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EFFECT OF BUILDING MASS ON ANNUAL HEATING ENERGY REQUIREMENTS

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Effect of building mass on annual heating energy requirements

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Summary. Based entirely on computer simulation, this study was carried out to determine the effect of the heat storage capacity of a building on its annual heating requirements. Specifically, the annual energy requirements were computed for a large office building and for a single-family house for three Canadian annual weather cycles and for a range of building interior and exterior wall thermal storage capacities. The study indicates that the thermal storage capacity of a building has a relatively small influence on the annual energy requirement for heating.

L'effet de la masse du bâtiment sur les besoins annuels d'énergie thermique

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Résumé. Fondée entièrement sur une simulation-ordinateur, l'étude a été exécutée afin de déterminer l'effet de la capacité d'emmagasinage thermique d'un bâtiment sur les besoins annuels en chauffage. Tout particulièrement, les besoins annuels d'énergie ont été enregistrés dans un grand immeuble à bureaux et dans une maison individuelle, soumis tous deux à trois cycles de températures annuelles, dont la capacité d'emmagasinage thermique des murs intérieurs et extérieurs différait. L'étude démontre que la capacité d'emmagasinage thermique d'un bâtiment n'a que relativement peu d'influence sur ses besoins annuels d'énergie pour le chauffage.

Effect of building mass on annual heating energy requirements

The extent to which building mass acting together with various building operation factors and climate affects the annual heating requirements of a building has been evaluated. Changes in annual energy requirements for heating resulting from changes in mass were determined by computer simulation: a single-family residence was simulated using a special version* of the ENCORE-CANADA Computer Program (1); a large office building was simulated by an unpublished computer program**.

Computer simulations

The following factors were varied during the simulation study:

Type of building

Single-family residence. The single-family house, a bungalow, was assumed to be well insulated and relatively tight, representative of the type of construction needed to meet new energy standards:

- length, 11.3 m
- width, 8.5 m
- gross floor area, 90 m^2
- volume, 415 m^3
- opaque exterior wall area, 71 m^2

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* This special version of the program uses a simple method to calculate infiltration heat loss due to combined wind and stack effect (Ref. 2, p. 416). The conduction heat loss through the basement envelope below outside grade level is not included in the calculations of house heating requirements.

** Computer program to simulate large office buildings based on the calculation methods outlined in "Procedures for Determining Heating and Cooling Loads for Computerizing Energy Calculations - Algorithms for Building Heat Transfer Subroutines", compiled and published by ASHRAE Task Group on Energy Requirements for Heating and Cooling of Buildings, 1975.

- glazed area, 21 m^2 (5.1, 3.4, 4.1 and 8.4 m^2 of double-glazed area in the four facades, respectively)
- basement wall area above grade level, 19 m^2
- opaque wall thermal resistance, 4.2 $m^2 \cdot K/W$
- ceiling thermal resistance, 6.2 $m^2 \cdot K/W$
- exposed basement wall thermal resistance 1.5 $m^2 \cdot K/W$
- occupancy, family of four
- appliances (television, stove, lights, refrigerator, etc.) approximate average power, 1.4 kW
- air leakage characteristics - average infiltration rate of 0.3 air changes/h (Note that this low leakage characteristic is possible with a "tight" house without a chimney.)

Large office building. The large office building was assumed to be constructed of many identical storeys with the following features:

- height of each storey, 3.6 m
- glazed area, half of exterior wall area double-glazed window
- each storey of the building consisting of nine zones: four are the four corners, four are the sides, and the ninth is the interior zone; the depth of the exterior zones was taken as 6 m, so that the ratio of glazed area to floor area of corner zones is 0.6 and of side zones, 0.3
- the annual heating energy supplied to each zone by the A-C terminal units was calculated (The energy to drive the A-C system, to heat and/ or cool ventilation air, and needed by building services was not included in zone energy balance; infiltration heating loads were also taken to be zero since it was assumed, for simplicity of calculations, that the building was pressurized.)
- occupancy, five days a week and eight hours a day
- occupancy sensible load 10 W/m^2 during occupied period
- lights, light power 30 W/m^2 during occupied period
- equipment power 4 W/m^2 during occupied period and 1 W/m^2 during unoccupied period.

Climate

Hourly weather data of 1970 for Winnipeg, Ottawa and Vancouver were used for the calculations.

Mass of interior construction

The following interior constructions were considered:

Light - 150 kg/m^2 of floor surface area

Medium - 350 kg/m^2 of floor surface area

Heavy - 600 kg/m^2 of floor surface area

Very Heavy - 700 kg/m^2 of floor surface area.

Mass of exterior wall was included in the interior mass if the insulating layer was on the outdoor side of the mass layer. For example, an exterior wall of heavy construction (such as a 25 cm thick concrete wall) increases interior mass by about 200 kg/m^2 for the perimeter zones and thus changes interior construction from light to medium or from medium to heavy and so on. When the insulating layer is on the interior side of the heavy layer, however, the contribution of exterior wall mass to the interior mass is considered to be negligible.

