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SERI/TP-721-1031
UC CATEGORY: UC-59c

CONF-810405--8

MASTER

R-2038

EFFECTS OF INTERNAL GAIN ASSUMPTIONS IN BUILDING ENERGY CALCULATIONS

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JANUARY 1981

PREPARED UNDER TASK NO. 1123.00

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A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

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EFFECTS OF INTERNAL GAIN ASSUMPTIONS IN BUILDING ENERGY CALCULATIONS

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ABSTRACT

The utilization of direct solar gains in buildings can be affected by operating profiles, such as schedules for internal gains, thermostat controls, and ventilation rates. Building energy analysis methods use various assumptions about these profiles. This paper describes the effects of typical internal gain assumptions in energy calculations.

Heating and cooling loads from simulations using the DOE 2.1 computer code are compared for various internal-gain inputs: typical hourly profiles, constant average profiles, and zero gain profiles. Prototype single-family-detached and multi-family-attached residential units are studied with various levels of insulation and infiltration. Small detached commercial buildings and attached zones in large commercial buildings are studied with various levels of internal gains.

The results of this study indicate that calculations of annual heating and cooling loads are sensitive to internal gains, but in most cases are relatively insensitive to hourly variations in internal gains.

INTRODUCTION

Some building energy analysis methods are said to be applicable to "skin-dominated" buildings in contrast to "load-dominated" buildings. This paper explores the meaning of this terminology and the applicability of such tools.

The term "skin-dominated" implies that the heating loads are predominantly a function of heat losses through the building envelope, including infiltration. This is assumed to be the case for conventional single-family-detached residences. In general, a building becomes less skin-dominated as:

- insulation is increased and infiltration is decreased, as in superinsulated houses;
- exposed envelope surfaces are reduced, as in attached and highrise buildings;
- internal-gain levels are increased, as in some commercial buildings.

Historically, heating energy requirements for skin-dominated buildings have been predicted based on the degree-day concept. Solar gains and internal gains have been accounted for through the use of a base temperature (usually 18.3°C) somewhat lower than the thermostat setpoint (usually 22.2°C). More recently, lower base temperatures have been suggested to account for several factors: lower thermostat setpoints, lower building heat-loss coefficients, and higher internal gains.

To account for increased solar gains, correlations have been developed by the Los Alamos Scientific Laboratory (LASL) based on simulations utilizing hour-by-hour values for solar radiation and ambient temperatures (1). While the hour-by-hour simulations did not include internal gains, the resulting Solar Load Ratio (SLR) method has the effect of allowing the user to specify average monthly internal gains. The specified level of internal gains is used to calculate the base temperature for a given thermostat setpoint and building heat-loss coefficient. This base temperature determines the number of degree-days for calculating heating loads used in the SLR method.

An annual tabular method has been derived from the SLR method for certain locations (1). This simplified method assumes a base temperature of 18.3°C, and hence provides less flexibility in consideration of internal gain levels. If the thermostat heating setpoint is assumed to be near 18.3°C and the solar-savings fraction is applied to a heating load based on degree-days below 18.3°C, then the internal gains are essentially neglected using the LASL annual method.

Detailed computer codes, such as BLAST and DOE 2.1, incorporate hour-by-hour simulation and allow the user to input a typical hourly profile for internal gains (or, more specifically, to input hourly profiles for the components of internal gains, such as occupants, lighting, and equipment).

In summary, three types of assumptions are commonly used for internal gains in building energy calculations: constant average profiles as in the SLR method, zero gain profiles as in the LASL annual method, and typical hourly profiles as in BLAST and DOE 2.1. The effects of these assumptions for different building types and various conservation options have been studied. The method of study was to use a single energy-analysis tool, DOE 2.1, with each of the three internal gain assumptions. The predicted loads are compared to determine the effects of internal gain assumptions.

BUILDING TYPES

Four building types are studied: single-family-detached (SFD), multi-family-attached (MFA), commercial-building-detached (CBD), and commercial-building-attached (CBA). The MFA case represents a south facing apartment in a multi-unit building. The CBA case represents a south zone in a large commercial building.

