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WINDOW OPENING IN HOUSES: AN ESTIMATE OF THE REASONS AND MAGNITUDE OF THE ENERGY WASTED

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SUMMARY

Detailed analysis of actual space heating requirements shows a much higher consumption in mild weather than had been predicted. This is mainly attributed to casual window opening, which accounts for 30% of the total energy used. This factor will become even more important in well insulated houses where the ventilation loss is proportionately greater.

An examination of the motives for window opening suggests that physiological needs for air can be neglected, odour removal is adequate but high humidity levels are the most likely cause. In the coldest days the outdoor air is dry and the windows act as dewpoint condensers hence moisture build up is not rapid. In warm days there is no heating, the outdoor air is not saturated and doors are left open. In mild winter weather the outdoor air is saturated and the house is heated. No condensation occurs on the windows and so a high infiltration rate is required to remove the internally generated moisture.

A servey of the moisture capacities of common materials as a function of humidity shows how a well furnished house has a large moisture storage capacity in the organic materials. The tendency to use man-made fibres reduces this storage and accentuates the problem.

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1. INTRODUCTION

Conventional heat loss calculations assume ventilation in houses to be one air change an hour in the design day weather ($-1^{o}C$ outside temperature)! This constitutes only a quarter of the total heat loss and great accuracy has not therefore been necessary. Two new factors are changing this attitude. The first is the emphasis on energy use throughout the heating season. This means that we will have to examine in detail how the house is commonly used throughout the heating season and the role of ventilation in this occupancy pattern. The second factor is the growing use of improved fabric insulation. This makes ventilation losses proportionately more important and they can account for half of the total needs.

Let us first examine the theoretical energy needs for a house.

2. ENERGY CONSIDERATIONS

(a) Theoretical heat losses

There are two heat loss routes from a house. The first and usually the largest is through the fabric of the building i.e. through the roof, walls and floor of the house. The quantity of heat loss is a function of the insulation value and the temperature difference across the component. Increasing the insulation value by thicker glass fibre loft quilts or by cavity infill reduces the heat loss. Typical design day heat losses for a three bedroom semi-detached house are illustrated in Figure 1. The second type of heat loss is the infiltration heat loss due to cold air entering cracks in the building and displacing the warmed room air. This loss is a function of the wind speed around the house and of the magnitude of the cracks around the windows and doors. It is not normally calculated but assumed to be an arbitrary air change rate of one an hour.

Both the fabric loss and infiltration loss are linearly related to temperature difference in the way illustrated in Figure 2.

(b) Incidental gains

The domestic consumption of electricity per household is steadily increasing. Over two thirds of households have a refrigerator, many now have a deep freezer [(2)]. Television is watched on average for nineteen house a week in winter and the few million colour sets in use already consume significantly more power than black and white sets [(3)]. Many households now have two televisions. Water consumption is rising and one third to a half of it is estimated to be heated and distributed in uninsulated pipes throughout the house. Only half of this energy reaches the taps. Lighting is switched on for much longer in winter. The magnitude of the solar gains will depend on cloud cover, building orientation and window size but even in winter sunshine can make a useful contribution to heating the building. Billington 1972 estimates the incidental heat gains in a typical house to be just over 2kW, of which only a small part varies with the season. These gains are superimposed on Figure 2.

(c) Theoretical seasonal energy loss

At any mean daily outdoor temperature there will be a corresponding heat loss and a contribution towards this loss from the incidental gains. The temperature at which the incidental gains equal the heat loss is termed the balance temperature and no heat is needed from the heating equipment at this or high outdoor temperatures.

The seasonal heat loss at any temperature below the balance temperature is the product of the daily energy loss at this temperature and the number of days in the heating season at this temperature. The distribution of days at each temperature is illustrated in Figure 3. The seasonal heat loss is the cumulative heat loss at each temperature below the balance temperature.

3. FIELD TRIALS

Field trials do not normally reflect heat losses corresponding to one air change an hour and conduction through the fabric. In practice these terms only apply at the coldest day condition, while in mild weather the incidental gains are not fully used and much more heating energy is supplied than would have been predicted. Winkens 1970 [5] shows this to be true for gas, electric and district heating and therefore it is more likely to be a user characteristic rather than a feature of a particular heat system.

Dick and Thomas 1951 [6] revealed an important but neglected factor which explained the energy use pattern. In British test houses studied there was a progressive opening of windows with increasing outdoor temperatures. This relationship is illustrated in Figure 4, and interpreted in terms of air changes in Figure 5. The average air change in these houses with flues were 1½ in the coldest weather 0°C but linearly increased with temperature to four air changes an hour at 15°C.

Field trials carried out in Bromley in 1968/69 by the Electricity Council [7] reveal the same pattern of energy use, Figure 6. Comparing the theoretical with the actual consumption we note that all the excesses occur in mild weather. This difference is attributed to the effect of window opening. The weather pattern for this area is given in Figure 3. Comparing the weather data with the energy used for each temperatures gives a seasonal heating energy consumption of approx. 12,000 kWh, very close to the actual consumption of these houses. Window opening is expected to account for a third of this, Figures 6 and 7.

The Bromley trials revealed one other feature. This was the effect of cold weather on the distribution of temperature throughout the house. Bedroom temperatures were directly linearly related to external temperature. In cold weather 0°C the bedroom temperature would drop to 15°C, rising to 20°C when the outdoor temperature was 15°C. The living room temperature where the thermostat was located was controlled at 19°C for the majority of the winter rising to 21°C when the external temperature was 15°C, Figure 8.

These two factors of window opening and temperature distribution through the house show that the heating energy is not a simple function of thermal insulation and temperature difference between the exterior and the thermostat setting. This has an importance not only on current use of energy but more importantly on the use of higher fabric insulation standards. In such circumstances the proportional energy loss through window opening will be increased. Insulation between floors will also be necessary to avoid high bedroom temperatures. The theoretical benefits of the higher insulation standards would only be partly achieved.

We now need to consider possible motives for opening windows.

4. VENTILATION

The object of introducing fresh air into a room is to supply the necessary oxygen for survival and to dilute the level of contamination to one which is acceptable and safe. The contamination can be simply body odours in a crowded room or moisture build-up due to perspiration and these are considered in detail.

(a) Physiological considerations

Breathing introduces oxygen into the lungs and enables carbon dioxide to be expelled. The amount of carbon dioxide produced is related to the oxygen absorbed in a way which depends upon the diet. The chemistry of metabolism leads to more carbon dioxide being created by the oxidation of carbohydrates than of fats. The proportion of carbon dioxide released is slightly less than that of oxygen absorbed (0.85 x volume of oxygen) for people on a normal mixed diet.[(8)]

People tolerate wide ranges of oxygen content without producing any marked effect of breathing. At sea level the percentage of oxygen can be reduced from 21% to 13% without alteration in breathing. When the oxygen percentage falls below 12% breathing is stimulated by lack of oxygen. This condition is unlikely to be encountered because of our sensitivity to carbon dioxide.

When the inspired air contains approximately 2% of carbon dioxide (outside air contains approximately 0.03% carbon dioxide) the depth of breathing increases. At concentrations of 3% to 5% there is a conscious need for increased respiratory effort and the atmosphere becomes objectionable. The breathing rate is increased. Concentrations over 6% are dangerous. (Bell, Davidson & Scraborough, 1968) [(8)].

The maximum allowable concentration of carbon dioxide for habitation is 0.5% which gives a generous safety margin for breathing comfort. This is calculated in terms of fresh air supply in Appendix 1 i.e. 4.5 m^3/h for a sedentary person. This is interpreted in terms of air changes related to personal space in Figures 9 and 10.

(b) Odour dilution

Odours in living rooms come mostly from the occupants themselves.

Healthy and clean people give off odours, even immediately after a bath. Such odours are not known to be harmful but do induce unpleasantness. This unpleasantness is related to the odour concentration, though adaptation occurs with prolonged exposure. Yaglou, Riley & Coggins 1936 [9] studied the factors influencing the generation of odours and the amount of dilution needed to bring the odour level to an acceptable level for newcomers to the room. There was no sex difference in odour generation providing perfume was not used. Age became important below 14 years since younger children created more objectionable odours. Odour generation was also strongly related to the time which had elapsed since the last bath.

Sensitivity to odours was such that it took three times more fresh air to change an assessment from 'strong' to 'moderate' and a further factor of three to reduce it to 'definite'. Crowding was very important with much more air being needed to dilute the odours created from a number of people. This quantity of fresh air needed to dilute odours to a moderate level which is neither pleasant nor disagreeable is also shown in Figure 9.

Yaglou 1955 [10] reported an extension of this study to include cigarette smoking. Three categories of observers were used, the smokers themselves, non-smokers sitting in the same room and observers making spot assessments and then retiring from the room. The smokers themselves were incapable of perceiving the smoke odour regardless of air flow. They were however more susceptible to irritation of eyes, nose and throat than the non-smokers or the observers and this was related to the contamination level. The non-smokers were sensitive to the amount of fresh air and for acceptable odour conditions required some 20% more fresh air than the smokers required to prevent irritation of the eyes. The observers required some 50% more fresh air for the same acceptability level.

Current fresh air recommendations for people working in rooms where smoking is permitted is also superimposed on Figure 9.

These recommendations are recalculated on the basis of air change rates for people living in rooms of ceiling height 2.4 m as in a conventional house, Figure 10.

(c) Humidity

Evaporation of moisture occurs through three mechanisms namely respiration losses, insensible perspiration through the skin and perspiration through the sweat glands. In normal circumstances a healthy 70 kg man working in a temperature climate loses approximately 400 g of moisture a day from the lungs and a further 500 g through the skin. The total moisture rate is 30 g/h during sleep rising to 40 g/h while awake [8]. This moisture level can become a contaminant in areas where humidity control is desired and can be removed either through condensation in air conditioning or by dilution with excess ventilation.

Humidity affects the sensations of warmth. This effect is very marked in those hot environments where the skin perspires to effect some cooling. The effectiveness of this evaporative cooling is very sensitive to the ambient humidity, decreasing in effectiveness with increasing relative humidity Bedford, 1936, [11] Inouye, Hick, Telser and Keeton, 1953 [12], Koch, Jannings and Humphreys, 1960[13] and Nevins, Rohles, Springer and Feyerherm, 1966 [14] all showed the thermal effect of humdity in the comfort region to be small Figure 11.

Other effects of humdity such as dryness or pleasantness have received little attention. Koch 1963 [15] and Rasmussen 1971 [16] showed how high humidities were reliably detected by subjects at temperatures of 25-28°C. McIntyre and Griffiths 1973 [17] studied effect of humidity at a normal sedentary comfort temperature of 23°C. They found that while variations in humidity did not affect feelings of warmth in the comfort region of 23°C increasing humidity increased the feelings of skin moistness. This is illustrated in Figure 12.

Current comfort Guides (IHVE 1970) [1] recommend a range between 40-70% relative humdity.

(d) Humidity: effect on materials within the building

Dry materials absorb moisture from the ambient atmosphere. When the humidity of the atmosphere increses so the equilibrium moisture content of the material increases. If the moisture is measured at constant temperature then this characteristic relationship between moisture and relative humdity is termed the absorption isotherm. Non-porous materials like glass have only surface moisture and even for finely dispersed products such as glass wood the moisture content is usually less than ½% by weight (Porezynski 1958)[18]. Porous materials, particularly organic ones such as leather, contain a network of interstitial capillaries and can absorb over half their dry weight of water from the atmosphere. The variety of absorption characteristics for a range of common household materials are illustrated in Figures 13 and 14. Leather, timber, skin, and wool all have high moisture capacities. Plasterboard, concrete, brick and the man-made fibres of nylon and terylene have low moisture capacities over a wide range of relative humidities [19-25]. Materials have high moisture retaining capacities when actually immersed in water but this is not considered here.

Most materials exhibit hysteresis i.e. the direction of moisture change has an effect on the equilibrium value. The moisture value of a material will be a little higher if it is dried down to equilibrium at a given relative humidity than if it was moistened up to the value. For wool, silk, rayon and nylon this hysteresis varies between 0.1-2.0% of the moisture regained from the dry. The moisture characteristic of organic textiles is not temperature sensitive i.e. the absorption isotherm only alters by less than 2% by weight for temperature changes from 12-35^{o}C [26] the rate at which these textiles respond to changes in humidity is usually minutes or at most hours for thick materials (Thompson 1925 [27]).

