CI/SfB

UDC

branz

BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND

REPRINT No. 5

AUGUST 1978

INTERACTION OF CLIMATE AND SPACE HEATING

PRESENTED AT: NEW ZEALAND METEOROLOGICAL SERVICE
SEMINAR, "CLIMATOLOGY & ENERGY", OCTOBER 1977.

42 Vivian St., Wellington, 1 – P.O. Box 9375 – Tel. 851479 – Teleg. BRANZ

INTERACTION OF CLIMATE AND SPACE HEATING

M. BASSETT H. TRETHOWEN

N.Z. Meteorological Service Seminar "Climatology & Energy"

October 1977

Abstract

It is a truism that the space heating needs of buildings are a function of the climate. The feature that has emerged only in recent years is the large degree to which the heating energy needs can be varied by manipulating specific architectural features of building design. This paper identifies and discusses some of these features and their climate dependance, including the effects of thermal mass, the heat balance of windows, orientation, insulation.

Of particular note is the effect of solar radiation received.

1. Introduction

The most important development which has occurred in recent years in studies on the space heating energy needs of buildings, has been the realisation of just how large can be the influence of certain architectural features. Choices such as orientation, window placement, use of thermal storage features, can either exploit or suffer from the climatic environment. The general nature of these interactions have been known for centuries, but their extent has been underestimated because of the difficulties of demonstrating and quantifying them.

Extensive studies worldwide have provided much of the quantisation needed, although a great deal more is still awaited. However many of the overseas studies are inapplicable to this country because of climatic differences. For this reason, most of the material in this paper is based on a few N.Z. based studies.

The principle factors affecting the space heating energy requirement of our buildings are:-

Building-Related

Heating level
Insulation
Windows and orientation
Size and shape of building
Thermal storage in structure

Climate-Related

Solar Radiation

Night sky radiation
Air temperatures
Wind and rain.

2. Heating Level

The heating energy requirement depends on the heating level adopted more than any other factor. The term "heating level" has 3 components:-

- indoor temperature maintained during "heating" periods.
- fraction of total time for which "heating" is applied.
- fraction of building which is "heated".

It is normal to consider the first of these as the most important, but it is probably the least. The most important factor is the fraction of time for which "heating" is maintained. The differential sensitivity of heating energy to indoor temperatures ranges from about 6% per C° in the colder regions to about 10% per C° in the north. The influence of the building fraction which is heated is indicated by an example - typically to heat half a single floor house will require about 70% of the energy to heat all of it. (See refs 1,2).

In Table 1 is indicated the comparative heating energy requirements for a reference house of 100 m^2 floor area, 18 m^2 windows, 1 air change/h ventilation. In (a) is given the gross energy needed for continuous whole-house heating to 20°C. In (b) is listed the nett space heating needs for the same standard, assuming that a total of 7,000 kWh/year of fortuitous heating is contributed by indoor activities and sunshine. In (c) is listed the nett heating requirement if half the house were heated 1/4 of the time, but includes a daily 'heat-up' allowance.

This last standard is chosen because it is representative of the sort of average heating standard which must apply now. The average energy usage per home (all fuels) for space heating is about 5,000 kWh/year, and there is 5-7,000 kWh/year of fortuitous heating.

Clearly a tremendously wide range of nett heating requirements may apply, according to the quality of insulation and duration of daily heating. Furthermore the proportionate advantage from insulation should be greatest in the milder climate of Auckland, especially where less continuous heating standards are used.

TABLE 1 - Typical Annual Energy Needs (From Ref 2)

(a) Gross requirements - continuous whole-house heating to 20°C
(b) Nett " " " " " to 20°C
(c) Nett " - half-house heating, 1/4 of time to 20°C

	Annual Heating Requirement (1000 kWh)				
Insulation thickness	0 (foil)	12.5 mm	25 mm	50 mm	100 mm
(a) Auckland	33	21	16	12	8.7
Wellington	43	27	22	16	11.5
Christchurch	49	31	25	18	13
Invercargill	59	37	29	21	16
(b) Auckland	26	14	9	5	1.7
Wellington	36	20	15	9	4.5
Christchurch	42	24	18	11	6
Invercargill	52	30	22	15	9
(c) Auckland	5.5	0.9	0.8	0.6	0.4
Wellington	8.5	2.9	1.1	0.7	0.4
Christchurch	10.5	3.9	2.1	0.8	0.6
Invercargill	12.5	5.9	3.5	0.9	0.7

3. Thermal Insulation

The effects of thermal insulation are now becoming widely known. Most of the discussion concerning insulation now tends to centre on the effects of thermal storage & whether occupants change their heating levels when in an insulated building. It has been established (Ref 4) beyond reasonable doubt that the observed heating levels are not significantly different in insulated and noninsulated buildings. The effects of thermal storage are discussed later.

Attention is more worthily focussed on several other factors:-

a) That insulation is proportionately more effective in milder climates than in colder ones.

b) That it is more effective to adopt a "wrap-around" approach to insulation (roof insulation is not enough).

c) That there is probably a technically and economically feasible level of insulation which can lead to the substantial elimination of space heating from the N.Z. energy budget.

