior illumination are much less significant than the effects of the extremely hot exterior temperatures and heat gains from sunlight. In all cases except Seattle, a combination of reducing the internal gains from lighting, the addition of building insulation and the reduction of heat gains from the sun can bring the cooling requirements of the building type back to present levels.

3.2. Skin Load Dominated Buildings

Two building type were simulated to represent the performance of the range of buildings in this category.

Single Family Detached Dwelling Mobile Home

SINGLE FAMILY DETACHED DWELLING - This building type represents the "house" as represented by nearly 74% of the population of residential living units. On a per square foot basis, the thermal characteristics of the "house" cluster well with all the other residential types except the mobile home. Thus, this is an absolutely dominant prototype. There are questions as to the depth of penetration of "air-conditioning" into this type as the climate warms. This is particularly true of regions like the Northwest where mechanical cooling is not typical. This will be discussed further in the paper's conclusions.

As one might suspect by this building type's definition, the dominant thermal energy load for the single family detached dwelling correlates well with the thermal character of the climate region under analysis. Thus, in the hotter climates the dominant load is cooling by as much as a 4:1 margin. In the middle latitudes of the US where the climate is evenly both cool and warm, the energy loads are equally split. In the Northern climate regions the heating loads outweigh the cooling loads by as much as 7:1, as can be seen in Seattle.

While the thermal energy loads were wide ranging under the 1 x CO2 simulation, there was a shift to cooling as the dominant thermal load in all climate regions except the most northern or cold areas. In the colder climates, the increases in energy demand for cooling are more than offset by decreases in heating requirements. Therefore on an annual basis, energy use is decreased under the "warmed" climate scenario. Under closer inspection, the cooling loads for these climates are up between 84% in Minneapolis and 146% Seattle. This is indicative a large proportional increase in a figure which is originally small. This relative small proportional increase should not be overlooked because of its absolute magnitude. In areas where electric utilities have peak summer loads, the proportional increase in demand may be a better indicator of future energy concerns than the absolute increase. In climate regions generally as warm or warmer than Chicago, the increases in annual cooling requirements are between 56% in Fort Worth and 87% in Chicago. These are extremely large absolute and relative magnitudes of increase in rates of cooling demand in some of the fastest growing regions of the United States.

The increasing thermal energy load for all locations is for cooling. Increasing the insulation of the building, shading it from the effects of the direct rays of the sun are two strategies simulated in this study. Neither strategy can reduce the effects of the overall warming to a prewarming level. Other strategies such as seasonal thermal storage, higher levels of thermal mass within the building shell, evaporative cooling, and night heat flushing may reduce these energy demands. The analysis of these strategies is beyond the scope of this study.

MOBILE HOME - The mobile home building type represents an extreme in both internal heat generation and thermal building character. It presently includes only 3.4% of the total residential floor area, but it is rapidly growing and regulated only generally for thermal construction performance. Lastly, nearly half of the mobile home units are located in the south, a heavily impacted area by global warming.

The magnitude of thermal energy demands for the mobile home prototype is 30-50% greater than in the single family detached residence. The basecase mobile home under the 2 x CO2 climate scenario has increased its cooling load by 50%-132% over the 1 x CO2 scenario. The distribution and proportioning of these demands is very similar to the other residential prototype. As with the single family residence, reducing the energy loads for cooling under "warmed" conditions to their "prewarmed" values is difficult, as measured by the strategies tested under this study. Given the implementation of the strategies tested for reducing cooling loads, all the mobile homes tested exceed the prewarmed values by a wide range, from Fort Worth at 13% to Seattle at 41%. Both reducing solar gains and increasing insulation have significant effects on reducing the cooling loads. The combination of these two strategies generally reduces the cooling loads by 25%-40%. Therefore other more efficient cooling strategies or the generic ones evaluated in this study will need to be taken to greater lengths in order to maintain a "close" to zero cooling energy growth position.

4. CONCLUSIONS

There are three general conclusions that can be drawn from this study.

1. The annual cooling loads in buildings will greatly increase in all building sectors and in all climate regions of the country. There is a corresponding decrease in heating loads due the climate warming, but this decrease does not compensate for the increase in cooling demand except in the coldest region of the United States, and for only the residential sector.

As outlined in the Simulation section of this study, all but a limited few building types, residential buildings, in the single coldest climate region studied will experience annual increases in energy demand due to global warming from additional greenhouse gases. Most building types in most regions, particularly true in the south, the fastest growing population region in the US, will experience from a 35% to 75% increase in summer cooling demands. These demands can be reduced using the generic strategies outlined in this paper. The commercial building sector can be kept a a "zero energy growth" while the residential building sector greatly increases in cooling demand in all climate regions, even when considering the implementation of the measures outlined in this study. If the use of air conditioning/refrigeration increases in cooler areas like the Pacific Northwest, at a rate similar to other areas of the US with similar climates to the warmed scenario, the increases in cooling energy demand of the residential sector of those regions, 75% to 135%, is overwhelming.