Timber absorbs a significant amount of moisture at high relative humidities with the more porous softwoods absorbing more than the hardwoods. The rate of change of moisture in such materials is very sensitive to the protective finishes of paint or varnish. It is usually slow for furniture and takes several weeks (Brewster 1931) [28].

Mildew problems occur with prolonged exposure of organic material in still air to relative humidities greater than 70% (MacIntyre 1937) [28]. Once mildew begins it is self-sustaining since the decomposition of the organic material provides a moisture source for propagation.

The moisture absorbing properties of typical common materials are summarised in Table 1 for a change in ambient relative humidity from 30-70% at ordinary room temperature ($\sim 20^{o}C$). Woodwork, lying principally as untreated flooring has the largest likely moisture holding capacity. Plasterboard, by virtue of the large surface area of a room, is the second largest moisture store. However, the rate of moisture change in this case will be very dependent on the surface coating; vinyl wallpaper for example has a very low vapour permeance and will prevent much of the ambient moisture from reaching the plaster. Carpets and upholstery are the next in moisture storage capacity. Wool has particularly high capabilities for water storage and when it is evenly spread as in carpets or upholstery would be expected to respond within minutes of changes in the ambient relative humidity.

5. EXAMINATION OF HOUSE OCCUPANCY

(a) Background

Data on moisture levels in British houses is rare. White 1972 [30], Ashton 1974 [31], agree on typical winter internal relative humidites of approximately 35-40% rising to 70-75% in summer. In terms of changes of relative humidity within the day the stabilising influence of the room contents has long been recognised. (Henry in Hearle ed. 1960 [32], Horie 1965 [32]). Well furnished rooms have stable humidities over the day while, bare or non-absorbent rooms have rapid fluctuations which reflect the instantaneous moisture loads due to people, meals and temperature changes.

Five factors influence the internal humidity in a room. These are the window temperatures, the infiltration rate, the external air moisture content, the moisture generation rate and the local absorption of furnishings. Taking these in turn.

(b) Dew point control of room humidity by the windows

The window is the coldest point in a room. The temperature of the glass therefore has an important role in determining the maximum humidity level in a room. If the dew point of the air in the room exceeds the temperature of the window glass then condensation will occur on the inner surface of the window. This will continue until the air dew point is the glass temperature. The surface temperature of the glass in turn is a function of the type of glazing, single or double, and the air temperatures and velocities on either side of the window. The glass itself has little thermal resistance and hence its temperature is very sensitive to air velocity. This influence of velocity is shown diagrammatically in Figure 15. In sheltered areas the glass temperature is just under midway between inside and outside temperature i.e. for $20^{\circ}C$ indoors and $0^{\circ}C$ outdoors the glass would be $9^{\circ}C$ (i.e. a relative humdity maximum of approx. 50%). The same window glass sited in a severely 'exposed' position would be at $4^{\circ}C$, equivalent to a maximum relative humidity of some 35%. The limiting relative humidities for single and double glazing are shown in Figure 16 as a function of outside temperature in a 'normal' exposed site. Davies 1973 [34] has studied the rate of condensation on surfaces and in design day conditions ($20^{\circ}C$ 80% inside, $0^{\circ}C$ outside) predicts a condensation rate of approx. 60 g/m^2h. Large rooms with small windows would remain for some hours at humidites above the glass due point conditions to the relative slow rate of change towards equilibrium.

(c) Infiltration rate

The effect of wind on a building is to create a pressure on the windward face of 0.5 - 0.8 times the velocity pressure of the free wind. This is reinforced by the negative pressure of 0.3 - 0.4 times the velocity pressure on the leeward face. The combined pressure difference is therefore approximately equal to the wind velocity pressure. This pressure difference forces cold air through gaps in the house fabric. The resistance to this air flow depends upon the number and size of the external gaps and upon the internal resistance of air routes through the house. Open plan houses with chimney have little internal resistance, a flueless house with cellular room layout and well fitting internal doors has a high resistance. Care in the finish of a house particularly with respect to the shrinkage of the wooden components is important. The leakage around the openable parts of windows and doors accounts for between 5-80. of the total air infiltration.

Data is sparse on the actual infiltration rates for modern houses. Masterman and colleagues 1935 (35) measured values of 0.5 - 1.0 air changes an hour in flueless dwellings with the lower value being appropriate for large rooms and the larger for small rooms. Air change rates in flued rooms could be up to 5.0 an hour. Window opening but with doors shut created values up to 20 air changes an hour which could increase to 30 air changes if the door was opened. Warner 1940 (36) measure ¾ of an air change an hour in flueless rooms, rising to 2.0 with a flue. Window opening in flats created 6.0 air changes an hour even when the external air speed was 1 m/s. Measurements carried out by the Building Research Station 1939/40 (37) showed how the presence of a flue could create 1.7 air changes an hour without heating. In heated rooms the rate varied from 0.7 air change for an anthracite stove to 4.5 air changes an hour for a coal fire. Dick and Thomas 1951 (6) studied the use of windows in houses and noted that many people kept a window open even in the coldest weather. The infiltration rate was estimated to be a minimum of 1.5 air changes an hour rising with increasing outdoor temperatures to 4 air changes an hour at the end of the heating season. Harris-Bass and colleagues 1974 (38) found air changes over 1.0 per hour in normal rooms.

(d) Moisture in outdoor air

The moisture retaining capacity of air is very sensitive to temperature holding more with increasing temperature. For the most of winter the outdoor air is approximately 90-100% saturated with water vapour [39]. This means that the actual moisture content of air can be expressed in terms of outdoor temperature, figure 17.

If this infiltration air is used to lower the water vapour content of buildings then much more air will be needed in the milder weather.

(e) Moisture generation rate

Moisture release from people through respiration and perspiration is well established physiologically. In normal circumstances a healthy 70 kg man working in a temperature climate loses approximately 400g of moisture a day from the lungs and a further 500 g through the skin, i.e. approx. 30 g/h during sleep and 40 g/h while awake.

Moisture release from other sources in a house are less well defined. Smith and colleagues 1948 [40] measured the moisture released from a wide variety of domestic jobs. Clothes drying was the biggest single item which could release 12 kg of water vapour from the family wash. Moisture from people was the second largest source and cooking particularly if on a gas cooker, was third ~2 kg per day. Others have made estimates of likely daily loads with 7 kg being a typical daily family quantity. Comparison of various authors' estimates are shown in Table 2.

(f) Moisture absorbing capacity of household materials

The sensitivity of finished goods i.e. cotton which has been dyed and treated with chemical finishes to relative humidity is much less known than the raw materials. However, assuming the final treatments of materials do not significantly affect their basic properties we can consider the likely range of moisture change in popular furnishing materials. To assess this we need to estimate the total quantity of each material in a room. This has been done in Table 1. Typical values for carpets are 30 kg for a wool one down to 12 kg for a cotton one. Curtains, even when lined, are relatively light at approximately 2 kg, while wallpaper if used on walls and ceilings can total 8 kg. Books vary from typically 1 kg for technical ones to 0.1 kg for paperback novels. Plasterboard is used in large quantities and 330 kg can be used in a room.

Using these weights together with the absorption isotherms from section 4(d) we can estimate the effective water storage if the relative humidity varied from 30-70%. The influence of temperature is small and has been neglected. The change in moisture in the wool carpet would be 23 kg. The carpets, curtains and upholstery would respond quickly because of their large available surface area. The wallpaper would depend upon its surface coating as would the plasterboard lining. The time constant for timber and for books would be several days rather than hours.

This summary suggests that the use of man-made fibres in carpets and the trend to washable plastic wallpapers accentuates the problems of condensation in areas not formerly troubled. The storage capacity is sufficiently large to absorb most fluctuations in hour by hour changes in moisture generation rates.

6. DISCUSSION

Comparisons of theoretical and actual energy use for space heating in a house highlights the importance of excess ventilation heat loss. This could account for a third of the seasonal energy used simply because windows are opened in mild weather and mild weather is the most common winter condition in Britain.

Assessments of the motivation to open windows show that carbon dioxide levels can be neglected, body odours are unlikely to be a problem since the normal air leakage in a house with closed windows is sufficient to dilute body odours to an acceptable level, but high humidity levels could become an embarrassment if windows are not opened. In cold weather the air leakage is very dry air and normal infiltration dissipates a large moisture burden. The windows also control the upper limits of humidity in such weather by providing a dew point control. The cold glass acts as a condensation plate. In mild weather the outdoor air is still almost saturated with water vapour but because of the higher temperature the absolute moisture content is also higher. More ventilation is required to remove the moisture generated in the house. In mild weather there is less likelihood of condensation on the windows removing moisture. This tendency to have windows wide open in summer and progressively shut them as the temperature falls is reinforced by the presence of cold draughts which open windows can create. The user habits are further reinforced by a sensation of moistness of the atmosphere in a way unrelated to temperature. At high humidities the skin is sensed as too wet and comfort declines. At low humidities the skin is too dry and comfort similarly declines.

Two factors, the personal sensation of humidity and the indirect sensation of feeling fabrics to be damp appear to be the major ones in controlling the opening of windows. Typical estimates of water release from the occupants of a room are summarised in Table 3 and this is converted to air flow needed to remove it to keep relative humidities in the house to 70% maximum, Figure 18. More accurate analysis would include the extra moisture generation created by other sources (Table 2), and the influence of intermittent occupancy for particular applications.

Future developments in insulation and the application of such techniques to houses will exaggerate the problem because the ventilation loss will then be the dominant factor. Lack of control could easily negate many of the potential advantages.

7. CONCLUSIONS

1. The loss of heat through infiltration becomes increasingly more important as fabric insulation techniques such as foam infill, loft quilting and double glazing become more popular.

2. This infiltration loss is exaggerated by the householders practice of opening windows, particularly in the mild weather which constitutes most of winter. In the test houses examined 1/3 more energy is used than predicted. A significant proportion of this is likely to be due to window opening.

3. A review of the personal needs for ventilation for carbon dioxide suppression, body odour control and humidity limitation shows excess humidity to be the key item.

4. The common materials such as carpets, curtains and upholstery store a significant amount of water and act as a moisture flywheel but the trend towards man-made fibres reduces this capacity.

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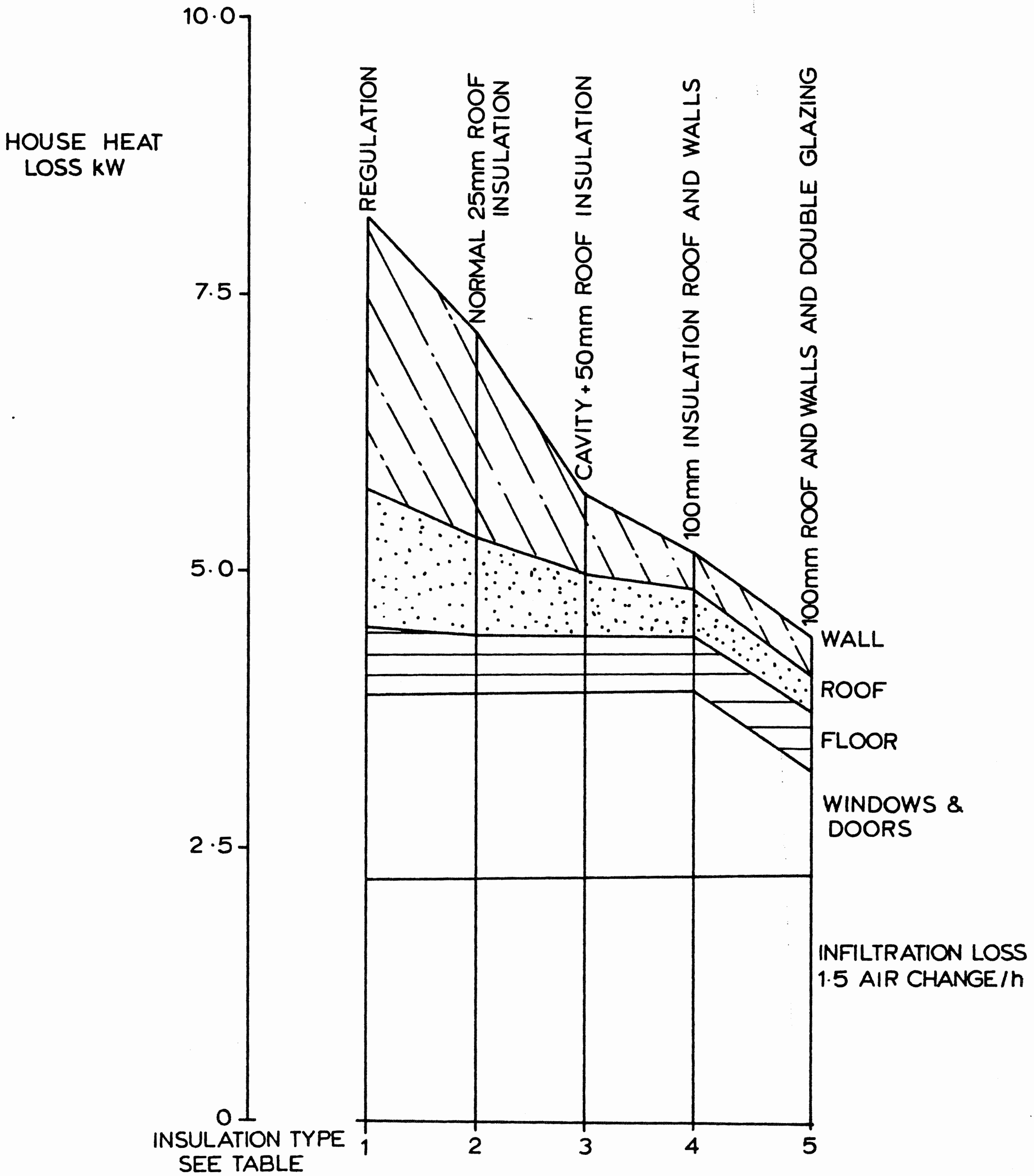