The first of these claims is easily demonstrated by considering the effect of the "fixed" heat energy gains (See Ref 4). The effect of occupants heat release, cooking, lights, and casual solar radiation gains may be taken to be approximately constant. The magnitude of these casual heat gains is an appreciable fraction of the total heating energy requirement. The data in Table 1 illustrates the point.

The scope for improved thermal insulation is indicated in Figs 1 and 2.

The effectiveness of insulating a particular part of a building is subject to the rule of diminishing returns. Reduction of heat loss to say 20-25% of the uninsulated loss for the particular part is relatively easy, but further reduction becomes rather more difficult. It is also likely to be unwarranted, as illustrated by Fig 1 which shows that the energy returns become small after a sufficient amount of insulation has been added.

There is a further factor. The heat losses from a building take place through 5 paths:-

Roof
Walls
Floor
Windows
Ventilation

It is evident from Fig 2 that to reduce the overall heat losses to a very low level will require attention to all 5 paths. It is also clear that extreme reduction of heat loss through any one path is not necessary and not particularly helpful.

The point which must now be addressed is whether the total heat losses can be reduced to the point where the building is more or less self-sufficient in it's thermal balance - i.e., will need no supplementary heating without use of active mechanical aids or special architecture. An indication in this direction is given in Fig 3, taken from Leslie's (Ref 1) 5 year, hour-by-hour analysis using real-weather records. Extrapolation suggests that supplementary heating energy will not be needed if the overall conductance becomes less than about 3 W/C^o per m^2 floor area. This result is compatible with simple calculation. If we place the figure 3 W/m^2C^o on to Fig 2 it becomes apparent that a goal of totally eliminating space heating becomes plausible if, (and only if) window and ventilation losses are reduced, but without extreme levels of insulation.

One climatic parameter often overlooked is that of radiation loss to clear sky. This is most evident at night, and affects roofs in particular. By extending the "solair" temperature concept to radiation losses as well as gains, the significance of this factor can be readily quantified. Night-time sol-air temperatures for a horizontal surface often reach 6 C^o below air temperature, with an average of about 3 C^o below air temperature. If the night sol-air temperature is ΔT_s below air temperature and the indoor-outdoor air temperature difference is ΔT_r, then a roof "insulation efficiency" can be derived as in Table 2.

TABLE 2 Effective/Rated Roof Insulation Resistance

			ΔT_s	C^o			
		0	2	4	6	8	10
				R_l/R_o			
ΔTr	0	-	0	0	0	0	0
	5	1.0	0.72	0.56	0.46	0.39	0.33
	10	1.0	0.83	0.71	0.63	0.56	0.50
	15	1.0	0.88	0.79	0.71	0.65	0.60
	20	1.0	0.91	0.83	0.77	0.72	0.67

That is, the effective resistance R_l during winter nights may be as low as 50% or 60% of the rated value R_o, with an average of 70% to 80% of R_o.

4. Windows and Orientation

The effect that windows have on the indoor climate is pro rata much greater than that of walls, roof and floor. Further, it is well known that the size, orientation and shading of windows have a large bearing on the heating requirement of buildings. This means there is a good deal of scope for designing energy-efficient buildings on this basis alone.

We have been able to place numbers on some of these effects, by using New Zealand climatic data to explore the heating demand in a functioning building with alternative window distributions. In Table 3 we compare the winter heating demand for a concrete masonry building with a shift of window area from the north to the south, and with the windows removed altogether.

TABLE 3 - Effect of Windows on Heating Requirements

MONTH	"Standard" Building	Windows Removed	N and S window areas exchanged
MAY 73	1990 MJ	2334	2723
JUNE	3545	3404	4319
JULY	4844	4397	5819
AUG	4150	3778	4769

The "Standard" house has 3.5 m^2 of windows facing E, W & S.
12 m^2 " " N

heating to 22°C was supplied between 1700 hr and 2300 hr each evening with no heating other than lighting and living loads at other times.

The simple move of the large north window to the south has increased the winter heating cost by 20% . Removing the windows altogether has little effect on energy required for the "standard" building.

Summer overheating is a hazard to be avoided and good design is able to make the most of winter solar gains, yet guard against overheating in the summer. The shading effect of eaves is particularly useful in reducing summer sun from the north, and the following table is proposed as a 'thumb rule' design aid. Assuming ventilation at 10 air changes/hour, excess temperatures should not result if Table 4 is adhered to.

TABLE 4 - Shading Required to Prevent Summer Overheating (from Ref 2)

Eaves Overhang	% Glazing in Perimeter Wall
0.5 m	20%
0.75 m	30%
1.0 m	40%

If for some reason it were desired to maximize summer heat gain and minimize winter solar heat gain, then horizontal windows (sky-lights) are the answer. The same is true to a limited extent for E and W windows where vertical slats are sometimes required to reduce early morning and late evening overheating in the summer.

Since there is growing demand for New Zealand climatic data reduced into a form where it is readily used in, for instance, 'degree day' calculations, we have been checking the applicability of various models which can be used to reduce raw data collected by the Meteorological Service. The following paragraph briefly illustrates this using solar gains as the example.

