THE ROLE OF THERMAL MASS IN COLD CLIMATES

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ABSTRACT The role of thermal mass in hot-dry climates is universally recognised: it would even out the large diurnal temperature variations. The effect is popularly referred to as the "thermal flywheel". I duscussed the role of thermal mass in warm-humid climates at the PLEA'96 conference, where I reported on a research project mounted to decide the lightweight/heavyweight dichotomy. The present paper looks at the advantages/ disadvatages of massive construction in cold climates, where heating is necessary.

1 TOOLS AND THE CLIMATE

The dynamic thermal response simulation module (HARMON) of the ARCHIPAK program is used as a tool to examine the problem, which is based on a harmonic analysis method, developed by the BRE (UK), known as the 'admittance procedure'.

From the available data three climates are selected: (1) the southernmost city of Australia: Hobart (lat. -42°), (2) Glasgow, in Scotland, (lat. 55.9°) and (3) Stockholm, in Sweden (lat: 59.3°). Fig.1 compares the annual temperature profiles of the three climates, with the comfort band superimposed in each case. Fig.2 is the pre-design climate analysis based on the psychrometric chart, also showing the potential of passive solar heating. In Hobart all 12 monthly climate lines are well within the passive solar *control potential zone* (CPZ). In Glasgow the lower limit of this CPZ is about 11°C, whilst the mean minimum of the coldest month is 1°C. Stockholm has so little solar radiation in January that a passive solar system is likely to maintain indoor comfort only down to about 11.5°C outdoor temperature, whilst the January mean minimum is -4°C. Obviously, some heating will be required in both these northern climates. This is confirmed by a quick steady-state calculation (for the lightweight variant and original configuration), using QBALANCE (another module of the ARCHIPAK program), which gives the required heating capacity as nil for Hobart, 1100 W for Glasgow and 1560 W for Stockholm.

2 THE VEHICLE

In order to reduce the effect of "noise", i.e. of uncontrollable variables (or those not being the subject of this study), a simple single room building is used as the study vehicle, which is 8 x 5 m on plan and 2.5 m high, as shown in Fig.3. This gives a floor area of 40 m² and a volume of 100 m³. The east and west walls are blank; the equator-facing wall has a 0.9 x 2.1 m door and a window, which was initially set as 4.5 x 1.5 m (as shown) but results are presented with windows of 8 m² and 12 m², being 20% and 30% of the floor area, respectively. The wall of polar orientation initially has a 1 m² window, but subsequently reduced to 0.5 m².

The first round of simulations looks at the two constructional variants described in Table 1. The door and window constructions are identical in both cases: 45 mm hollow-core flush door and a window with timber frame and double glazing. This is later replaced by triple glazing, using low-e glass.

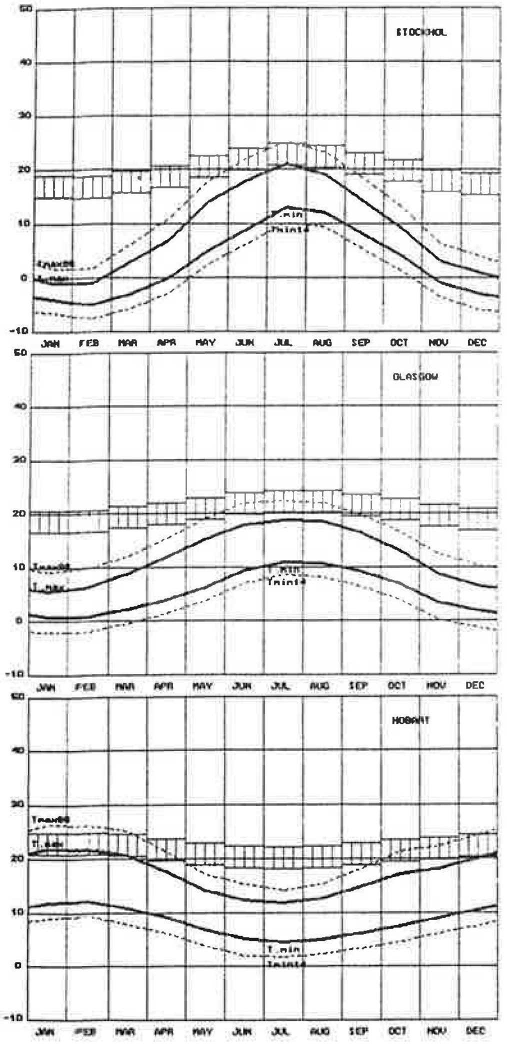

Fig.1 Temperature profiles: mean max, mean min, 86th%-ile of maxima and 14th%-ile of minima