SEMI-DETACHED HOUSE : 90m² FLOOR 6 x 7·5m PARTY WALL PLAN
TWO FLOORS 4·7m HIGH
20m² WINDOW 72m² WALL AREA, 220m³ VOLUME

DESIGN CONDITIONS: 19°C INDOOR -1°C OUTDOOR

FIGURE 1
REDUCTION IN HEAT LOSS WITH INSULATION.
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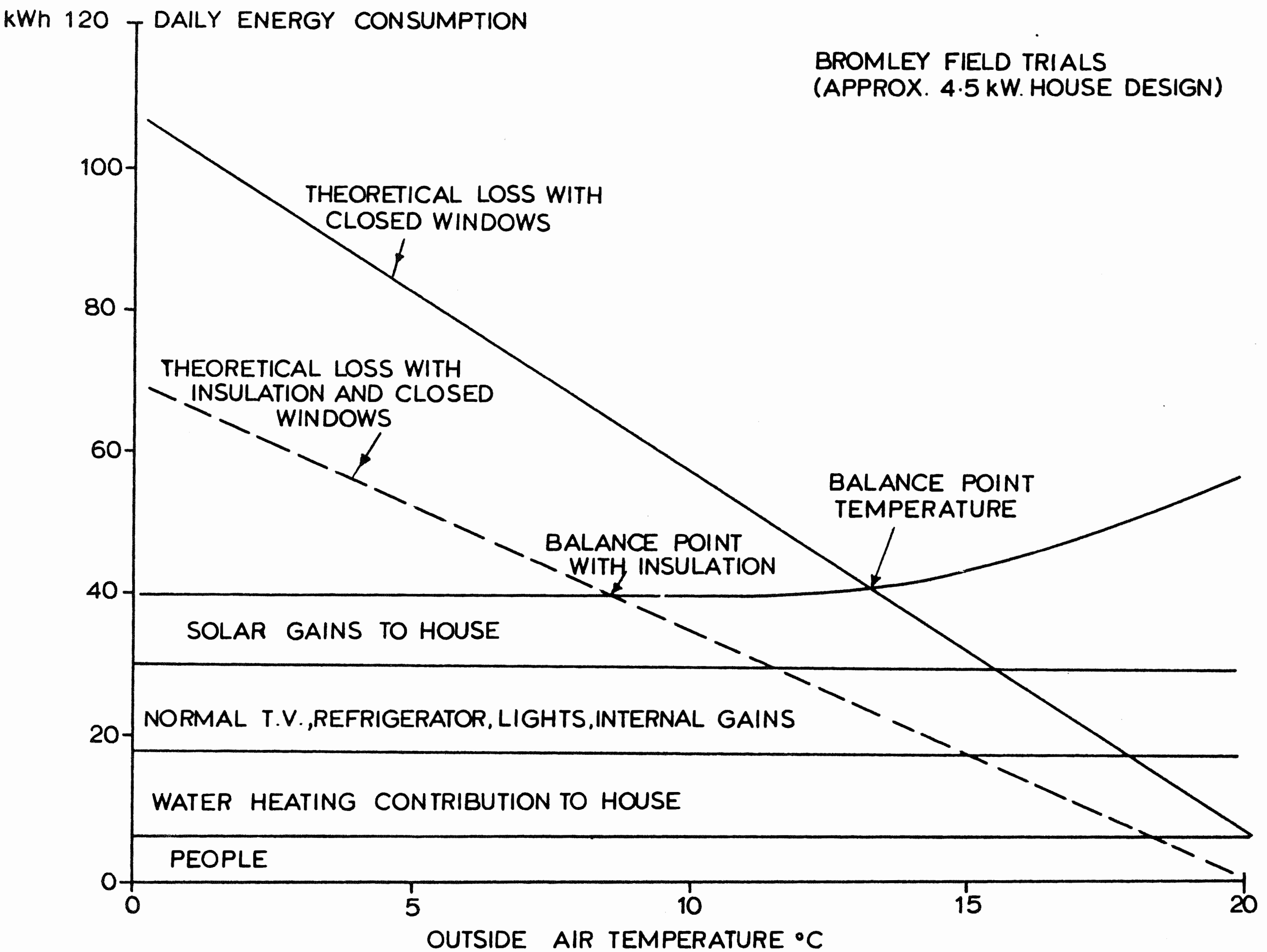
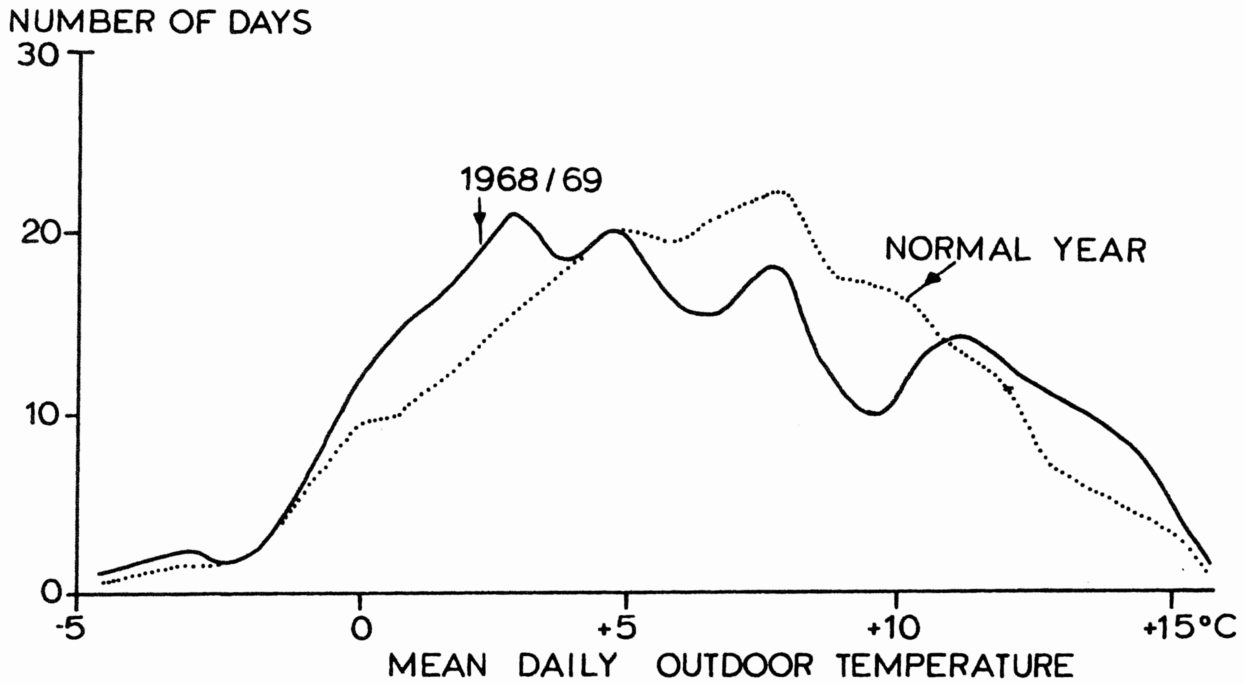


FIGURE 2.
ILLUSTRATION OF THE BALANCE POINT TEMPERATURE FOR A HOUSE.
ECRC/M801



MITCHELL, PARKER & HASLETT 1971[44]

FIGURE 3
FREQUENCY DISTRIBUTION OF MEAN DAILY TEMPERATURE FOR THE BRITISH HEATING SEASON.

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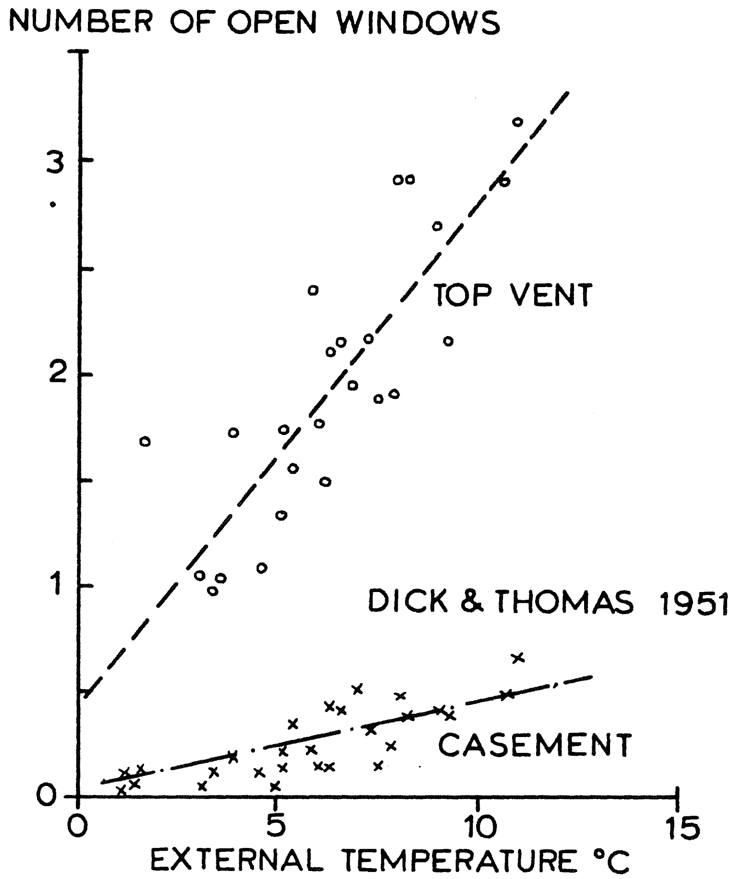

FIGURE 4.

THE NUMBER OF WINDOWS OPEN AT DIFFERENT OUTDOOR TEMPERATURES.