Thermostat set-point schedules

Single-family residence:

(i) Constant at 22.2°C

(ii) Daytime at 22.2°C
Nighttime at 18.3°C

Large office building:

	Occupied Period		Unoccupied Period	
	Heating	Cooling	Heating	Cooling
Schedule (i)	20.0°C	23.9°C	18.3°C	25.6°C
Schedule (ii)	21.7°C	22.2°C	20.0°C	23.9°C
Schedule (iii)	20.0°C	25.6°C	15.6°C	37.2°C
Schedule (iv)	22.2°C	22.2°C	22.2°C	22.2°C

Throttling range in all cases was assumed to be 1.7 K.

Orientation

Single-family residence. Three orientations were considered: major glazed facade facing south, west, or north.

Large office building. Orientation was to the cardinal directions.

Discussion of results

Single-family house

The calculated annual heat requirements are listed in Table I for different house interior masses, thermostat set-point schedules, orientations and locations. The numbers in the table indicate that any variation of internal heat storage capacity (e.g., variation in mass of the interior of the house) has a relatively small effect on annual house heating needs. For example, for the most sensitive case considered (Vancouver, 18.3° - 22.2°C thermostat set-point schedule, south orientation) the annual heating requirement for light (L) and heavy (H) interior constructions differs by only about 5 per cent. In absolute terms, the difference in annual heating requirement is small; the largest difference listed in Table I is about 300 kW·h.

In general, the thermostat set-point schedule and orientation have greater effect on annual house heating requirement than any change of interior mass from light to heavy. As well, the mass in the exterior wall has practically no effect on the house heating requirements if it does not contribute to interior mass. This was checked by numerous computer runs where the exterior wall insulation was considered to be on the indoor side of the wall mass layer.

Large office building

Tables II to IV give the calculated annual heating requirements for four thermostat set-point schedules, three orientations, two types of zone (i.e., two window-to-floor area ratios), three locations and different values of interior mass. The values listed are the annual heating energy required to maintain the prescribed zone air temperatures. This heat is supplied by A-C terminal units (e.g., steam or water heating coils, induction terminal units, electric heaters, etc.). The energy needed to condition and deliver ventilation air and the energy that might be wasted in controlling the air-conditioning units is not included in these values.

The listed values show that the annual heating requirement of a zone depends on building mass, orientation, climate, thermostat set-points and window-floor area ratio. In particular, the low and high thermostat set-points for heating and cooling, respectively, have a significant effect on heating requirements. For example, the heating requirement is nearly zero for a south zone in Vancouver with thermostat set-points of 20.0°C - 15.6°C and 25.6°C - 36.7°C; the heating requirement is 26.7 kW·h/m^2 for a constant thermostat set-point of 22.2°C and light interior construction.

Although the heat storage capacity of a large office building does have an effect on the annual heat energy needed to maintain prescribed temperature levels, it is usually of much less significance than the other factors that affect the total energy needs of the building. It is not possible to derive a simple yet accurate calculation method to account for the mass effect in a specific building design because this effect depends on so many factors (e.g., type of building construction, climate, building use). In cases where an accurate estimate is required, therefore, it has to be determined using computer programs for building energy use estimation that are capable of accounting for all of these parameters. DOE-1 (3) and BLAST (4) are two examples of such programs.

Conclusion

Results for single-family house simulations indicate that passive heat storage, resulting from heavy interior construction, does not influence the total annual heating requirements significantly.

Results for the office building analysis indicate that the impact of building mass on energy consumption is small. It is possible, however, that for a particular case (e.g., very large windows and south orientation plus constant thermostat setting) the impact could be significant and it should therefore be taken into account in the prediction of building energy needs.

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TABLE I. Annual energy requirement for heating of single-family house*

Units: kW·h/(house, year)

Location** and Deg Day °C	Interior Mass	Orientation					
		South		West		North	
		Thermostat Set-Point Schedule °C					
		22.2-22.2	18.3-22.2	22.2-22.2	18.3-22.2	22.2-22.2	18.3-22.2
Vancouver 3007	L	2144	1671	2548	1993	2841	2232
	M	2094	1632	2494	1957	2796	2207
	H	2059	1577	2467	1908	2762	2152
	Diff	85	94	81	85	79	80
Ottawa 4673	L	7892	6714	8858	7663	9538	8294
	M	7765	6613	8766	7594	9469	8260
	H	7663	6501	8693	7508	9405	8182
	Diff	229	213	165	155	133	112
Winnipeg 5889	L	12638	11111	14031	12494	14713	13129
	M	12478	10981	13916	12398	14629	13083
	H	12331	10834	13807	12272	14541	12978
	Diff	307	277	224	222	172	151

Diff = Difference in annual heating requirements between light and heavy interior construction

*excluding losses through walls and floor below outside grade level

**house thermal model used is peculiar to colder climate and thus the values listed for Vancouver are relatively low

TABLE II. Annual energy requirement for heating of large office building*

Units: kW·h/(m^2 of floor area, year)

Location - Winnipeg (5889°C Heating Deg Day)