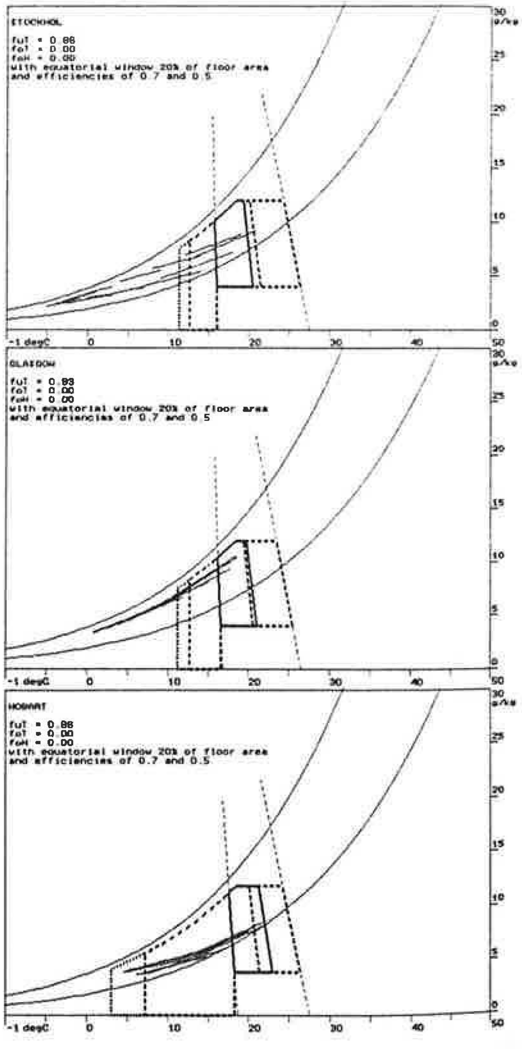

Fig.2 Summer and winter comfort zones, with monthly climate lines and passive solar CPZ

Table 1 **The construc**

construction	
Lightweight	
floor	20 mm timber
walls	timber frame, 6
roof	clay tiles, foil-f
Heavyweight	
floor	r.c.slab on grou
walls	6 mm fibrous c
roof	clay tiles,foil-fa

*EPS = expanded polystyrene w

The U-values of light a
difference in the admittanc
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From these several observa
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construction reduces
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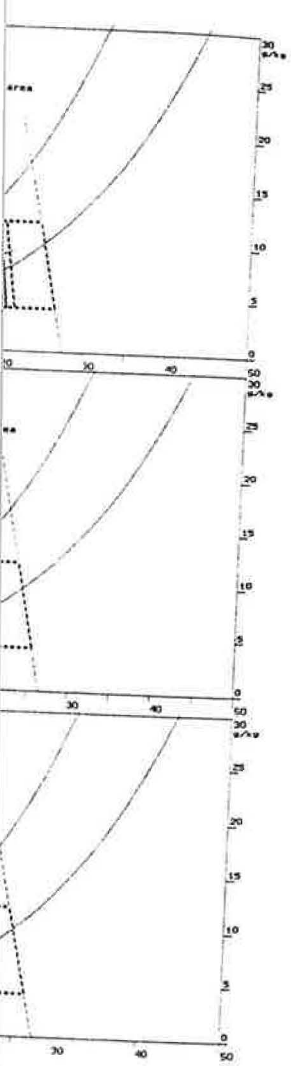
Table 2 **Results of the fi**

		window	ventilation	locatio
A	1 2 3	8 m²	1.5 ach	Stockho Glasgow Hobart:
B	1 2 3	8 m²	0.5 ach	Stockho Glasgow Hobart:
C	1 2 3	12 m²	1.5 ach	Stockhol Glasgow Hobart:
D	1 2 3	12 m²	0.5 ach	Stockhol Glasgow Hobart:
E	1 2	as D but triple window		Stockholr Glasgow
F	1 2	as E but heating added		S: + 1500 G: + 1000

cing wall has a 0.9 x 2.1 ; shown) but results are 30% of the floor area, ndow, but subsequently

its described in Table 1. ; mm hollow-core flush later replaced by triple



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and passive solar CPZ

Table 1 The construction types examined

construction		U-value	admittance
Lightweight			
floor	20 mm timber boarding, 100 mm EPS *over moderately ventilated space	0.81	2.92W/m²K
walls	timber frame, 6 mm fibrous cement, cavity, 125 EPS, 13 plasterboard	0.24	0.86
roof	clay tiles, foil-faced sarking, attic, 150 EPS, 13 mm plasterboard	0.23	1.01
Heavyweight			
floor	r.c.slab on ground, 1 m edge insulation, with carpet	0.74	5.60
walls	6 mm fibrous cement, cavity, 125 mm EPS, 200 concr.block, 10 plastering	0.24	5.71
roof	clay tiles,foil-faced sarking, attic, 125 mm EPS, 125 mm r.s.slab	0.27	6.57