Each building type is simulated as a single thermal zone. For the attached building types, glazed areas are reduced to avoid severe overheating. Exposed floor areas are adjusted to allow for storage of available winter solar gains.

Table 1. RESIDENTIAL REFERENCE BUILDING/ZONE

Location:	Washington, D.C. Typical Meteorological Year weather
Floor Area:	111 m^2
Walls:	0.299 W/(m^2 K) insulation
Roof:	0.189 W/(m^2 K) ceiling insulation vented attic (2.0 air-changes per hour, average*)
Floor:	% carpet, see Table 2 0.1 m concrete slab 0.568 W/(m^2 K) insulation
Windows:	double glazing area of south glazing, see Table 2 4.1 m^2 north glazing
Shading:	1.0 shading coefficient (Oct through Apr) 0.5 shading coefficent (May through Sep) 1.1 m horizontal overhang, (0.3 m above south windows)
Thermostat setpoints:	25.6° C cooling 21.1° C heating (8 am to 10 pm) 14.6° C heating (11 pm to 7 am)
Infiltration:	See Table 2
Night insulation:	See Table 2
Economizer:	10.0 air-changes per hour, maximum to 25.4° C (Oct through Apr) to 21.2° C (May through Sep)

*Infiltration is temperature- and wind-dependent according to Achenbach-Coblentz (8).

Residential Building Types

The residential reference building (see Table 1) is similar to a passive solar residential prototype used in previous comparative energy analyses (2). The prototype is derived from the Hastings Ranch House, the Tennessee Valley Authority Solar House #1, and Building Energy Performance Standards (BEPS) insulation and infiltration levels (3,4,5).

The SFD configuration analyzed is based on the residential reference building and includes 12.3 m^2 of south glazing and a 0.1-m concrete slab floor which is 50% carpeted. Three levels of energy conservation (see Table 2) are studied: standard (SFD), low infiltration (SFD, LI), and low infiltration with night insulation (SFD, LI, NI).

The multi-family configuration is based on the residential reference building and includes 8.2 m^2 of south glazing and a 0.1-m concrete slab floor which is 100% carpeted. The nonsouth walls, the ceiling, and the floor are adjacent to conditioned zones and, therefore, are assumed to be adiabatic. The mass effects of these surfaces are included in the model through the use of custom weighting factors in DOE 2.1. Three levels of energy conservation (see Table 2) are studied: standard (MFA), low infiltration (MFA, LI), and low infiltration with night insulation (MFA, LI, NI).

Table 2. RESIDENTIAL BUILDING CASES

SFD	Residential reference building with: 12.3 m^2 south glazing, 50% carpet 0.6 air-changes per hour, average*
SFD, LI	SFD with: 0.3 air-changes per hour, average*
SFD, LI, NI	SFD with: 0.3 air-changes per hour, average* 0.631 W/(m^2 K) night insulation (8 am through 6 pm) (Nov through Mar)
MFA	Residential reference building with: 8.2 m^2 south glazing, 100% carpet adiabatic nonsouth surfaces 0.6 air-changes per hour, average*
MFA, LI	MFA with: 0.3 air-changes per hour, average*
MFA, LI, NI	MFA with: 0.3 air-changes per hour, average* 0.063 W/m^2K) night insulation (8 am through 6 pm) (Nov through Mar)

*Infiltration is temperature- and wind-dependent according to Achenback-Coblentz (8).

Commercial Building Types

The commercial reference building (see Table 3) is similar to the residential reference building, except for changes in roof construction, thermostat settings, ventilation, etc.