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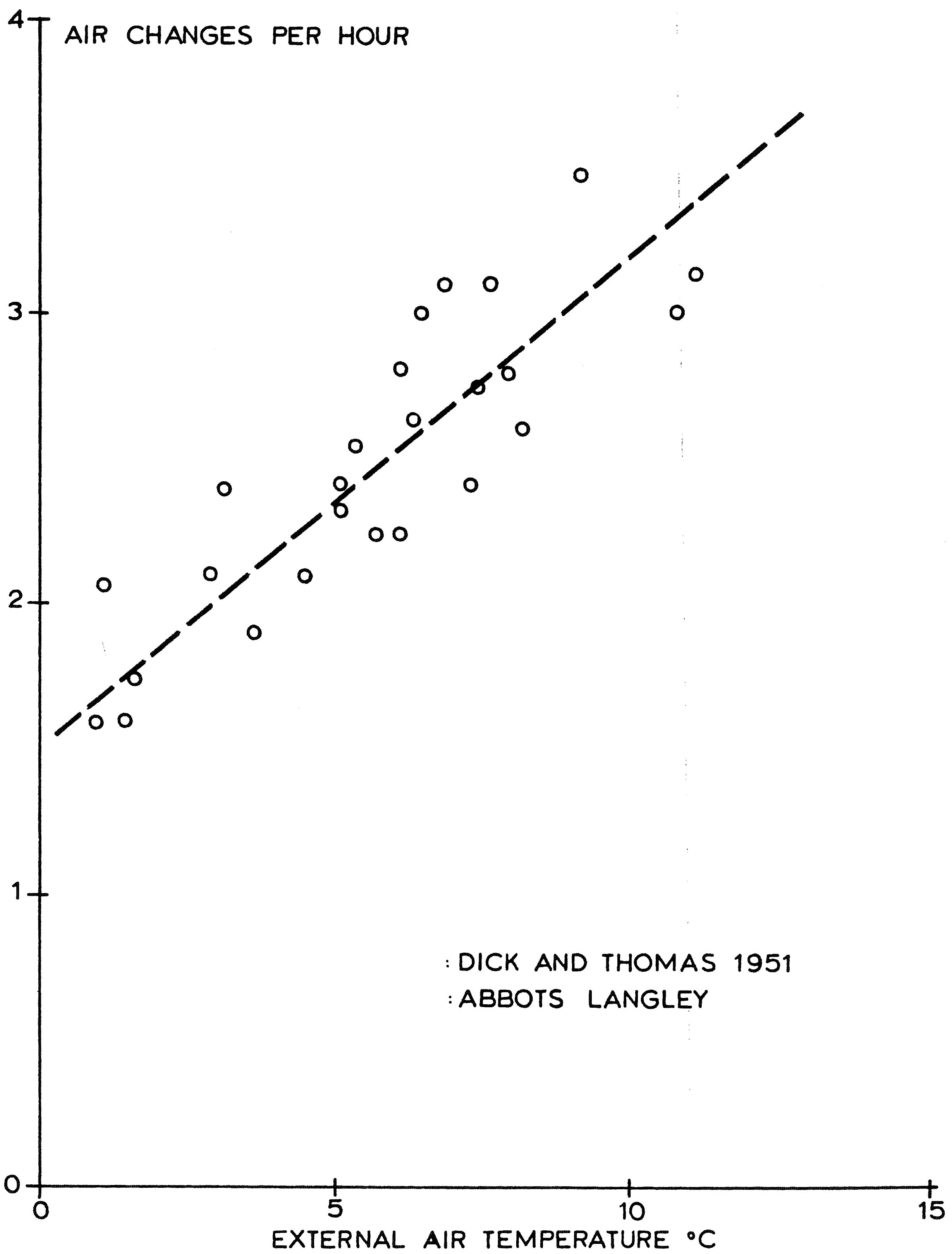

FIGURE 5.
AIR CHANGE RATE IN TEST HOUSES RELATED TO THE OPEN WINDOWS.

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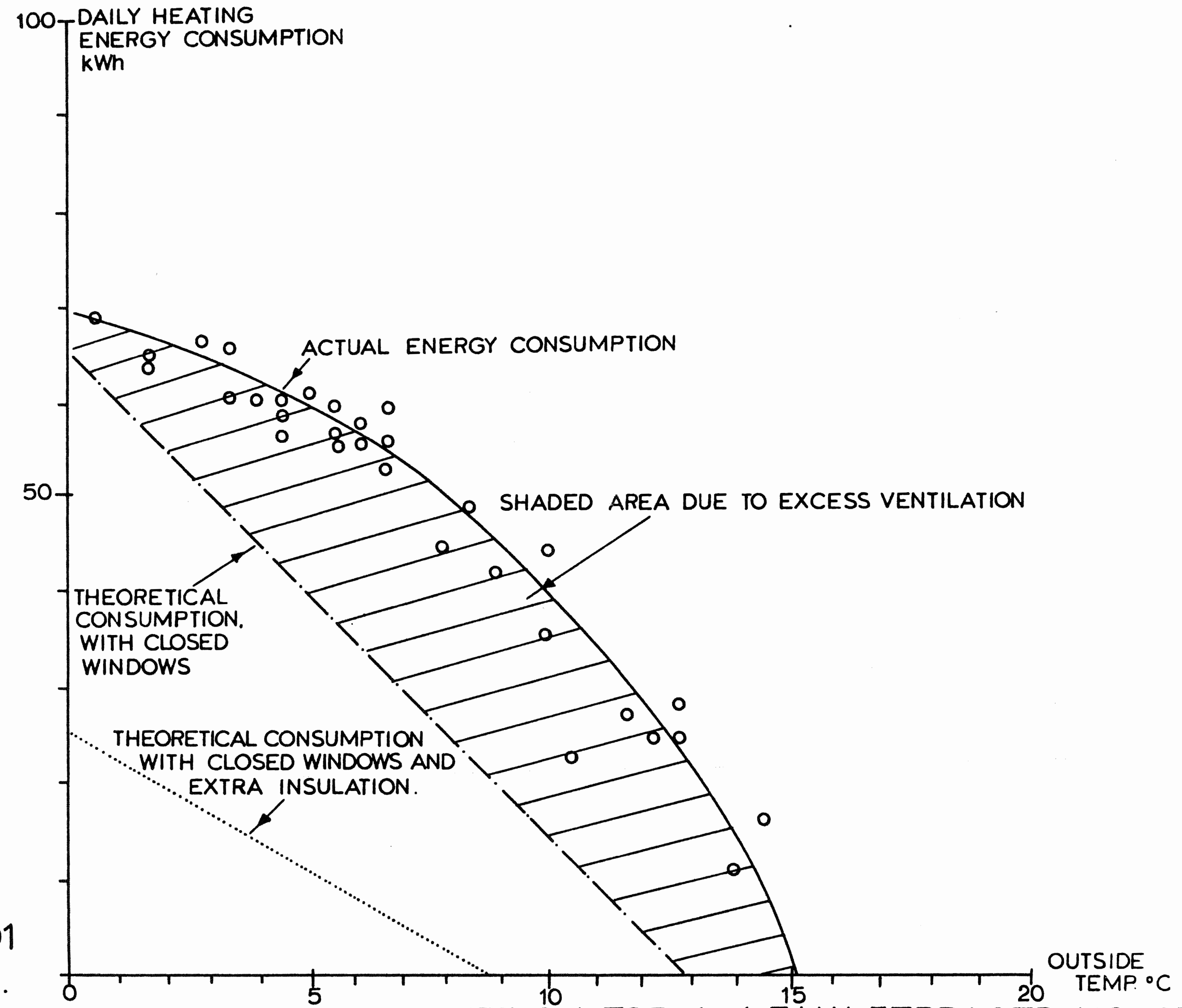

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FIGURE 6.

ACTUAL DAILY ENERGY CONSUMPTION FOR A 4·5 kW TERRACED HOUSE.

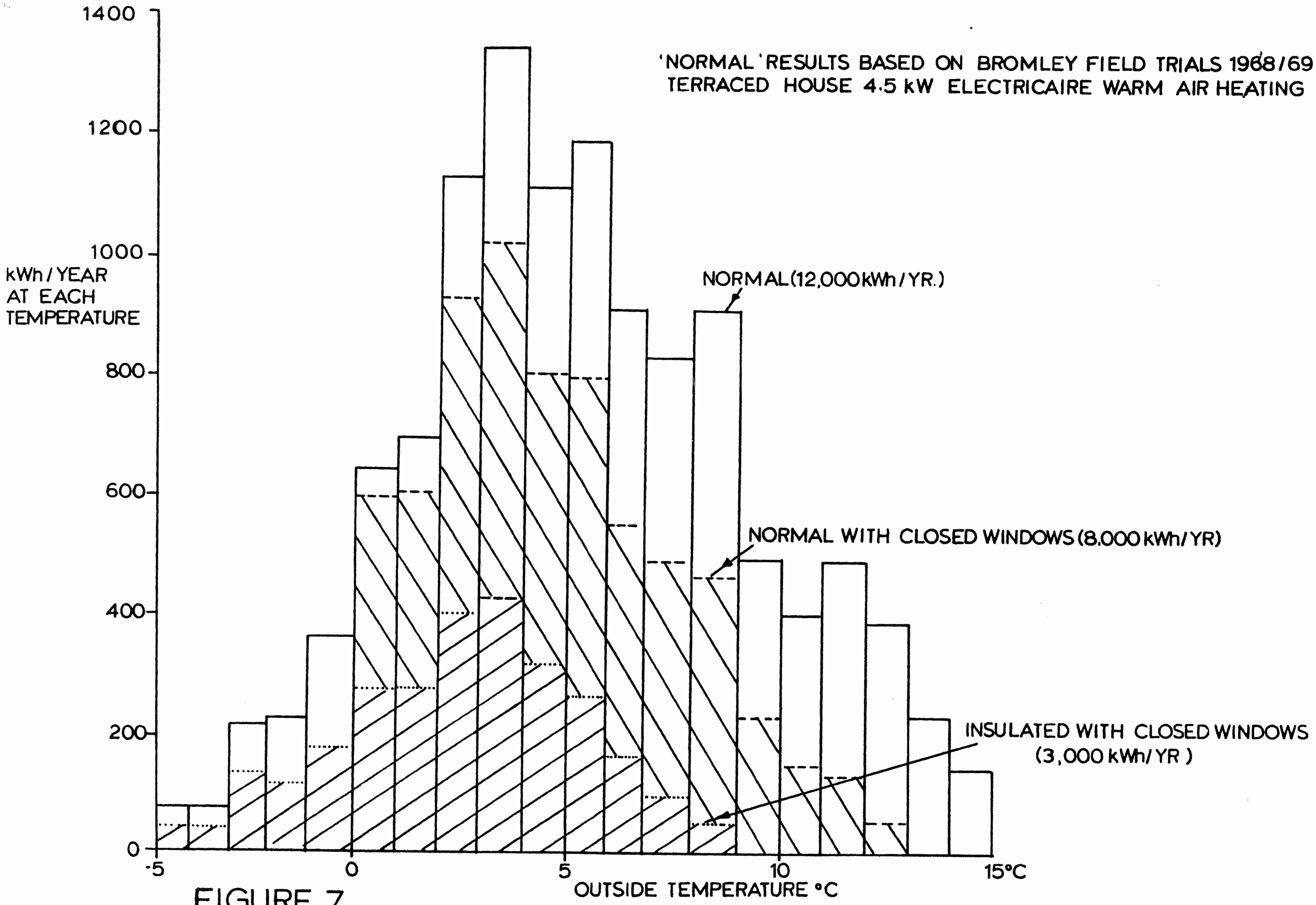

FIGURE 7.

ECRC/M801 SEASONAL ENERGY SPECTRUM WITH TEMPERATURE.