*EPS = expanded polystyrene which has properties similar to glass wool batts

The U-values of light and heavy variants are kept similar, but there is a significant difference in the admittance, due to the heavy layer inside of the insulation. Table 2 gives a summary of results of the first 32 simulation runs in terms of the indoor mean, the indoor maximum and the amplitude of temperature variation (mean-to-peak) and Fig.4 shows 10 (of the 16) graphs of pairs of temperature profiles produced by light and heavy variants.

From these several observations can be made:

1. the mean temperatures of the pairs are practically identical, but the heavy construction reduces the amplitude, thus also the maximum
2. the reduction of ventilation to 0.5 ach (A→B or C→D) improves the indoor mean by about 1 K (by up to 2.5 K in Hobart); in both light and heavy construction.

Table 2 Results of the first run of simulations

	window	ventilation	location	Lightweight Ti.av	Ti.max	amplitude	Heavyweight Ti.av	Ti.max	amplitude
A 1	8 m²	1.5 ach	Stockholm:	0.4°C	4.1°C	3.67 K	0.4°C	1.3°C	0.88 K
2			Glasgow:	6.2	10.5	4.34	6.3	7.3	0.98
3			Hobart:	14.8	22.4	7.66	14.8	16.6	1.73
B 1	8 m²	0.5 ach	Stockholm:	1.3	5.3	3.99	1.4	2.3	0.84
2			Glasgow:	7.3	11.9	4.67	7.3	8.3	0.96
3			Hobart:	16.9	25.1*	8.23	17.0	18.6	1.67
C 1	12 m²	1.5 ach	Stockholm:	0.9	6.0	5.04	1.0	2.2	1.25
2			Glasgow:	6.8	12.6	5.78	6.9	8.3	1.42
3			Hobart:	16.6	26.9	10.27	16.6	19.1	2.47
D 1	12 m²	0.5 ach	Stockholm:	1.9	7.4	5.50	2.0	3.3	1.24
2			Glasgow:	7.9	14.2	6.23	8.0	9.4	1.39
3			Hobart:	19.0	30.1*	11.12	19.1	21.5	2.44
E 1	as D but		Stockholm:	2.6	8.1	5.47	2.7	3.8	1.15
2	triple window		Glasgow	8.6	14.8	6.17	8.7	10.0	1.28
F 1	as E but		S: + 1500 W	18.9	24.5	5.61	19.2	20.4	1.15
2	heating added		G: + 1000 W	19.5	25.6*	6.17	19.7	21.0	1.28

3 the first improvement (B 3) already causes early afternoon overheating in Hobart with the lightweight building, but not with the heavy one. This is even more pronounced with the enlarged window (D 3, marked *).

4 enlarging the equatorial window by 50% (A→C or B→D) improves the indoor mean by 0.5 - 0.6 K in the northern locations, but in the sunny Hobart winter the improvement is much larger: 1.8 - 2.5 K.

5 in Hobart all-day comfort can be ensured with enlarged window, reduced ventilation and heavy construction (D 3), confirming the CPZ prediction (Fig.2).

6 in the two northern locations (but not in Hobart) further improvement is necessary: triple glazing, using low-e glass. This improves the indoor mean by 0.7 K (D→E).

7 with the lightweight variants solar heating increases the indoor temparature only from noon onwards. Before this the south window is still a net loser of heat.

8 in run E (Glasgow) the peak temperature is approaching comfort with the lightweight variant, but this suffers a large diurnal variation. Some heating is necessary.

9 with the addition of a continuous heat input of 1500 and 1000 W in Stockholm and Glasgow, respectively, the daily mean becomes acceptable, but with the lightweight version afternoon overheating occurs (marked ⁺). The heavyweight building will ensure all-day comfort.

The conclusion can be drawn from the above that in Hobart (and similar moderately cold and sunny-winter climates) a passive solar system can ensure winter comfort, provided that the building has sufficient mass. In colder climates some heating will be necessary. Run F assumed a continuous heating, but in a real situation in most cases the heating would be intermittent and the occupancy pattern variable.