The heat gain through a window is the balance of solar gain and heat loss by conduction. These two terms can be modelled separately and calculated from the relevant meteorological variables. Bassett (Ref 3) has described the calculation of the solar gain contribution from the direct and diffuse solar components. These in turn are derived from the horizontal global radiation and cloud cover measurements. The empirical relationship used provides a sufficiently accurate way of calculating the solar gain through windows using data routinely recorded by the N.Z. Meteorological Service. Fig 4 has been included to illustrate the correlation between measured and derived data.

In Figure 5 is plotted the solar heat gains through windows as polar diagrams, and the conducted losses as a circle, uniform for all compass directions. This is specific to the 1975 Wellington winter but is representative of data currently being calculated from Meteorological Service records for other centres and times of the year.

Figure 5 demonstrates that in the Wellington winter of 1975:

a) The average solar gain through windows in the Northerly sector from NE to NW exceeded the average conducted loss by an average of 1 kWh/m^2 day. For North facing windows gains exceeded losses on 85% of the days.

b) East and West facing windows came close to breaking even and the use of blinds or curtains at night could restore the energy balance in favour of solar gain. Days when gains exceeded losses for Easterly windows were roughly equal in number to days of net loss.

c) Windows in the Southerly sector of SE to SW lost an average of 0.7 kWh/m^2 during the day.

The window energy balance can be influenced with shading, double glazing, curtains and various applied coatings. Perhaps the most common of these are curtains, which, if drawn at night to a close fitting of the window space, reduce the conducted heat loss by at least 20%. Double glazing which remains effective during daylight hours can be relied on to reduce these losses by 50%. This means that double glazing in a well heated house would allow a saving of 0.3 kWh/m^2 day over single glazed windows with curtains applied at night.

Various heat abosrbing glasses and reflective coated glasses are available for summer heat control. They also exclude wintertime sunshine, without offering significant reduction in heat losses. The reflective treatment is only partly effective at infrared wavelengths, because the coatings are more or less opaque at those wavelengths.

5. Size and Shape

The larger building, and the nearer to spherical in shape, the less are its heating needs per unit of size, because of the simple reduction in the ratio of surface area to volume.

As a reminder of the magnitude of this effect, Fig 6 shows typical design values of heating needed per m^2 of floor area. This may range from over 140 W/m^2 for a small shed, to less than 20 W/m^2 for a large multifloor building, when the ventilation rate is assumed to be 1 air change per hour, and the same standard of construction is used. It is this effect that allows lighting to be of scant importance as a heating source in dwellings, but a major one in large buildings, where it may even be adequate alone to provide all the heating needs. We should be aware that our familiarity with this fact does not lead us to contempt of it. The current architectural trend to angular protrusions on building is an energy wasting form.

6. Thermal Storage

The thermal capacitance of a building incrases with its mass. Annual heating energy requirements differs according to the heating regime adopted. It has been shown by Leslie (Ref 1) that for continuous heating extra mass is an advantage, but for intermittent heating the mass is a disadvantage except in our northern-most climate of Mangere.

By far the greatest effective contribution to building mass is provided by the floor and ground. The walls and roof provided a further but much smaller effect. The relative savings, taking zero mass as a reference are typically as in Table 5.

TABLE 5 - Heating Energy Savings Contributed by Thermal Storage in Specific Parts of a Typical Floor Dwelling

	Continuous Heating		Intermittent Heating	
	FLOOR/GROUND	WALL& ROOF	FLOOR/GROUND	WALLS & ROOF
MANGERE	35%	18%	14%	8%
CHRISTCHURCH	14%	5%	-26%	-3%

In Table 5 the annual heating energy requirement for a concrete floor, concrete masonry building with normal mass in the floor, (or wall + roof) is compared with that for the same building and location but with zero mass.

However Table 5 compares a "heavy" building with a massless building, not with a 'light' building. Lightweight buildings also exhibit some thermal storage. As is demonstrated in Fig 3 the heating energy required for both lightweight and heavyweight buildings is very much in line with their respective overall conductances. The differences in heating energy needs between "light" and "heavy" walls is equivalent to about 3-6% in overall building conductance to the advantage of mass in continuous heating, but to the disadvantage of mass for intermittent heating (except in Mangere where the effect is neutral. To achieve the improvement indicated in Fig 3 by utilizing more massive construction would require the use of practical but currently unconventional construction details.

The difference is greater in the case of heavyweight roofs, but is also dependent on the location of the insulation. With an externally insulated roof, the addition of mass can reduce heating energy (by 2-6%) for continuous heating, but increase it for intermittent heating (by 4% in Christchurch and 16% in Mangere). For internally insulated roofs the effect of mass will be smaller.

The specific effect of solar radiation has been found to be of very major importance. This is clearly illustrated in Table 4, in which a sun-exposed house is compared with an identical totally-shaded one. There can be no doubt that site selection, choice of sun-angles to neighbouring buildings, and control of vegetation, will have very marked effect on heating energy needs. At this stage it is not certain how much of this effect is due to solar heat collection through windows, and how much to the solar warming effect on the building exterior.