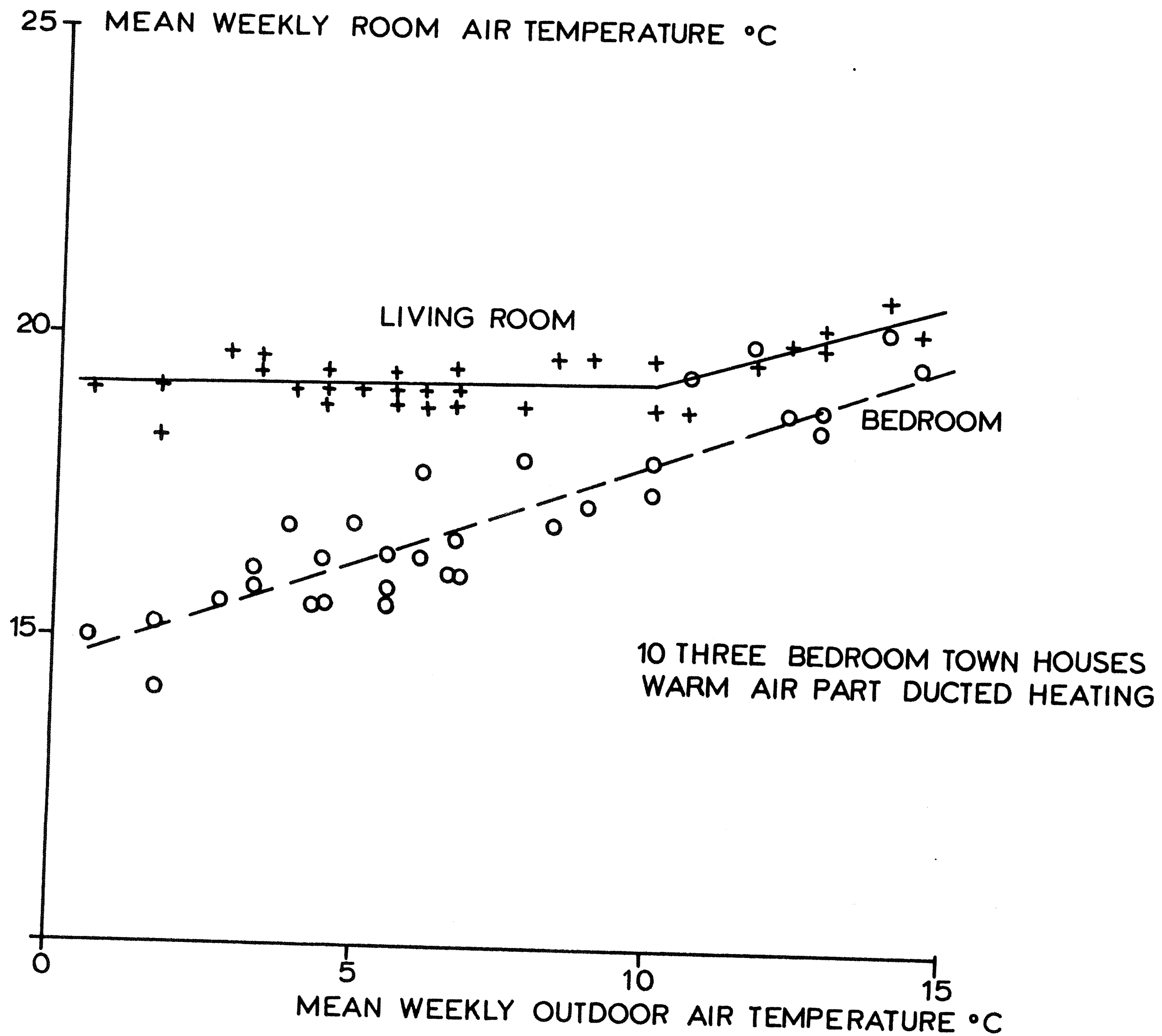

FIGURE 8
THE DISTRIBUTION OF TEMPERATURE WITHIN A HOUSE
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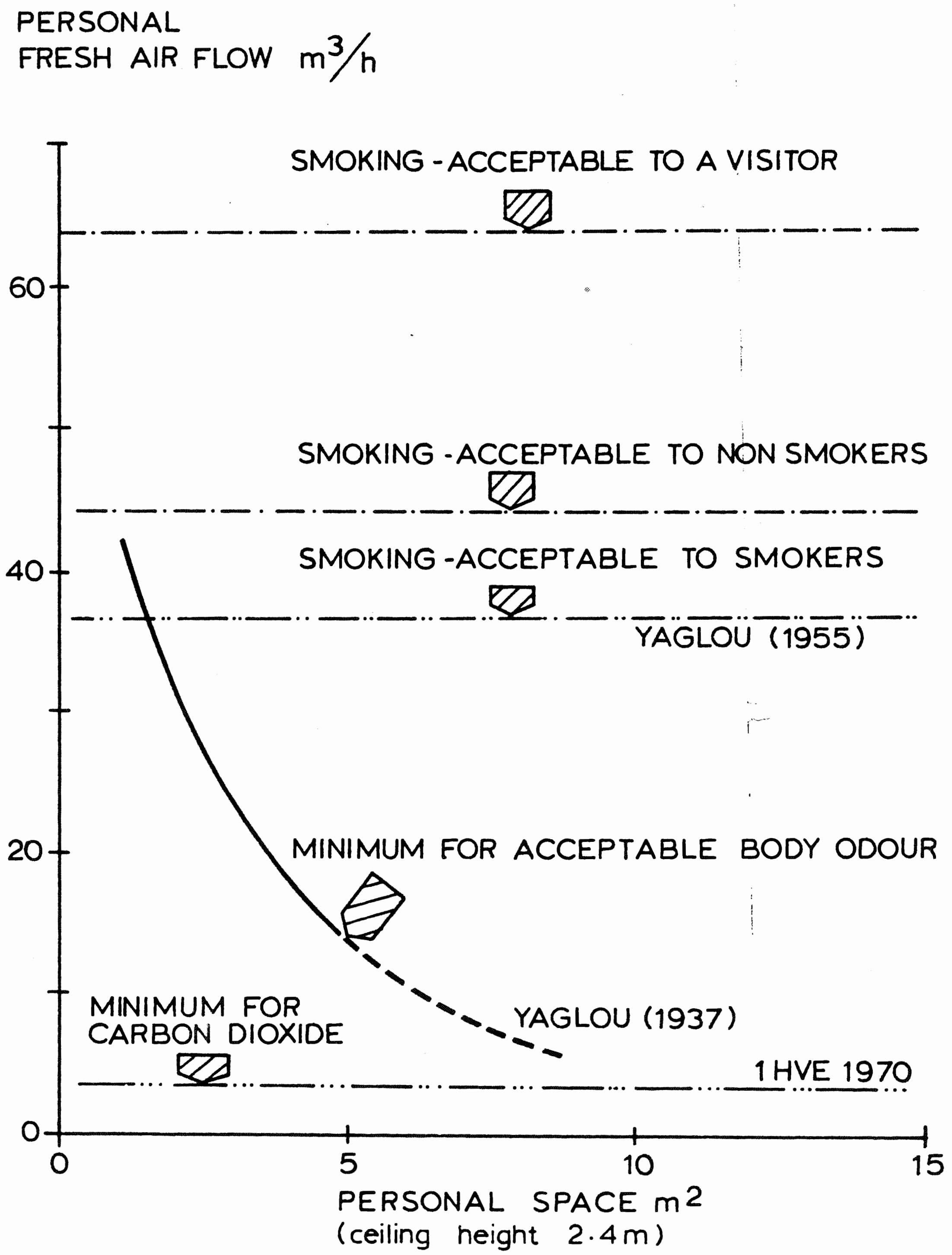

FIGURE 9.

PERSONAL FRESH AIR NEEDS (CIGARETTES SMOKED AT 8 / HOUR)

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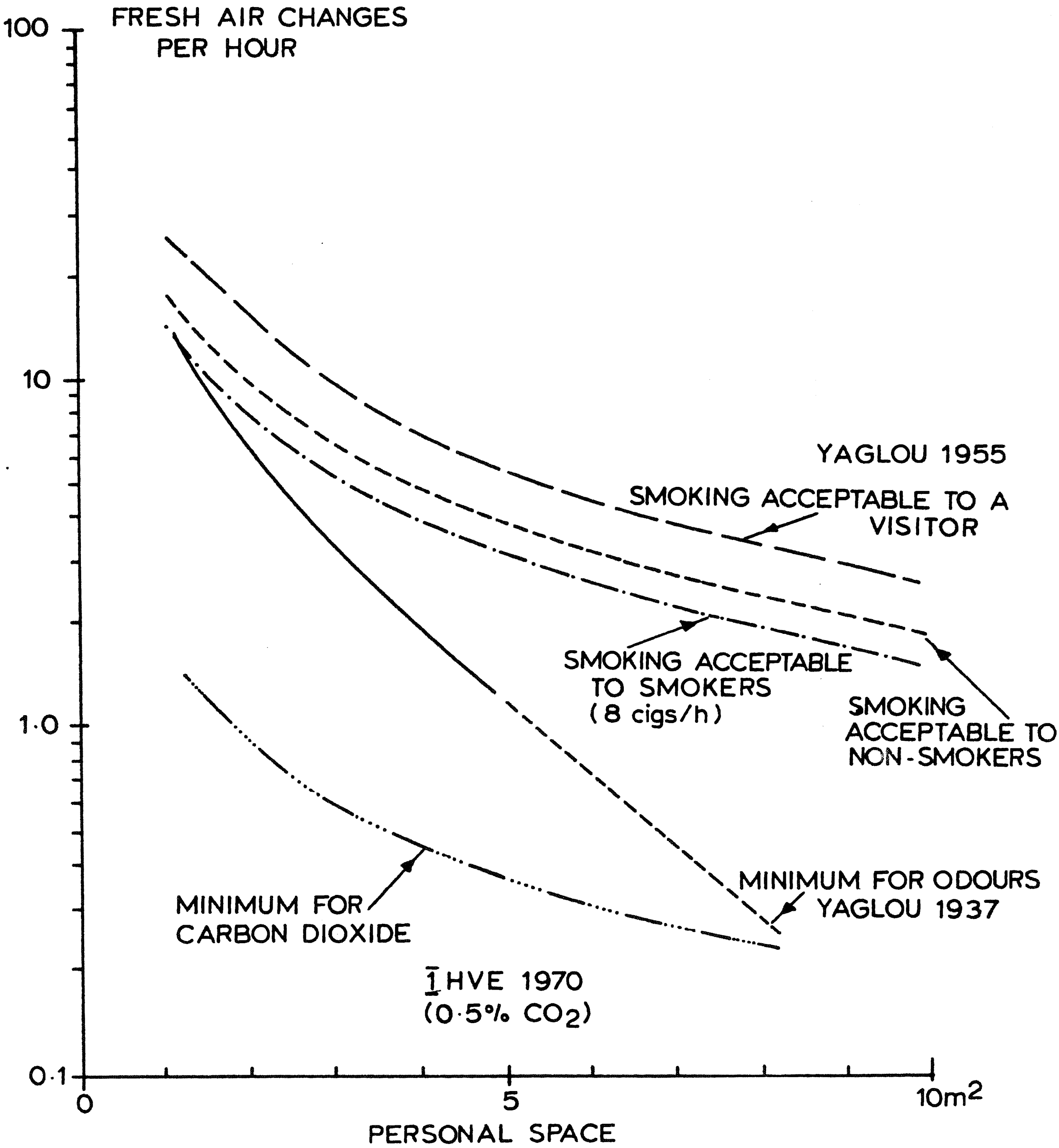

FIGURE 10
FRESH AIR CHANGES AS A FUNCTION OF PERSONAL SPACE (CEILING HEIGHT 2·4m ASSUMED)

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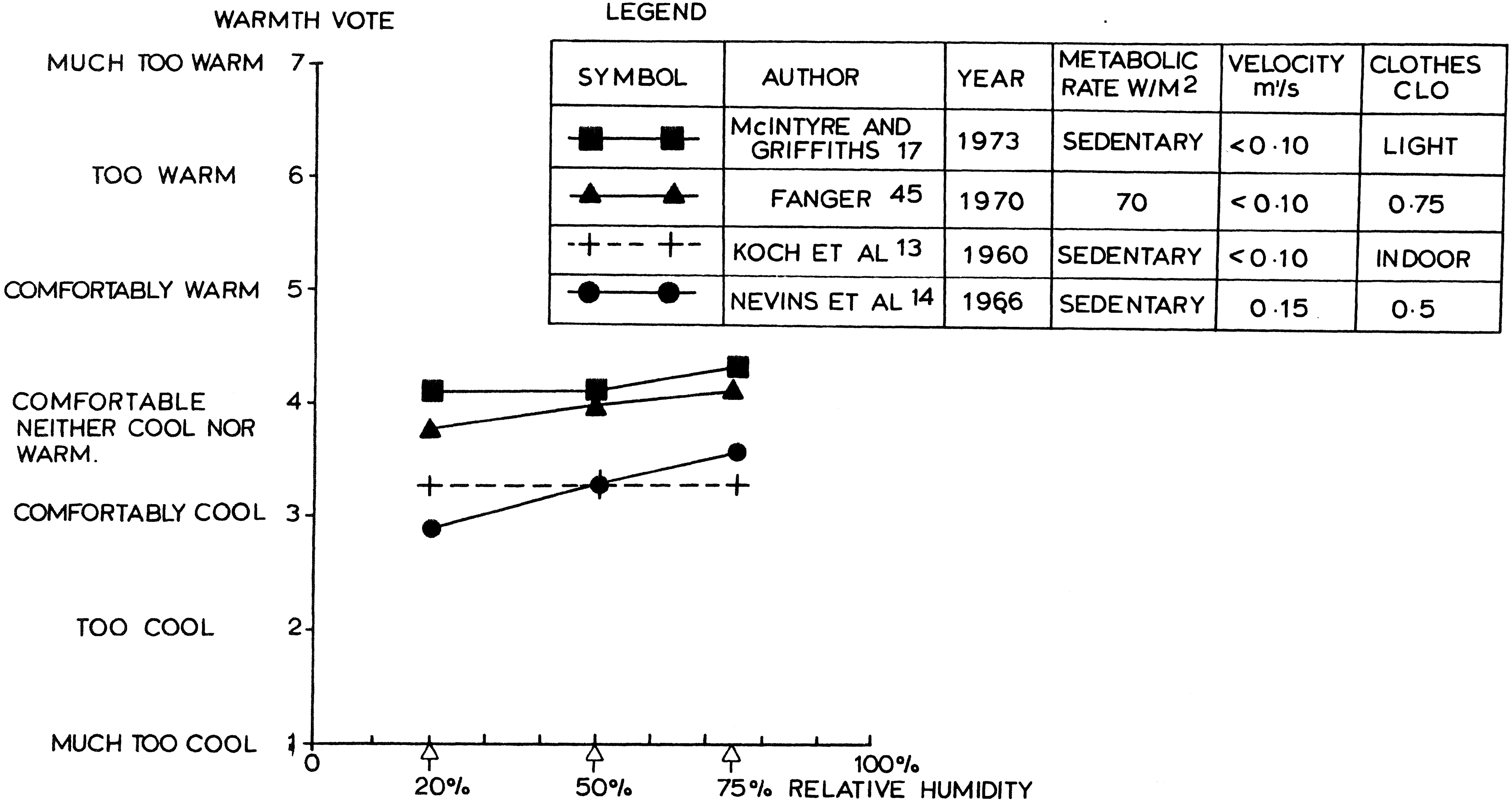

FIGURE 11

THE INFLUENCE OF HUMIDITY ON WARMTH AT 23°C AMBIENT [AIR AND MEAN RADIANT TEMPERATURE.]