	Orientation	Interior Mass	Thermostat Set-Point Schedule °C			
			20.0 - 15.6	20.0 - 18.3	21.7 - 20.0	22.2 - 22.2
Ratio of window and floor area = 0.3	North	L	66.4	79.9	89.7	114.
		M	65.1	78.1	87.6	110.
		H	63.2	76.2	85.2	106.
		VH	61.3	74.6	83.6	104.
		Diff	5.1	5.3	6.1	10.
	West	L	50.1	60.8	69.7	92.8
		M	48.6	59.1	67.0	88.0
		H	46.8	57.0	64.4	83.1
		VH	45.3	55.9	63.2	81.4
		Diff	4.8	4.9	6.5	11.4
	South	L	9.92	19.1	30.5	61.3
		M	7.85	13.8	22.0	49.0
		H	5.44	10.4	15.3	36.5
		VH	4.14	9.16	14.0	31.4
		Diff	5.78	9.94	16.5	29.9
Ratio of window and floor area = 0.6	North-west	L	157.	186.	205.	241.
		M	155.	183.	202.	236.
		H	152.	180.	199.	231.
		VH	150.	178.	197.	229.
		Diff	7.	8.	8.	12.
	South-west	L	82.5	107.	128.	170.
		M	77.9	99.2	117.	155.
		N	73.0	93.0	108.	142.
		VH	70.1	89.3	104.	135.
		Diff	12.4	17.7	24.	35.

Diff = Difference in annual heating requirements between light and very heavy interior construction

*Heat supplied by terminal units

TABLE III. Annual energy requirement for heating of large office building*

Units: kW·h/(m^2 of floor area, year)

Location - Ottawa (4673°C Heating Deg Day)

	Orientation	Interior Mass	Thermostat Set-Point Schedule °C			
			20.0 - 15.6	20.0 - 18.3	21.7 - 20.0	22.2 - 22.2
Ratio of window and floor area = 0.3	North	L	40.4	51.5	60.2	83.6
		M	39.0	49.9	57.9	79.9
		H	37.3	48.1	55.7	75.8
		VH	35.6	46.5	54.4	73.5
		Diff	4.8	5.0	5.8	10.1
	West	L	25.9	34.3	41.9	64.0
		M	24.6	32.5	39.0	58.7
		H	22.9	30.8	36.3	53.2
		VH	21.6	29.9	35.7	51.4
		Diff	4.3	4.4	6.2	12.6
	South	L	2.35	8.71	17.1	44.4
		M	1.17	4.92	10.8	34.0
		H	0.22	1.91	5.66	22.6
		VH	0.01	1.14	4.20	17.8
		Diff	2.34	7.57	12.9	26.6
Ratio of window and floor area = 0.6	North-west	L	98.0	122.	139.	174.
		M	95.6	119.	135.	168.
		H	93.0	116.	132.	162.
		VH	91.4	115.	131.	160.
		Diff	6.6	7.	8.	14.
	South-west	L	44.1	63.9	82.2	122.
		M	39.9	56.5	71.7	108.
		H	35.8	50.8	62.8	93.4
		VH	33.8	49.1	60.3	87.1
		Diff	10.3	14.8	21.9	34.9

Diff = Difference in annual heating requirements between light and very heavy interior construction

*Heat supplied by terminal units

TABLE IV. Annual energy requirement for heating of large office building*

Units: kW·h/(m^2 of floor area, year)

Location - Vancouver (3007°C Heating Deg Day)

	Orientation	Interior Mass	Thermostat Set-Point Schedule °C			
			20.0 - 15.6	20.0 - 18.3	21.7 - 20.0	22.2 - 22.2
Ratio of window and floor area = 0.3	North	L	8.56	16.5	24.7	51.0
		M	6.73	14.1	21.4	46.6
		H	4.68	11.4	17.9	41.5
		VH	3.34	10.2	16.7	39.8
		Diff	5.22	6.3	8.0	11.2
	West	L	4.99	9.71	15.2	36.2
		M	3.91	8.03	12.7	31.3
		H	2.43	6.40	9.98	25.5
		VH	1.31	5.47	9.29	23.9
		Diff	3.68	4.24	5.91	12.3
	South	L	0.83	2.50	5.79	26.7
		M	0.46	1.44	3.37	17.9
		H	0.05	0.63	1.67	11.0
		VH	0.00	0.11	1.06	7.47
		Diff	0.83	2.39	4.73	19.23
Ratio of window and floor area = 0.6	North-west	L	31.5	51.2	67.2	106.9
		M	29.1	48.4	63.1	98.1
		H	26.7	45.6	59.9	91.3
		VH	24.8	43.2	57.3	86.2
		Diff	6.7	8.0	9.9	19.8
	South-west	L	12.2	23.8	37.3	75.9
		M	9.74	19.5	29.2	60.3
		H	7.54	16.3	24.1	47.8
		VH	6.16	15.2	22.5	42.5
		Diff	6.04	8.6	14.8	33.4

Diff = Difference in annual heating requirements between light and very heavy interior construction

*Heat supplied by terminal units