TABLE 6 - The Effect of Solar Radiation on Annual Heating Energy Requirement for an Uninulsated Concrete Building in an Intermittent Heating Regime GJ (From Ref 1)

	MANGERE	KELBURN	CHRISTCHURCH	INVERCARGILL
Radiation included	20.5	49.4	57.9	70.6
Radiation excluded	47.8	85.0	86.4	104.0
Ratio	2.34	1.72	1.49	1.47

SUMMARY

The heating energy needs of buildings is strongly affected by:-

- The heating standard adopted
- The degree of thermal insulation
- The degree of sun-exposure
- Details and orientation of windows.

It is suggested that a goal of improved heating standards, in conjunction with the substantial elimination of supplementary space heating, may be feasible in the N.Z. climate. This goal appears feasible if and only if window and ventilation heat losses can be reduced, but does not require exceptionally high insulation levels for roofs, walls and floors.

REFERENCES

1. S. Leslie — "Heating requirements for heavy domestic buildings"
N.Z. Energy Research and Development Committee Report No. 16.
Auckland 1976.
(Also as BRANZ Report R17).

2. H. Trethowen — "Impact of building design on energy conservation"
Energy conservation in buildings symposium, N.Z.
Institution of Engineers (Building Services Group) Wellington 1973.

3. M. Bassett — "Wintertime heat balance of windows"
BRANZ Report R21. Wellington 1976.

4. — "Survey of household electricity consumption 1971-72 "
(The temperature-insulation study) Dept of Statistics Wellington 1976.