3 INTERMITTENT OPERATION

The CIBSE steady-state heat loss calculation method has some fudge-factors provided which adjust the heating requirement for intermittent operation. Applying these for a 5-day week and 8-hour working day, to the above variant E, we get the following heating requrements for a typical working day of January:

	continuous	intermittent, with quick plant response:	
Glasgow			save
lightweight	28.7 kWh	11.8 kWh	59%
heavyweight	28.2	20.2	28
Stockholm			
lightweight	46.1 kWh	18.9 kWh	59%
heavyweight	45.4	32.6	28

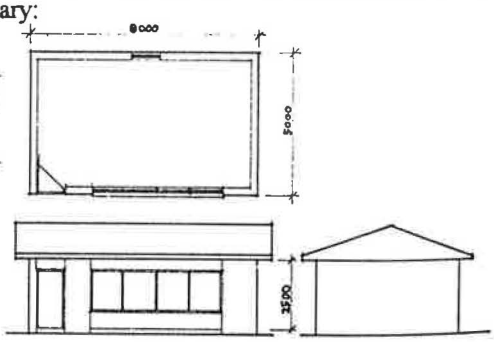
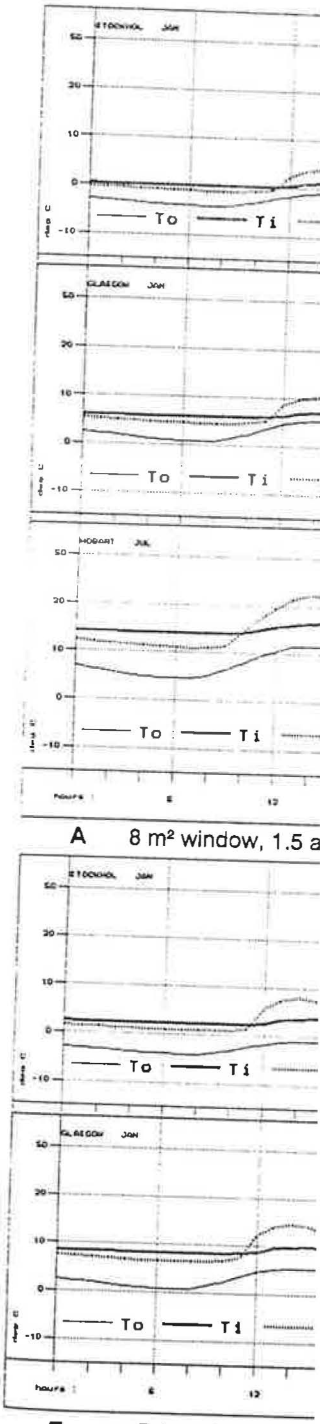


Fig.3 The house used as a study vehicle

This shows that *with continuous heating the heavyweight building is (slightly) better*, but with intermittent heating lightweight building would save some 59%, whilst the heavy building the saving would be only about 28%. So, *with intermittent heating the lightweight building shows an advantage.*



A 8 m² window, 1.5 a

E as D but triple glazin

Fig.4 Temperature p

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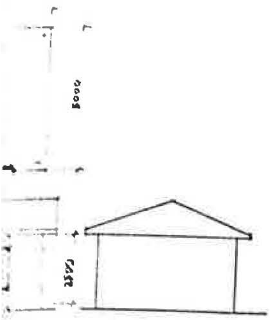