The CBD configuration is based on the commercial reference building and includes 12.3 m^2 of south glazing

Table 3. COMMERCIAL REFERENCE BUILDING/ZONE

Location:	Washington, D.C. Typical Meteorological Year weather
Floor Area:	111 m^2
Walls:	0.299 W/(m^2K) insulation
Roof:	0.237 W/(m^2K) insulation Built-up roof
Floor:	% carpet, see Table 4 0.1 m concrete slab, 0.568 W/(m^2K) insulation
Windows:	double glazing area of south glazing, see Table 4 4.1 m^2 north glazing
Shading:	1.0 shading coefficient (Oct through Apr) 0.5 shading coefficient (May through Sep) 1.1 m horizontal overhang, (0.3 m above south windows)
Thermostat setpoints	25.6° C cooling (8 am through 6 pm) 21.1° C heating (8 am through 6 pm) 32.2° C cooling (7 pm through 7 am) 10.0° C heating (7 pm through 7 am)
Economizer:	10 air-changes per hour, maximum to 25.4° C (Oct through Apr) to 21.2° C (May through Sep)
Ventilation:	1 air-change per hour (7 am to 6 pm)
Infiltration:	0.5 air-changes per hour, constant (7 pm through 6 am)

and an 0.1-m concrete slab which is 50% carpeted. The level of energy conservation is not varied in the commercial cases. Rather, the level of internal gain is varied as described in the next section and in Table 4.

The CBA configuration is based on the commercial reference building and includes 8.2 m^2 of south glazing and an 0.1-m concrete slab which is 100% carpeted. The nonsouth walls, the ceiling, and the floor are modeled as described for the MFA configuration. Occupant density and additional internal gains are as assumed for the CBD configuration cases.

PROFILE ASSUMPTIONS

Three types of internal-gain profiles are studied: typical hourly profiles, constant-average profiles, and zero-gain profiles (see Figs. 1 and 2). The typical hourly profiles are based on the internal gain profiles used to develop Building Energy Performance Standards (BEPS) (5,6). The constant average profiles supply the same daily total internal gains as the typical hourly profiles. Zero internal gains were used in some of the simulations for purposes of comparison.

Residential Profile Assumptions

The residential hourly profile varies slightly from the BEPS profile on an hourly basis according to work by

Table 4. COMMERCIAL BUILDING CASES

CBD, 1W	Commercial reference building with: 12.3 m^2 south glazing 50% carpet 9.3 m^2 per occupant 10.8 W/m^2 lighting
CBD, 2W	CBD with: 21.5 W/m^2 lighting
CBD, 3W	CBD with: 32.3 W/m^2 lighting
CBA, 1W	Commercial reference building with: 8.2 m^2 south glazing 100% carpet 9.3 m^2 per occupant adiabatic nonsouth surfaces 10.8 W/m^2 lighting
CBA, 2W	CBA with: 21.5 W/m^2 lighting
CBA, 3W	CBA with: 32.3 W/m^2 lighting

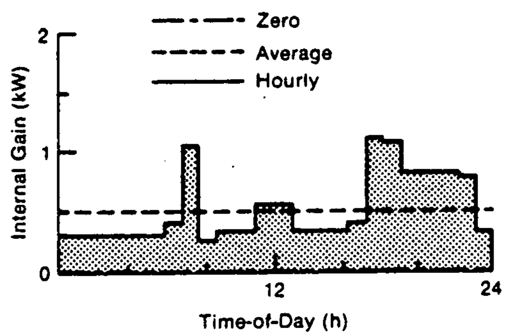

Fig. 1. Residential Internal Gain Profiles.

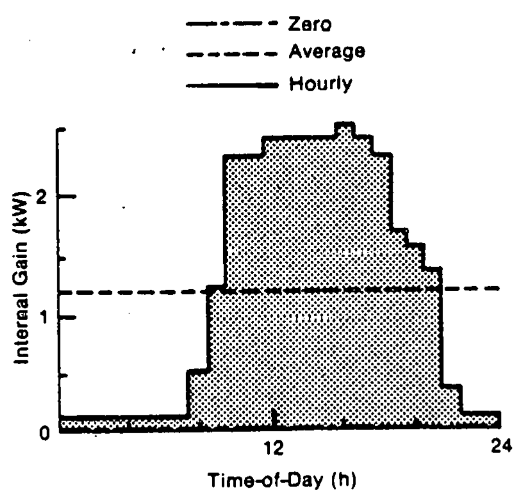

Fig. 2. Commercial Internal Gain Profiles.