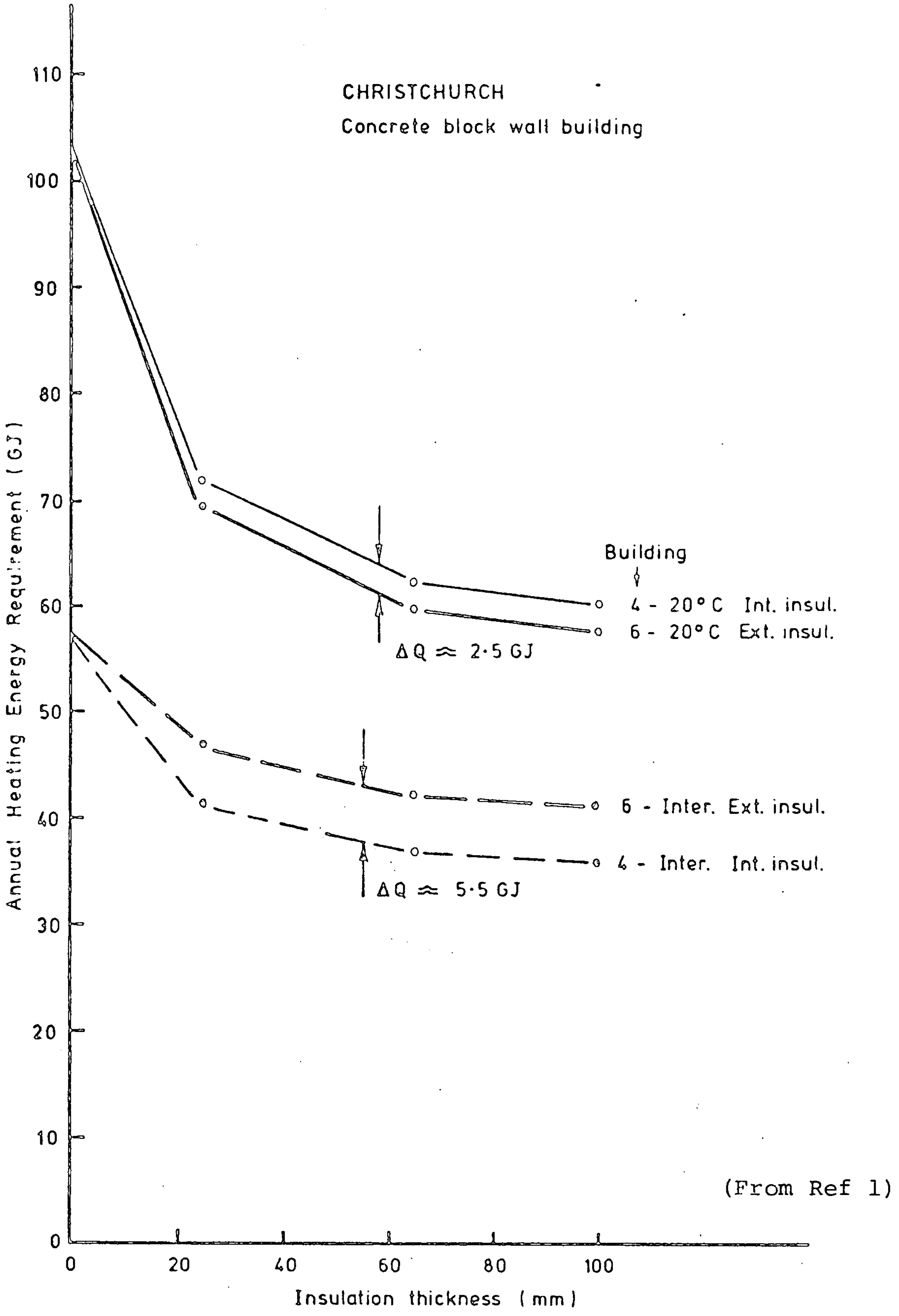


FIG. 1 EFFECT OF THERMAL INSULATION THICKNESS AND