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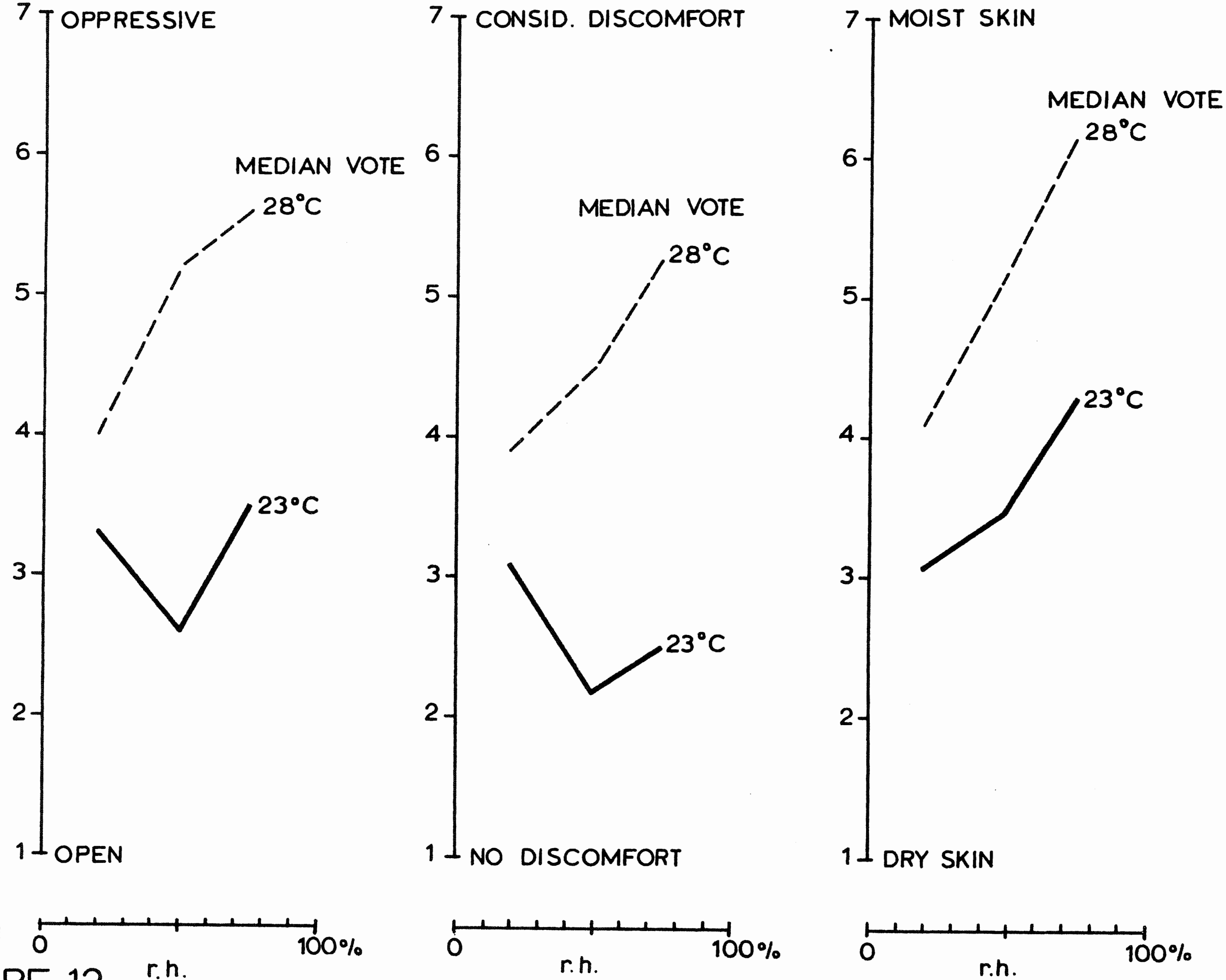

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FIGURE 12

THE NON-THERMAL INFLUENCE OF HUMIDITY (McINTYRE & GRIFFITHS 1973)

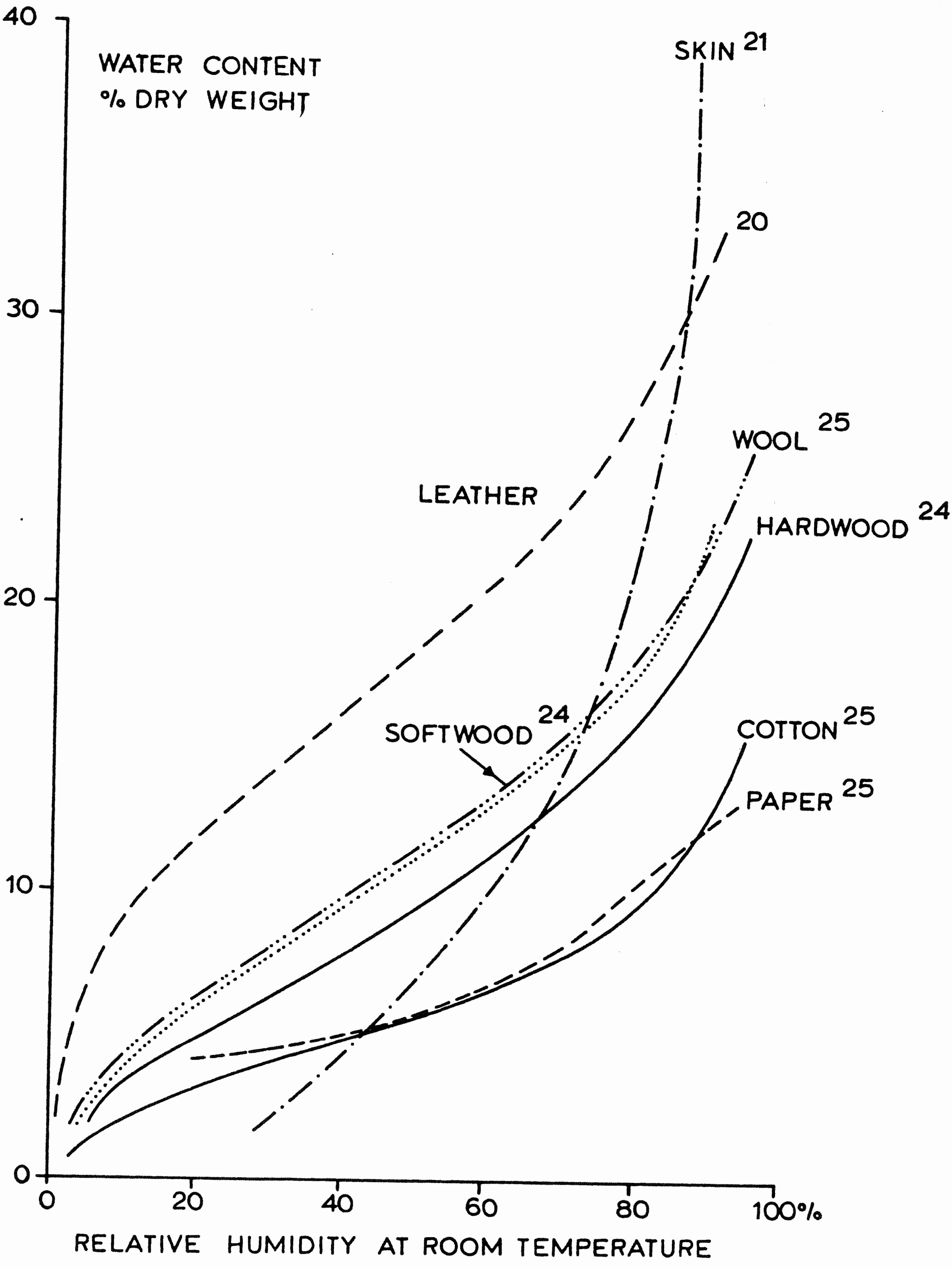

FIGURE 13
ADSORPTION ISOTHERMS FOR SOME COMMON ORGANIC MATERIALS

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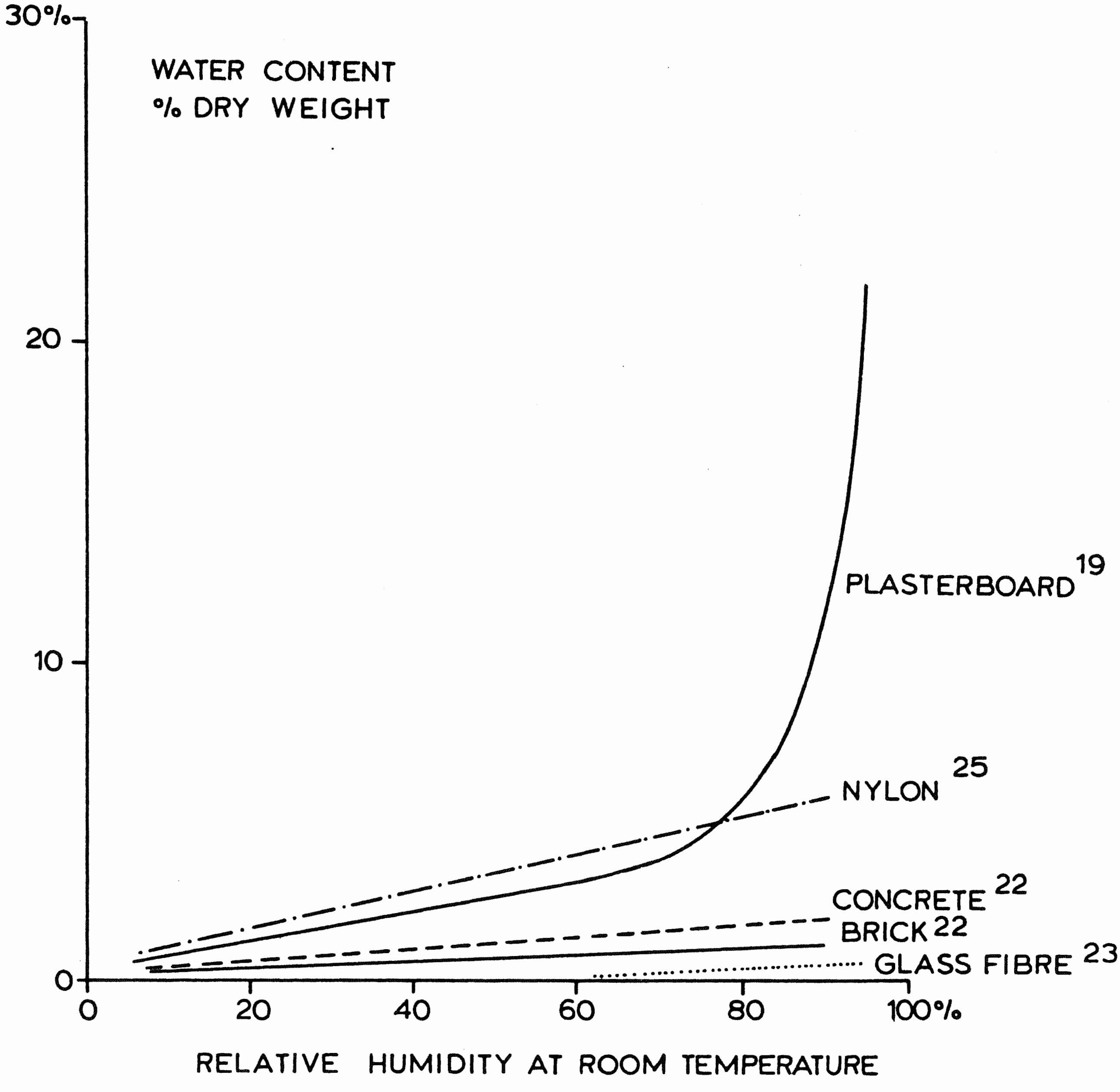

FIGURE 14
ADSORPTION ISOTHERM FOR COMMON BUILDING MATERIALS.