Carroll (7). The daily total for internal gains is identical to the BEPS daily total at 14.6 kWh/day. For all residential cases, the internal gains are based on assumptions of a 1.6 kWh/day from 3.2 occupants, 2.8 kWh/day from lighting, and 10.2 kWh/day from household appliances (see Fig. 3).

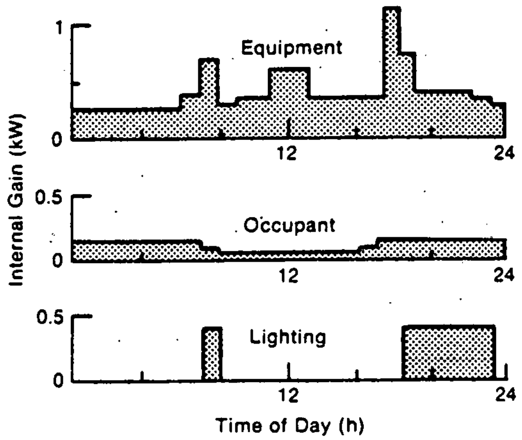

Fig. 3. Residential Internal Gain Components.

Commercial Profile Assumptions

The shape of the commercial hourly profile is based on the BEPS schedules for occupancy and lighting (see Fig. 4). For all commercial cases, the occupant density was assumed to be 9.3 m^2 per occupant. Internal gains from lighting and equipment were studied at 10.8 W/m^2, 21.5 W/m^2, and 32.3 W/m^2. When the BEPS schedules are applied to these peak values, daily total internal gains are 7.4 kWh/day from 11.9 occupants and 13.0 kWh/day, 26.0 kWh/day, or 39.0 kWh/day from lighting.

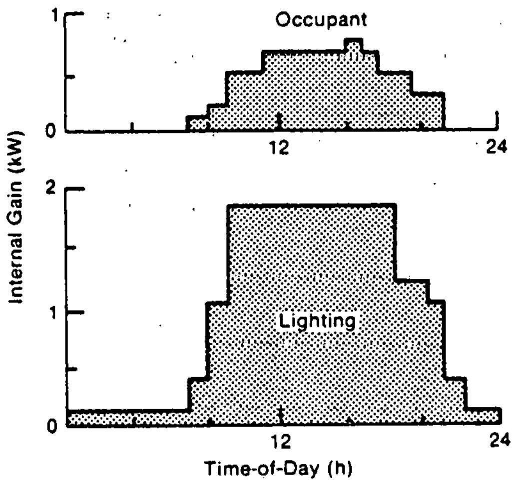

Fig. 4. Commercial Internal Gain Components

DISCUSSION OF RESULTS

Results are plotted as heating and cooling loads versus normalized internal gains (i.e., the ratio of annual internal gains to annual zero gain heating loads). The use of this ratio is an attempt to indicate the degree to which a building is potentially "load-dominated."

The heating/cooling loads reported are the heat extraction/addition rates required to maintain indoor temperatures according to the specified thermostat schedules. Effects of secondary heating, ventilating, and air conditioning systems and of mechanical equipment efficiencies are not included. Cooling loads do not include heat extracted by the economizer cycle. While both heating and cooling loads are plotted, only the heating load results are discussed in detail, because the primary focus of this paper is to investigate applicability of design tools which predict heating loads.

Results for Residential Buildings

The zero internal gain profiles produce substantially larger annual loads than those produced by typical hourly profiles (see Fig. 5). Annual heating loads are over-predicted by 42% for the single-family-detached and by 390% for the multi-family-attached with low infiltration and night insulation.