2. The timing, magnitude and duration of the individual changes in the energy demand of buildings is as important a concern as the sheer magnitude of the changes in annual energy demands. The changes in the timing and magnitude of demand, either annually or perhaps more importantly during peak hot climatic events will impact owners of buildings through additional demand charges, utilities through additional demand during limited resource periods, and designers and builders of buildings who will have to adapt their strategies of design and construction of buildings.

This study has identified a growth in peak cooling loads in most climate regions and most building type, in the range of 4% to 10%. This increase in geographic areas with saturated peak loads could be the biggest challenge from global warming. This study was unable to identify the critical features of timing and duration of these new peak loads. These issues will be key to energy policy planners.

Employers and commercial building owners will be confronted with one or more of three key choices:

a. Paying increased building and maintenance costs due to higher construction and energy costs.

b. Lowering illumination levels, the largest factor in increasing cooling loads in most commercial building in most climate regions, in buildings to reduce energy use, thus possibly reducing the productivity of their workers.
c. Allowing temperatures in the workplace to exceed the commonly considered upper limit to thermal comfort in the United States. This could threaten the productivity of workers, as could changes in illumination level. There are wide ranging precedents for higher limits to thermal

comfort in other countries. Here the limits are established physically, psychologically and culturally. The habituation of thermally acceptable conditions should be carefully researched.

This study characterized three different approaches to limiting energy demand growth; lower lighting power densities by 50%, doubling the R-values of exterior wall assemblies, and shading all window apertures so as to reduce the suns penetration by 75%. These measures are generic by nature and could be accomplished, but not without some hardship. In the residential sector in particular, these measures could be seen as extreme.

Reducing the lighting power density can be accomplished in several ways. The introduction of the mandatory use of daylight as a primary method of illuminating the interior environment can greatly reduce lighting energy use. This can also introduce other problems such as additional solar overheating and integrating the control of the electric lights with the daylight. More efficient electric lighting technology is a second way to meet the strategy limits. As mentioned previously, lowering lighting standards, thus reducing lighting power density would begin to accomplish the same task as the daylighting strategy. Again, there are productivity questions that would have to be confronted. There are other unanswered questions such as, is the connected computer load increasing in commercial buildings. If this is true, there would be additional internal heat generating loads that are not included in the cooling requirement scenarios of this study. Lastly, it should be noted that the reduction of lighting loads has a great effect in commercial buildings, it has no noticeable effect in the residential sector of buildings.

Doubling the R-value of the building skin's insulation was the second strategy tested. This had very positive effects in the hot southern climates, especially on commercial buildings. This strategy would generally add 4" to 8" in thickness to the exterior wall with present insulating technology. In commercial buildings of the south where insulation standards are presently low, this could be accomplished fairly simply. In Northern climates, especially in the residential sector, this additional wall thickness would require the institutionalization of whole new methods of construction to accomplish the needed 12" to 24" insulation thickness. Another strategy would be to reduce window area, thus increasing the overall insulation of the skin. This has obvious detrimental effects on the quality of the workplace that would have to be considered. New insulation technologies would have to be explored to accomplish much of the insulation strategy. These technologies would include expanded research in new technology windows with "smart" shading and insulation.

The addition of dense shading to the windows of building when cooling is a problem has obvious positive effects. This type of shading can be accomplished in many ways. It has very positive effects on energy demands, but is also has some critical side effects. Shading lowers interior lighting levels thus the ability to use daylight. It has a depressing effect on the interior of high latitude buildings in the winter when daylight illumination is naturally at its lowest. Lastly, the simplest way to reduce sunlight penetration is to reduce the amount of window area. This has the same detrimental effects identified with this strategy in increasing the insulation value of the wall.

3. New methods of energy resource acquisition will have to be implemented to respond to the additional energy demands. The most difficult aspect of this problem may be in implementing the incremental measures to attain these resources between the present and the 2050 GISS Global Climatic Change scenario.

There are four apparent methods for increasing the availability of the energy resources needed to fuel the increased energy demands of global warming. The most direct method is increasing the direct generation of energy, secondly, increasing conservation of the energy resource thus identifying conservation as an energy supply technology, thirdly, decreasing thermal and visual/lighting comfort standards, with the previously outlined potential problems in comfort and productivity, and lastly, change the patterns of use. This would entail the curtailing of heat generating activities in buildings during the hottest periods of the day.

The second of these methods, energy conservation as a energy resource technology, is the focus this paper. The technologies assessed for improving the building stock were generally existing. These technologies are being demonstrated in state-of-the-art energy conservation design technology demonstration projects, such as the Bonneville Power Administration's Energy Edge; and the BPA, Natural Resource Defense Council, and Seattle City Light "Commercial Lighting Demonstration Project." Projects such as these are demonstrating that energy end-uses such as lighting can be reduced by more than 50% from there existing state-of-the-art ASHRAE 90.1P energy code-compliant levels.