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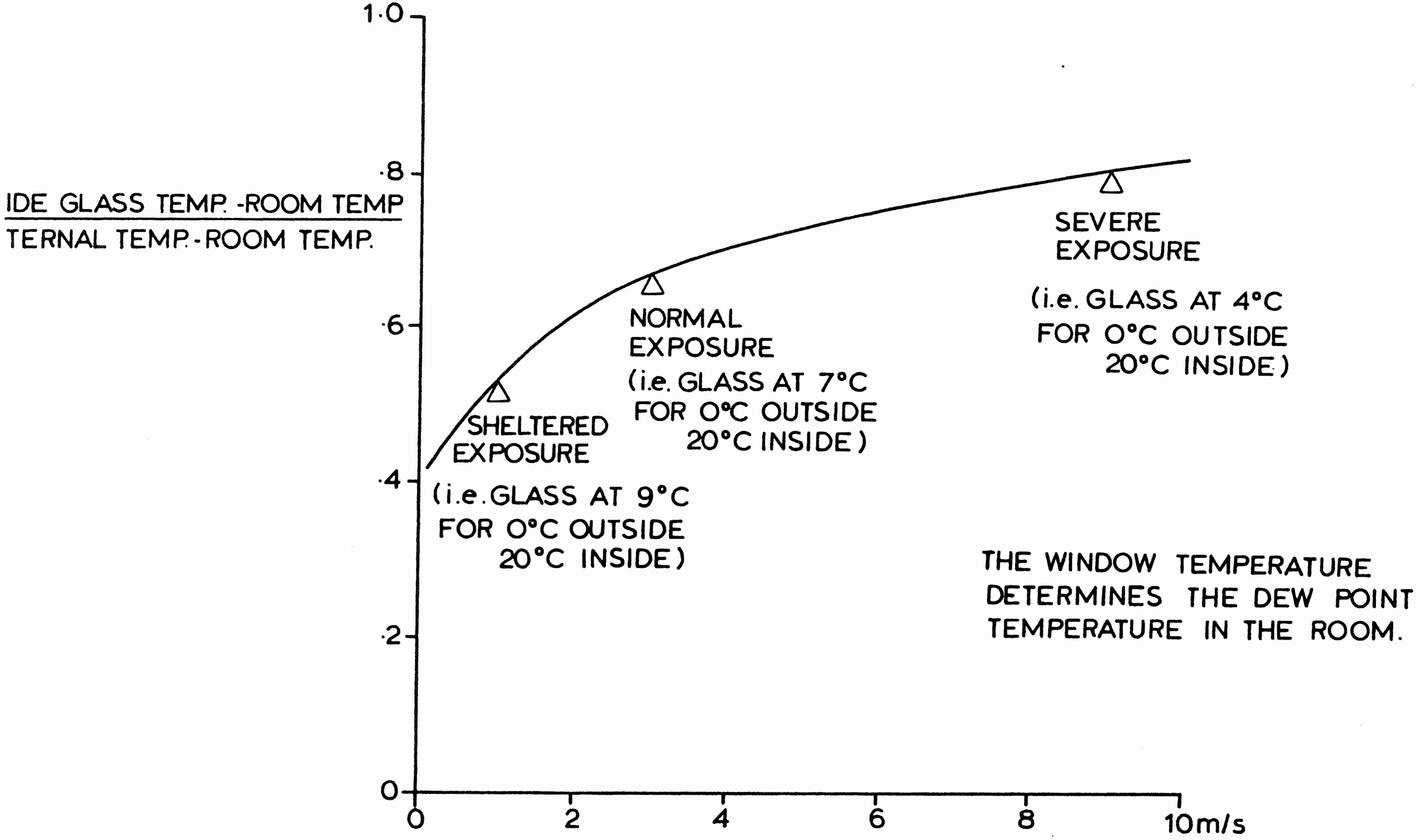

FIGURE 15.
THE INFLUENCE OF WIND VELOCITY ON WINDOW TEMPERATURE (SINGLE GLAZING)

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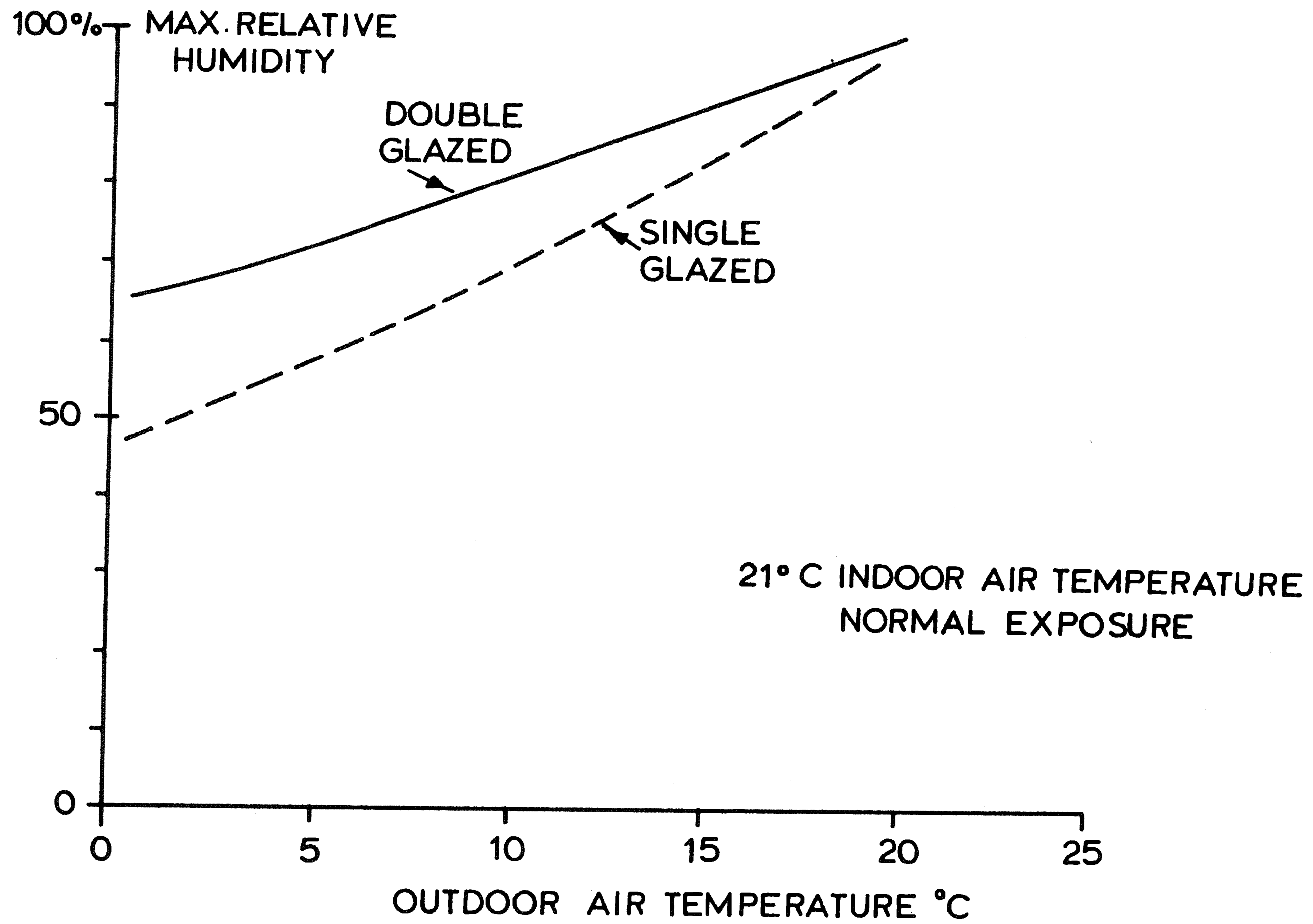

FIGURE 16
THEORETICAL MAXIMUM RELATIVE HUMIDITIES FOR SINGLE AND DOUBLE GLAZING.

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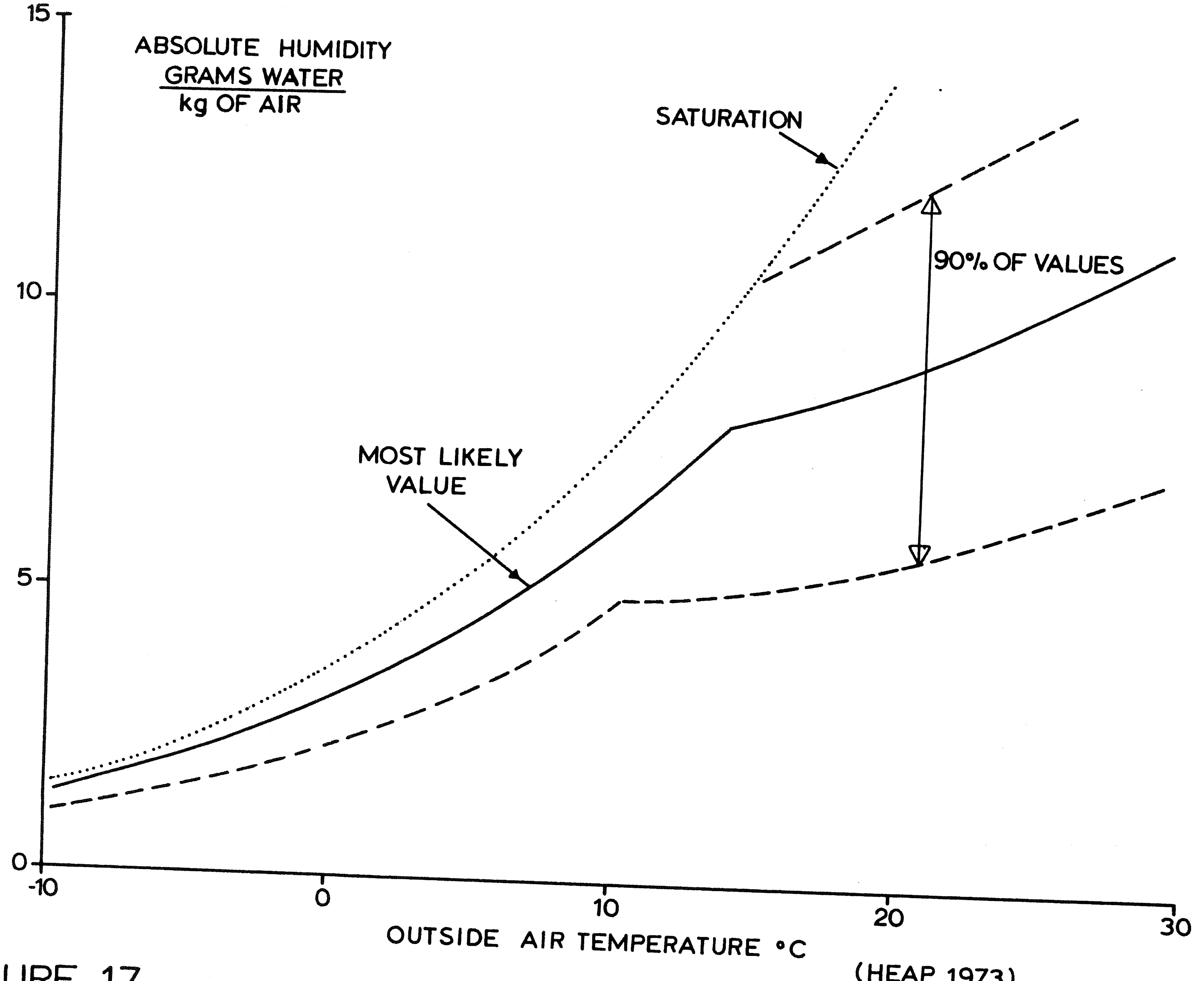