The average internal gain profiles over-predict the annual heating loads by very small amounts for all the

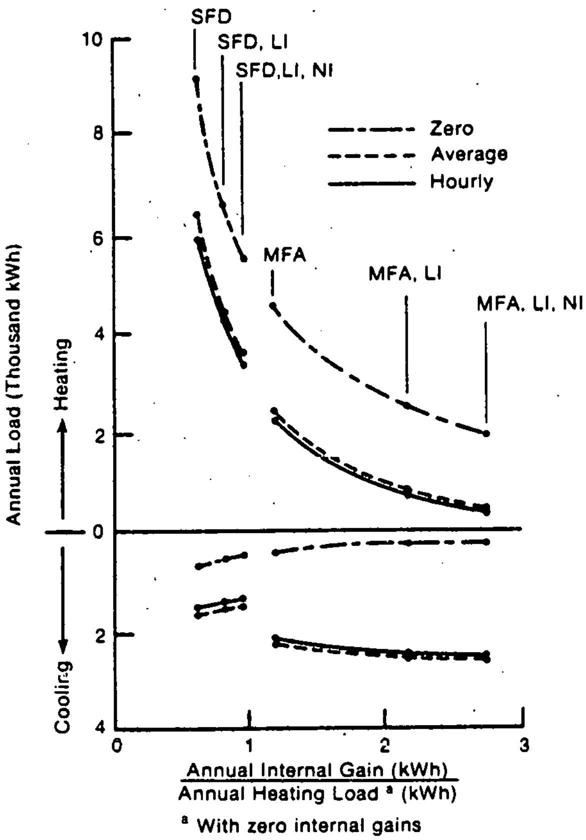

Fig. 5. Residential Annual Heating and Cooling Loads for Average, Hourly and Zero Internal Gains.

residential cases studied. The annual discrepancies are less than 2% in all cases. On a daily basis, the discrepancies are more significant:

(1) Average profiles under-predict the daily total heating loads for some days (see Fig. 6). The internal gains from the average profile are better utilized than the more variable gains from the hourly profile. In this case, heating loads occur predominately during the early morning, when gains from the average profile are greater than those from the hourly profile.

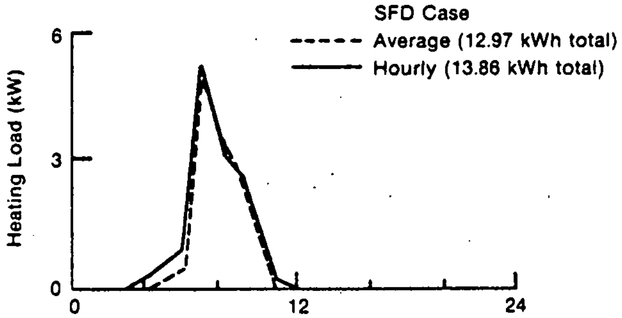

Fig. 6. Residential Hourly Heating Loads Based on Hourly and Average Gains for a Day with Morning Heating Demand (March 9)

(2) Average profiles over-predict daily total heating loads for some days (see Fig. 7). The demand for heat is variable such that hourly profile internal gains are well utilized. In this case, heating loads occur predominately during the evening when greater than average internal gains are available from the hourly profile. In general, heating demand varies hour-by-hour due to factors such as ambient temperature, solar gain, thermostat setback, and movable insulation.

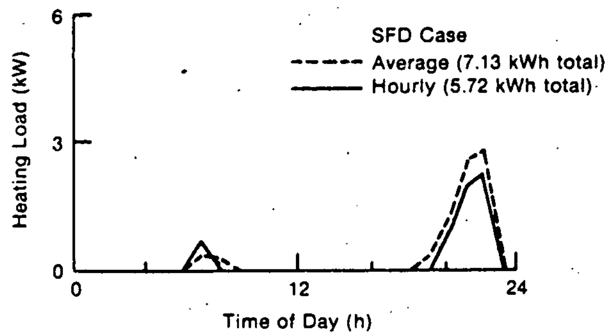

Figure 7. Residential Hourly Heating Loads Based on Hourly and Average Gains for a Day with Evening Heating Demand (March 10)