ORDER ON ANNUAL HEATING ENERGY REQUIREMENTS OF HEAVY BUILDINGS

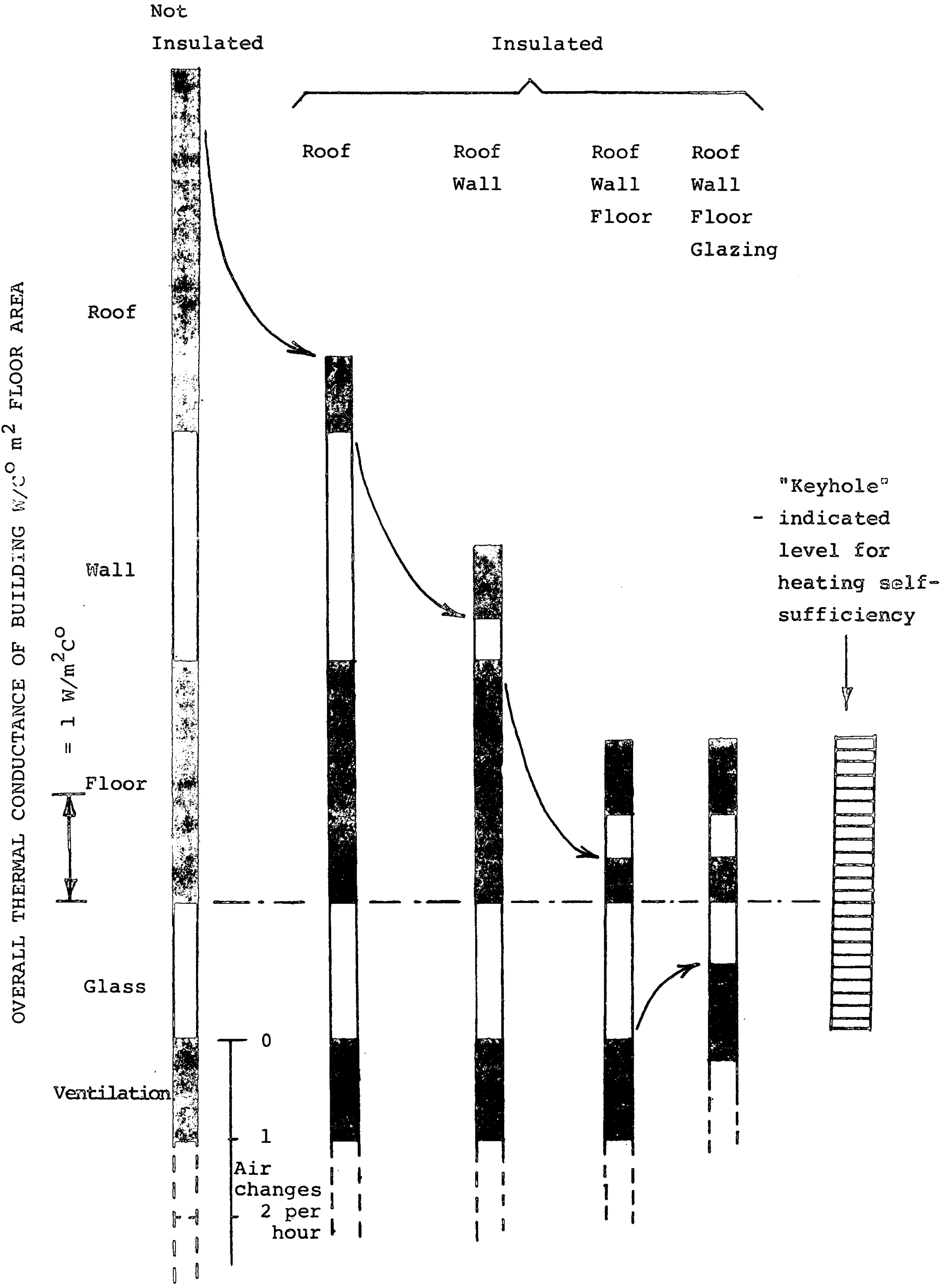