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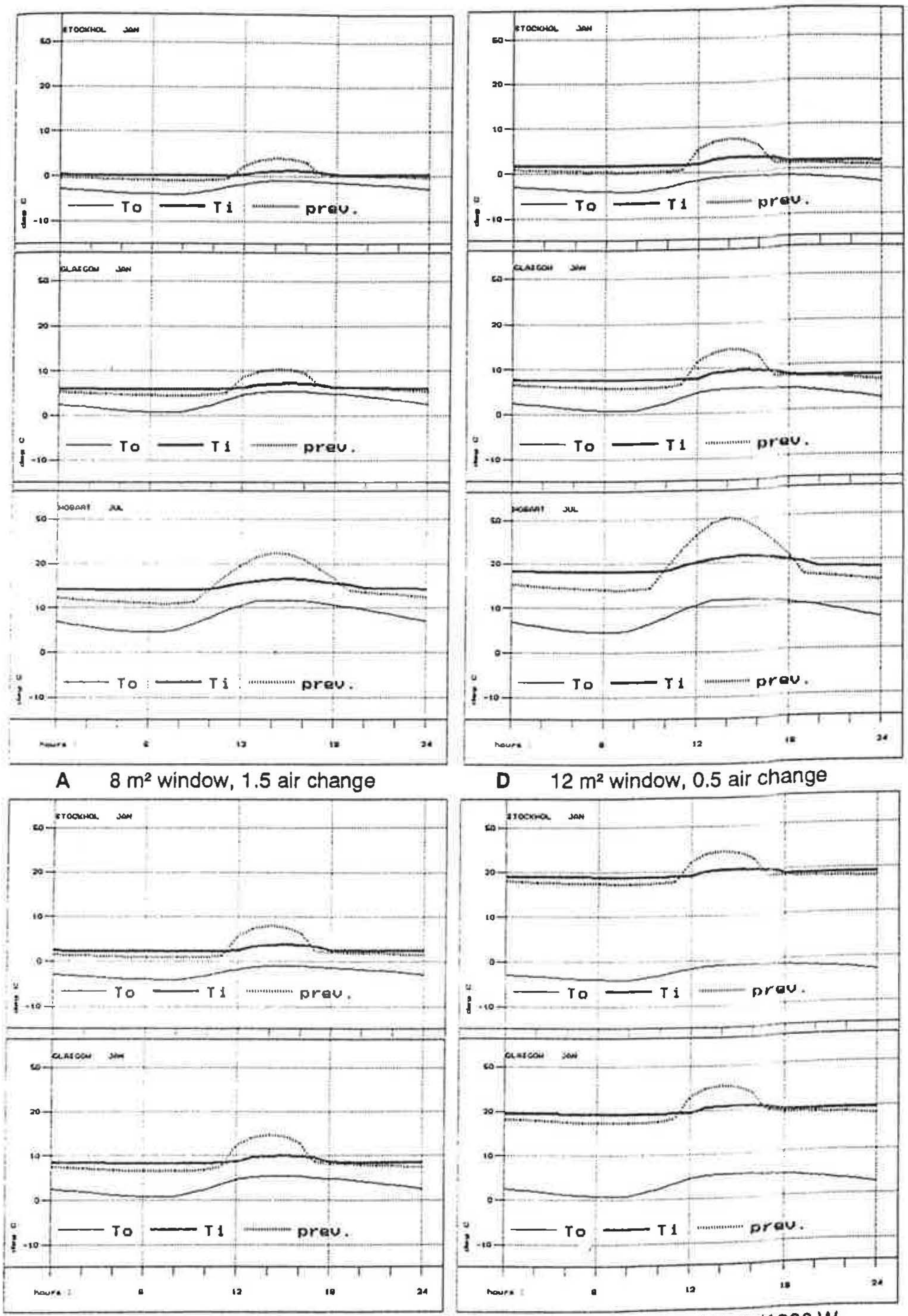

A 8 m² window, 1.5 air change

D 12 m² window, 0.5 air change

E as D but triple glazing

F with heat input of 1500/1000 W

Fig.4 Temperature profiles of heavy and lightweight constructions

Dynamic response analysis shows a somewhat different picture. In Glasgow, assuming an 8-hour occupancy, a heavy building and a quick response system, the above daily 20.2 kWh of heat input may be a 1.8 kW heater operating for 11 hours. This results in a temperature profile which is within the comfort band during the day, dropping to 16.4°C at night. If the same input is applied to a lightweight building, serious overheating occurs in the afternoon and the nighttime temperature may be as low as 12.2°C.

The lightweight building would need 11.8 kWh for a working day, or a 1.2 kW heater for 10 hours. This would produce indoor temperatures below comfort in the morning, excessive in the afternoon and dropping to below 10°C at night. The heavy version would give similar temperatures in the morning, reaching the lower comfort limit in the afternoon and dropping at night only to 14.7°C.

Repeating the same exercise for Stockholm shows a similar trend: the CIBSE method appears to *overestimate the requirement for a heavy building and underestimates the requirement for the lightweight building.*

This conclusion is confirmed by the heating requirements predicted by HARMON used in the "energy" mode (with variable heating and the thermostat set to the 18.5°C design temperature, with a ±1 K dead band):

Table 3 Predictions of daily heating requirement

			heavyweight heating	lightweight heating	saving
Glasgow	CIBSE	continuous	28.2 kWh	28.7 kWh	- 2%
	CIBSE	intermittent	20.2	11.8	42%
	HARMON	intermittent	18.3	13.9	23%
Stockholm	CIBSE	continuous	45.4 kWh	46.1 kWh	- 2%
	CIBSE	intermittent	32.6	18.9	42%
	HARMON	intermittent	27.5	22.3	19%

CONCLUSION

The heavyweight building ensures more even and comfortable conditions than the lightweight and uses slightly less energy, if both occupancy and heating are continuous.

If both occupancy and heating are intermittent, then the lightweight version uses less energy, although during the OFF period it will cool down quite drastically.

However, with intermittent heating (e.g. night shut-down) but continuous occupancy, as in most residential buildings, the heavyweight version would maintain acceptable conditions during the OFF period.

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