(3) Average profiles correctly predict daily total heating loads for some days (see Fig. 8). If for every hour of the day a heating load remains after accounting for internal gains, then the internal gains are fully utilized for that day. If

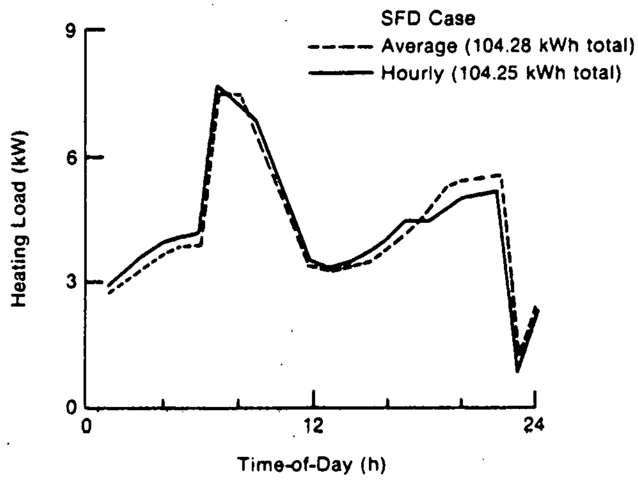

Figure 8. Residential Hourly Heating Loads Based on Hourly and Average Gains for a Day with Continuous Heating Demand (January 16)

this situation occurs for both profile types, then there is no discrepancy in the resulting daily loads, because daily total internal gains are identical. (This generalization assumes that there is no net heat transfer to or from the building mass over the day.) A significant portion of the seasonal heating load occurs on such days. For conventional residences this is the case because most of the heating load occurs during the heating season rather than during the swing season. Even for buildings with drastically reduced heating loads, weather extremes cause a few days of this type, and a significant portion of the small seasonal heating load occurs on these days.

The absence of larger annual discrepancies is apparently the result of offsetting effects of daily under-prediction and over-prediction, and a significant proportion of the loads occuring on days with correct prediction.

Results for Commercial Buildings

The zero gain profiles produce large discrepancies when loads are compared to those produced by the typical hourly profiles (see Fig. 9). Annual heating loads are over-predicted by 73% for the commercial-building-detached with 10.8 W/m^2 lighting, and by 1737% for the commercial-building-attached with 32.3 W/m^2 lighting.

The average profiles slightly under-predict or moderately over-predict the annual heating loads for the commercial cases studied. For the commercial-building-detached, the largest discrepancy is an 11% over-prediction and, in most cases, the discrepancies are less than 1%. For the commercial-building-attached, the discrepancies are larger as a percentage of heating loads, but still very small in absolute terms. In terms of daily heating loads, the results are similar to those for the residential cases:

(1) Average profiles under-predict daily total heating loads for some days (see Fig. 10). The discrepancies in morning heating loads are larger than in the residential case, and are affected by

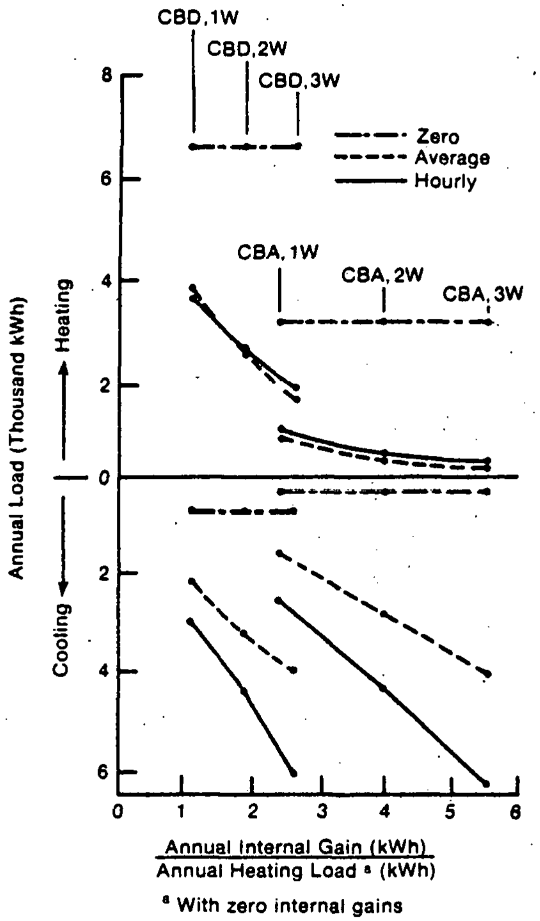

Fig. 9. Commercial Annual Heating and Cooling Loads for Average, Hourly and Zero Internal Gains