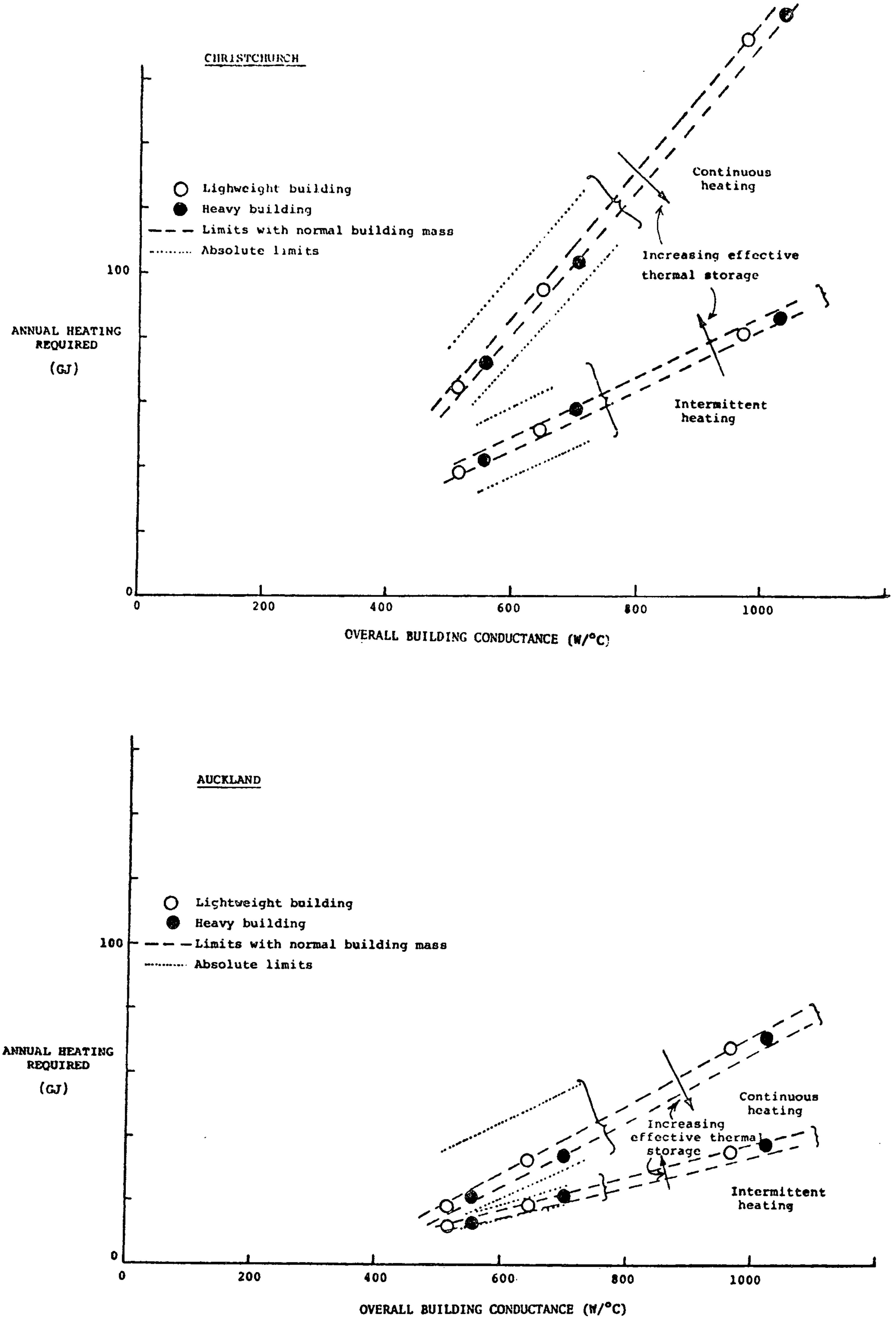
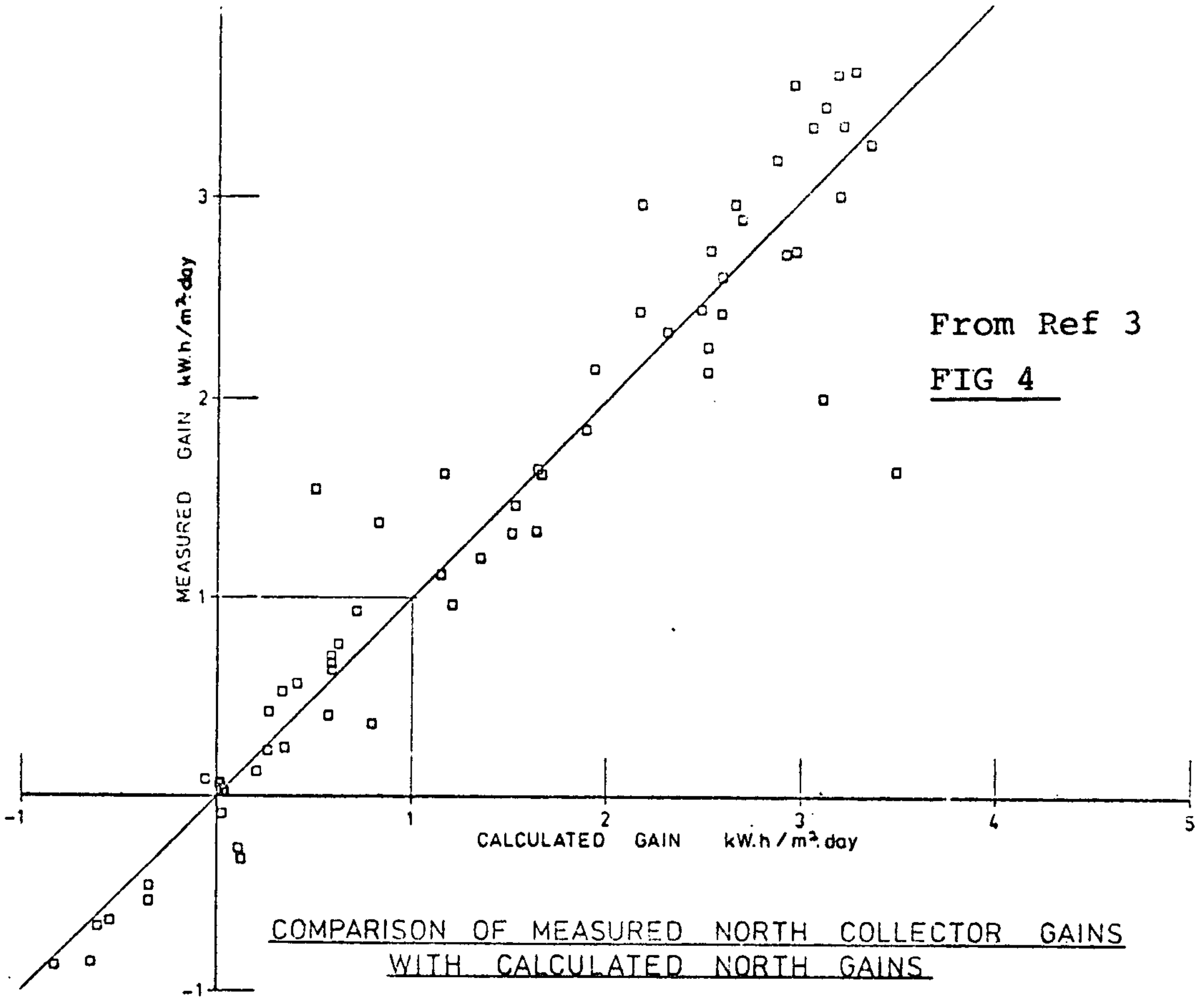