Conservation efforts such as those explored in this paper create a building stock that is much more resistant to the energy demand effects of Global Warming. Less energy conserving buildings will require energy at ever increasing rates as the atmosphere gets warmer. Thus, the more energy conserving the general building stock, the more insulated the building sector of the economy will be from the higher outdoor temperatures.

It can be noted from the generalized graph in Figure 4.1 that the greater the mix of new technology buildings, ie.,1990's building stock, the less apparent are the impacts of atmospheric warming. If this study had used a mix of older buildings with newer buildings, rather than a homogeneous mix of ASHRAE 90.1P code-compliant buildings, the rate of increase in building energy use due to atmospheric warming would have been greatly amplified. Thus the reader should note the conservative nature of the impacts of Global Warming as assessed by this study. Similarly, this study did not assess the amplitude of changes in short-term, 3-10 day, *seasonal weather events*, only the amplitude changes of *annual average* temperature change. The amplitude of changes in seasonal weather events make a significant difference in the range of *peak* energy demands. The study has shown that given the existing pattern of seasonal events, warmed by the average climatic conditions predicted by the GISS 2xCO2 scenario, peak cooling demands will increase from 6-12%. Since the majority of the cooling of buildings occurs with electricity, an increase in the peak load of 10% may be of greater importance than an increase in the annual cooling load of 40-50%. If further study of the character of Global Warming indicates that the amplitude of seasonal weather events will increase, this will have a huge effect on utility loads through larger increases in peak building energy demands.

There are four responses to these conclusions that are clearly called for.

1. The primary focus of building response to global warming should be on the design of the

building envelope and its interiors rather than on the building's environmental control systems. Over the life of a building the lighting and environmental control systems will be changed or updated several times. Meanwhile, the "envelope" or exterior surface geometry and material of the building will stay essentially as it was designed over the building's life. If every attempt isn't made to design and build the most efficient building shell, many resources will be lost in supplying the energy demands made by these difficult to change inefficiencies. The building envelope design more than the mechanical systems design present the greatest opportunity to save resources over the life of the building. Much effort should be made to save these otherwise "lost-opportunity resources."

2. **The design of the building envelope and interiors should focus on the investigation of *regional* differences in the energy demand patterns.** This report proposes that the "lost opportunity resources" at the building envelope will very from region to region of the United States. Design strategies that may be the most effective in the southeast for an office building will have little effect on the same building type's energy performance in the cooler climates of the Pacific Northwest. This study identifies many of these regional differences at the most generic level. If the energy resources to support the buildings of the future are not to be lost, regional - zero energy growth - global warming strategies for design must be researched and demonstrated.

3. **The investigation of regional building design alternatives should focus on the careful design and use of building windows as sunlight protecting and daylight admitting apertures, where the use of daylight is fully integrated with the design of the most efficient electric lighting.** The strategy that seemed to provide the greatest improvement in the performance of commercial buildings across most every region of the United States was the improved design of the window aperture. This included the reduction of direct sun penetration by the careful design of sun screening elements of the fenestration, and the enhancement of building interior illumination by the use of daylight. The improvement in lighting design included the careful setting of productive but not excessive standards for illumination in the workplace, and the support of the most efficient and humane lighting technologies. The improved design of windows to control sunlight, daylight and view will return the greatest energy resource value.

4. **Research and demonstration of building design technologies that target building unit area *zero energy growth* should be a high priority of the 1990's.** There are obvious social, cultural and economic costs to reaching the zero energy growth model proposed in the building design responses identified in this paper. Perhaps the most difficult element to accomplishing these measures is the need for incremental changes in building tradition. How are these changes to be supported? One possibility is to set the ASHRAE 90.1P standard as a "zero energy growth limit". As the climate gets warmer over the next 50 years and the climate models change for building energy code compliance simulations, buildings would have to perform better to meet the constant **performance goals**. This would mean the adopting of a consistent national set of *design and construction performance goals*, in an industry notoriously diverse, resistant to regulation, and thus being a difficult sector of the economy to which one can quickly transfer new technologies. The setting of energy performance targets with the goal of reducing energy growth to as close to zero as possible is an obtainable objective for the 1990's. Research and demonstration of building design and technologies that reach these targets should be a high priority of the 1990's.

Thus, the research and demonstration of **new regional building energy demand targets**, focusing on the saving the *lost opportunity resources* in the design of the building's envelope and interiors should be of the highest priority. The clearest target for study in reducing energy use under Global Warming is the research and design of **windows**. The research, design, and demonstration of windows that act as an architecturally integrated lighting system with the electric lighting; admitting daylight, view, and cooling ventilation without admitting sunlight; should be a major thrust for building institutions of the 1990's.

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