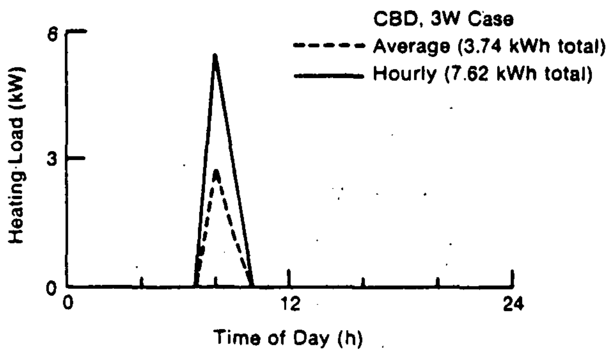

Fig. 10. Commercial Hourly Heating Loads Based on Hourly and Average Gains for a Day with Morning Heating Demand (January 11)

gains during the previous hours. The extra gains from the average profile during the night setback period cause the temperature to decline more slowly, resulting in smaller heating loads when the thermostat is set up in the morning.

(2) Average profiles over-predict daily total heating loads for some days (see Fig. 11). The discrepancies are larger than in the residential case, and occur in the afternoon rather than in the evening.

(3) For the commercial building cases studied, with the night setback to 10.0°C, no days require 24-hour heating.

The small annual discrepancies are the result of offsetting effects of days of the first and second type.

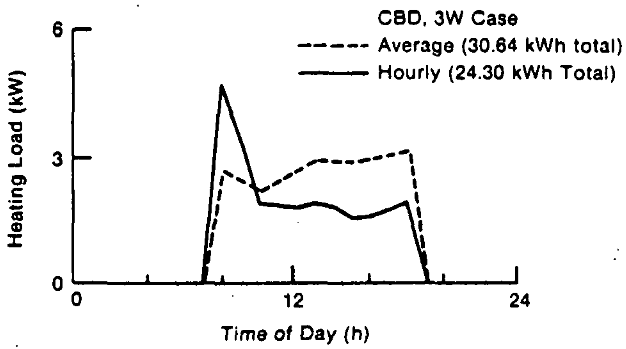

Fig. 11. Commercial Hourly Heating Loads Based on Hourly and Average Gains for a Day with Afternoon Heating Demand (January 10)

CONCLUSIONS

If internal gains are not accounted for in energy calculations, for the location and cases studied, the following conclusion can be stated:

- Heating loads will be *significantly* over-predicted and cooling loads will be significantly under-predicted for both residential and commercial buildings.

If average internal gains are used in energy calculations, for the location and cases studied, the following conclusions can be stated:

- Annual heating loads will differ only slightly from loads predicted with hourly internal gains for residential and commercial buildings.
- The small annual heating load discrepancies do not increase for increasingly load-dominated buildings. However, the discrepancies do increase, in percentage terms, as the annual heating loads become very small.
- Daily and hourly heating loads are, at various times, under-predicted and over-predicted.
- Annual cooling loads will differ only slightly from loads predicted with hourly internal gains for residential buildings, and annual cooling loads will be significantly under-predicted for commercial buildings.

Further investigation is necessary to determine the effects in other locations and the sensitivity of heating loads to hourly variation in factors other than internal gains, such as thermostat schedules and ventilation rates.

ACKNOWLEDGEMENT

This work was supported by the U.S. Department of Energy, Office of Solar Applications for Buildings, Passive Division.

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