FIG 2. Cumulative Effect of a Progressive Insulation Programme



(From Ref 1).

FIG. 3 THE EFFECTS OF THERMAL STORAGE & INSULATION ON HEATING ENERGY REQUIREMENTS



From Ref 3

FIG 4

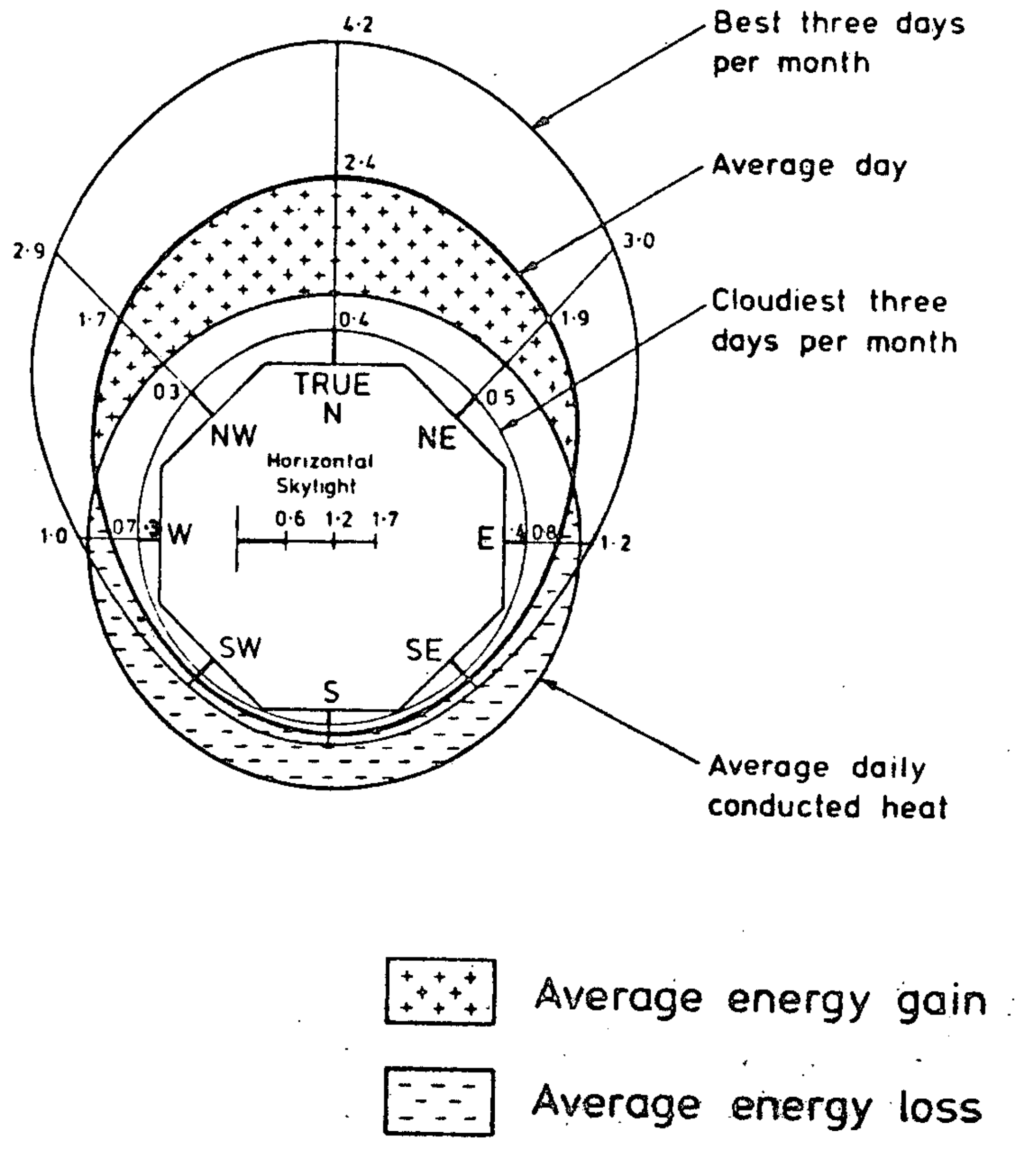
COMPARISON OF MEASURED NORTH COLLECTOR GAINS WITH CALCULATED NORTH GAINS

AVERAGE WINTER DAY SOLAR HEAT GAINS THROUGH WINDOWS FACING VARIOUS DIRECTIONS

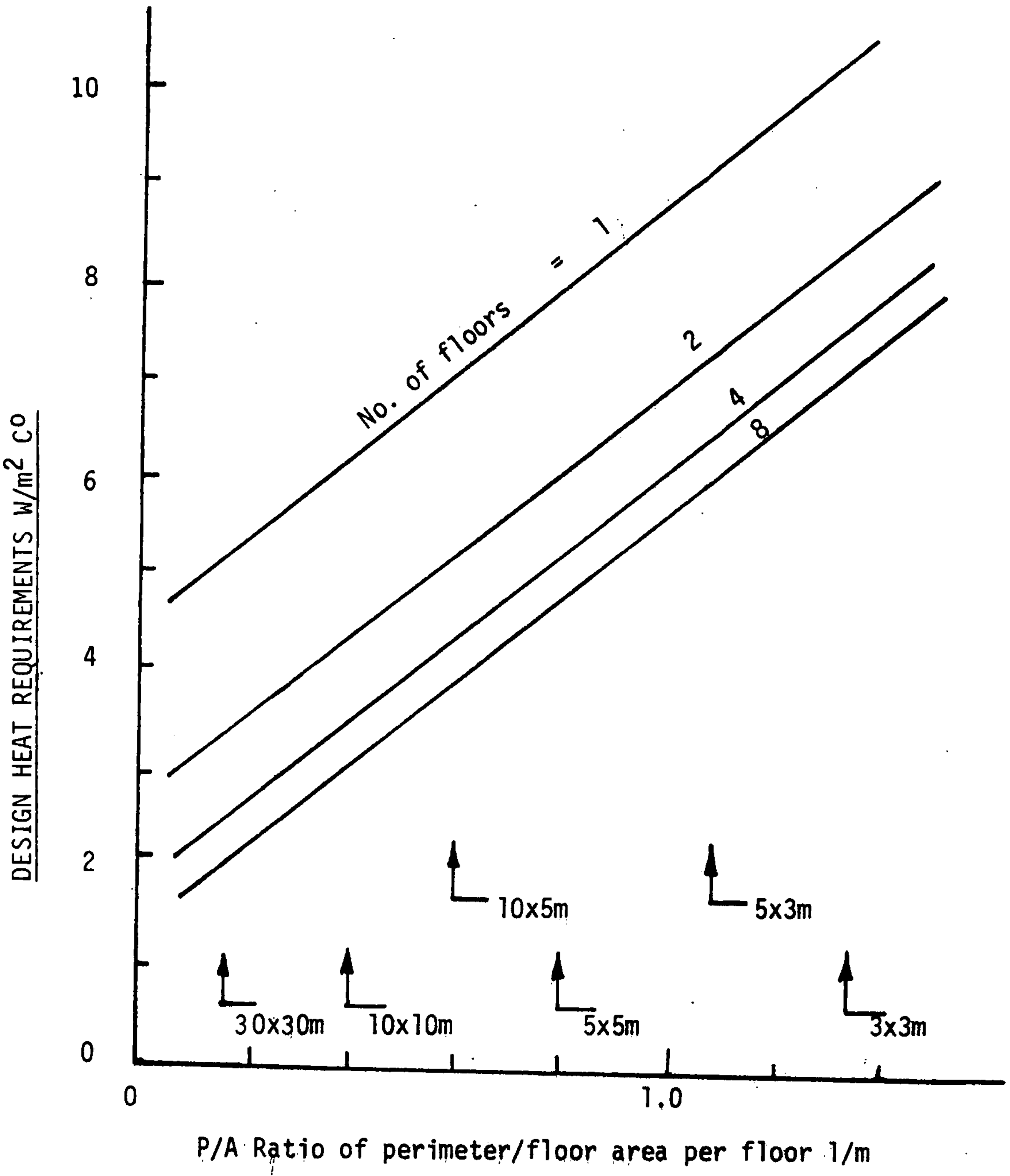
From Ref 3

FIG 5

SOLAR ENERGY ADMITTED :



JUNE-JULY DATA FOR
WELLINGTON FROM THE
1975 METEOROLOGICAL
RECORD.



Floor height = 2.5 m

Mean thermal resistance of envelope = 0.6 C° m^2/W

FIG 6 TYPICAL DESIGN HEAT LOSS PER UNIT FLOOR AREA (From Ref 2)