FIGURE 17
THE VARIATION OF HUMIDITY WITH AIR TEMPERATURE.
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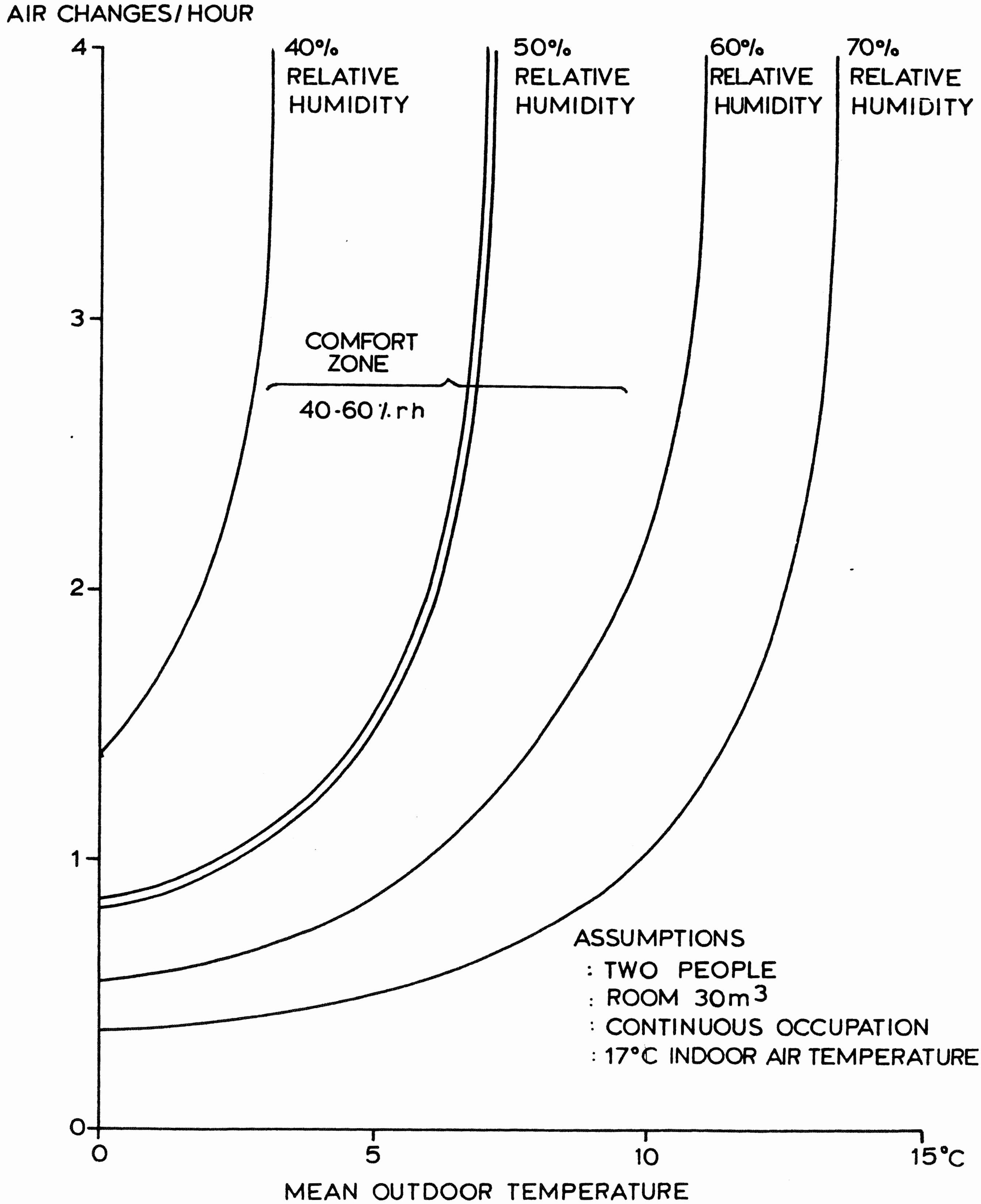

FIGURE 18.
THE RELATIONSHIP BETWEEN INDOOR HUMIDITY AND AIR CHANGE RATE.

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APPENDIX 1

Fresh air supply to suppress carbon dioxide build up

Assumptions:

- Basal oxygen requirement, adult male 240 ml/min.
- Normal sedentary activity, adult male 350 ml/min.
- Carbon dioxide released is 0.85 x volume of oxygen used.
- Maximum permissible level of carbon dioxide in fresh air for continuous exposure is 0.5% by volume.
- Normal background carbon dioxide in fresh air is 0.03% by volume.

Calculation:

let CO_2 released be Rm ml/min, = 0.85 x oxygen used
CO_2 in fresh air be F% by volume.
fresh air flow be Q ml/min.

then max. CO_2 level is 0.5% $= \frac{R + QF}{Q + R}$

i.e. fresh air flow $= R \left(\frac{1 - 0.005}{0.5 - F\%}\right) \times 100$ ml/min.

For sedentary work, carbon dioxide release R = 0.85 x 350 ml/min
= 297 ml/min

min. fresh air needed $= \frac{297 \times 100}{0.47}$ = 63.2 litres/min
(3.8 m^3/h per person)

Taking a typical room 3 x 4 x 2.5 m (30 m^3) containing two people the required fresh air is 2 x 3.8 m^3/h i.e. ¼ air change/hour.

TABLE 1

Moisture absorbing characteristics of typical materials
(Room 3 x 4 x 2.4 m high).

Use	Material	Spec. wt. kg/m^2	Assumed total wt. in room kg	Change in moisture 30-70% r.h. % dry weight	Total change in moisture 30-70% r.h. kg
Carpet	Wool	2.5	30	8	2.4
	Wool/nylon	1.7	20	7.2	1.5
	Rayon	2.0	24	6	1.5
	Cotton	1.0	12	4	0.5
Curtains	Cotton (lined)	0.5	2	4	0.08
Wallpaper	Paper (inc. ceiling)	0.2	8	8	0.6
Upholstery	Cotton	0.5	4	4	1.6
Books	Paper Technical Paperback	 - -	 1.0 kg each 0.1 kg each	 8 8	 0.08 0.01
Woodwork	Wood	-	150 kg	8	12
Plasterboard	Gypsum	7.3	330 kg	2	6.6

TABLE 2

MOISTURE GENERATION RATES IN HOUSES

Activity	AUTHOR			
	Smith 1948 [40] USA	Fournol 1957 [41] FRANCE	Conklin 1958† [42] USA	Loudon 1971 [43] ENGLAND
Family size	4		4	5
Personal evaporation per hour per day	 5 kg	50-80 g/h	52 g/h 2.5 kg	24 g/h 1.7 kg
Floor mopping	~1 kg per kitchen	-	1.1	-
Clothes washing Clothes drying Dish washing	2 kg 12 kg/week		2 kg 12 kg 0.5 kg/day	0.5/day 5 kg/day
Cooking Breakfast Lunch Dinner	15 kg/week* 0.4 kg 0.5 kg 1.2 kg		 0.4 kg 0.5 kg 1.2 kg	3 kg/day (gas)
Baths Shower Tub	 0.2 kg 0.05 kg		 0.2 kg 0.1 kg	1.0 kg/day (incl. dishes)
House plants	0.02 kg			
Daily quantity	25 kg washday 11.4 kg av.	†† 10 kg light 26 kg medium 42 kg heavy	21.9 washday 7.9 kg ordinary	15.4 washday 7.2 average

†† Calculated for 216 m^3 dwelling based on release rates of 2 g/h, 5 g/h, and 8g/h.

† Conklin's data quoted in HMSO 1970 appears to be from Smith's study.

* 42% from food, 58% from gas cooker.

TABLE 3(a)

The Influence of air change on relative humidity for an internal temperature of 17°C

assumptions: one sedentary person contributes 40 gram/hour moisture
: specific volume of air 0.83 m^3/kg

Fresh air per person		Extra moisture added by person g/kg air	External Temperatures																	
			-5°C			0°C			5°C			10°C			15°C			20°C		
m^3/h	kg/h		initial moisture g/kg air	final g/kg air	r.h. at 17°C	initial moisture g/kg air	final g/kg air	r.h. at 17°C	initial moisture g/kg air	final g/kg air	r.h. at 17°C	initial moisture g/kg air	final g/kg air	r.h. at 17°C	initial moisture g/kg air	final g/kg air	r.h. at 17°C	initial moisture g/kg air	final g/kg air	r.h. at 17°C
5	6.0	6.6	2.2	8.8	73%	3.3	9.9	82%	4.6	11.2	93%	6.3	12.9	sat.	8.3	14.9	sat.	9.2	15.8	sat.
10	12.1	3.31	2.2	5.5	46%	3.3	6.6	54%	4.6	7.9	65%	6.3	9.6	80%	8.3	11.6	96%	9.2	12.5	sat.
20	24.1	1.66	2.2	3.9	32%	3.3	5.0	41%	4.6	6.3	52%	6.3	9.0	66%	8.3	10.0	83%	9.2	10.9	91%
30	36.2	1.1	2.2	3.3	27%	3.3	4.3	36%	4.6	5.7	47%	6.3	7.4	61%	8.3	9.4	78%	9.2	10.2.	86%
40	48.2	0.83	2.2	3.0	25%	3.3	4.1	34%	4.6	5.4	44%	6.3	7.1	59%	8.3	9.1	76%	9.2	10.0	83%

TABLE 3(b)

The influence of air change on relative humdity for an internal temperature of 21°C

assumptions: one sedentary person contributes 40 gram/hour moisture
: specific volume of air 0.843 m^3/kg

Fresh air per person		Extra moisture added by person g/kg air	External Temperatures																	
			-5°C			0°C			5°C			10°C			15°C			20°C		
m^3/h	kg/h		initial moisture g/kg air	final g/kg air	r.h. at 21°C	initial moisture g/kg air	final g/kg air	r.h. at 21°C	initial moisture g/kg air	final g/kg air	r.h. at 21°C	initial moisture g/kg air	final g/kg air	r.h. at 21°C	initial moisture g/kg air	final g/kg air	r.h. at 21°C	initial moisture g/kg air	final g/kg air	r.h. at 21°C
5	5.9	6.72	2.2	8.9	56%	3.3	10.0	64%	4.6	11.3	72%	6.3	13.0	83%	8.3	15.0	96%	9.2	15.9	sat.
10	11.9	3.36	2.2	5.56	35%	3.3	6.6	42%	4.6	8.0	51%	6.3	9.6	61%	8.3	11.6	74%	9.2	12.5	80%
20	23.8	1.68	2.2	3.88	24%	3.3	5.0	32%	4.6	6.3	40%	6.3	8.0	51%	8.3	10.0	64%	9.2	10.9	68%
30	35.7	1.12	2.2	3.32	21%	3.3	4.4	28%	4.6	5.7	36%	6.3	7.4	47%	8.3	9.4	60%	9.2	10.3	66%
40	47.6	0.84	2.2	3.04	19%	3.3	4.1	27%	4.6	5.4	35%	6.3	7.1	46%	8.3	9.1	58%	9.2	10.0	64%

APPENDIX 2

Glass temperature, (inside surface) for dewpoint control

Assumptions: 'normal' exposure

: surface resistance outside = 0.055 $m^2{}^oC/W$
: convective coefficient inside h_c = 3.0 $W/m^2{}^oC$
: radiant coefficient inside h_r = 5.7
: emissivity of glass E = 0.9
: Conductivity of glass 1.05 W/m^oC

Inside surface resistance $R_i = \frac{1}{Eh_r + h_c} = \frac{1}{.9 \times 5.7 + 3.0} = 0.123\ m^2{}^oC/W$

Resistance through 5 mm glass $= \frac{0.005}{1.05}\ m^2{}^oC/W = 0.005\ m^2{}^oC/W$

Total thermal resistance = 0.055 (outside) + 0.005 (glass) + 0.123 (inside)
= 0.183 $m^2{}^oC/W$

Room/inside glass temperature diff. $= \frac{0.123}{0.183}$ i.e. .66 of inside/outside temperature diff.

Indoor Temp °C	Outdoor Temperature °C											
	-5°C		0°C		5°C		10°C		15°C		20°C	
	dewpt °C	r.h. %	dewpt °C	r.h. %	dewpt °C	r.h. %	dewpt °C	r.h. %	dewpt °C	r.h. %	dewpt °C	r.h. %
17	2.3	37	5.7	47	9	59	12.3	74	15.[illegible]	92	-	-
21	3.7	32	7.0	40	10.3	50	13.7	62	1[illegible].0	78	20.3	95