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Ventilation to Reduce Indoor Condensation

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PAPER 10

VENTILATION TO REDUCE INDOOR CONDENSATION

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SYNOPSIS

Condensation causing mould and mildew is a common problem in New Zealand buildings. A reasonably balanced combination of air exchange and heating will prevent condensation. The relationships between these are presented graphically, showing the combinations which will prevent condensation under given ambient conditions. Finally, the amounts of natural ventilation available with various window openings and windspeeds are presented, as a means to achieve the required ventilation rate.

INTRODUCTION

Condensation, mould, and mildew growth arise when building occupants release moisture into the air (in particular from cooking and washing) which raises indoor relative humidity. These problems are longstanding in New Zealand, often causing significant damage to room surfaces.

Indoor humidity can usually be reduced by air exchange with outdoors. But as houses built in New Zealand since the 1960's are more airtight than older ones (typical infiltration rates are on the order of ½ air change per hour)[1] there are now increasing chances of harmful levels of moisture in houses.

These conditions imply that air exchange is often necessary in modern houses to reduce the concentrations of moisture, to avoid adverse effects. Under some conditions, infiltration is enough to avoid these effects, but the potential for ventilation must be considered to ensure this.

Correctly visualising the relationships between heating and air exchange in reducing condensation, and understanding the potential for natural ventilation by means of opening windows should help both designers and homeowners avoid humidity problems.

REQUIREMENTS FOR CONDENSATION

Moisture is generated in buildings from human respiration, as well as from cooking and washing, as outlined below[2,3] in Table 1. This moisture usually takes the form of water vapour in air, which serves to raise the indoor absolute humidity. Condensation occurs when air of a given humidity cools to its dewpoint.

TABLE 1 - SOURCES AND AMOUNTS OF MOISTURE GENERATION IN HOUSES

Source	Amount of moisture generated	
	Average (kg/day)	Peak (g/sec)
Clothes drying, unvented	12.0	1.50
Clothes washing	2.0	0.15
Cooking, unvented	2.2	0.30
Showers, each	0.2	1.50
Dishwashing	0.5	0.25
Human metabolism, at rest	0.1	0.004
Human metabolism, hard work	0.3	0.01

Thus, a requirement for surface condensation is that a surface be at or below the dew point temperature of the room air. Given a knowledge of this dewpoint temperature, the condensation risk can easily be determined by the "temperature index"[4] of the surfaces, and the indoor and outdoor temperatures.

The temperature index is defined as a ratio of thermal resistances: of the outside-air to inside-surface divided by that of the outside-air to inside-air. This ratio is between zero and one, approaching one when the surface is well insulated (low condensation risk), and approaching zero when the surface is poorly insulated (high condensation risk).

$$\text{Thus} \quad T \text{ surface} = T \text{ out} + (\text{Temperature Index}) \times (T \text{ in} - T \text{ out})$$

$$\text{where Temperature Index} = \frac{R \text{ (surface to outside air)}}{R \text{ (indoor air to outside air)}}$$

Temperature indices were calculated for various building components, using their "handbook" values for thermal resistances.

The surface thermal resistances used in this calculation were varied to span the range of values for different conditions and yield a more general result than simply using the "handbook" values throughout.

Thus, three thermal resistances were used for both the inside and outside surfaces, including handbook values of 0.12 and 0.03, respectively.[5] Also typical high and low values of 0.18 and 0.09 (inside) and 0.10 and 0.01 (outside)[6] were included in the set of calculations. The inside surface temperature index was calculated for all nine possible combinations, and the mean and standard deviation of these results computed and reported in Table 2.

TABLE 2 - CALCULATED TEMPERATURE INDICES FOR BUILDING SURFACES

6 mm thick Single glazing	.26 ± .16
R - 1.5 insulated wall	.92 ± .02
R - 1.5 insulated wall at corner	.78 ± .05
R - 0.9 uninsulated cavity wall	.88 ± .03
R - 0.9 insulated wall at corner	.71 ± .06

The assumptions built into the temperature index calculation at the corners are that the indoor air film there has a thermal resistance value of R = 0.36, three times that of a normal indoor vertical surface, corresponding to a dead air pocket about 1 cm thick.[7]

The importance of this is that the temperature indices of room surfaces determine the conditions under which condensation will occur in a room, and the lower indices common to corners mean that condensation occurs there before it does on plane walls.

CONDENSATION CONDITIONS IN BUILDINGS

The relationship between the amounts of heating and air exchange needed to prevent condensation on room surfaces were calculated as follows:

For a given indoor moisture release rate, air change rate, and outdoor air temperature (assuming saturation humidity), the steady state indoor absolute humidity is calculated, using the formula:

$$\text{W in (kg/kg)} = \text{W sat (T out)} + \frac{\text{moisture release rate (kg/day)}}{24 * p * V * \text{ACH} \qquad \text{(kg/day)}}$$

where:
W in = indoor absolute humidity (kg/kg)
W out = outdoor saturation absolute humidity (kg/kg)
p = air density (kg/cubic meter)
V = House volume (cubic meters/air change)
ACH = air change rate (air changes/hour)

This absolute humidity is converted to a dew point temperature, which is the temperature that the building surfaces must be kept warmer than to prevent condensation. Then knowing the temperature indices for each surface, the minimum room air temperature to prevent condensation is calculated from:

$$\text{T room} = \text{T out} + \frac{\text{(T surface - T out)}}{\text{(Temperature Index)}}$$

Then the heat requirement is found directly from the indoor and outdoor air temperatures and the building heat loss coefficient.

This calculation was performed for two houses, one insulated to New Zealand standard 4218P (a typical new house) and a totally uninsulated house (a typical "old" house). The moisture release rate chosen was 8 kg/day (typical for a family with washing and cooking but no unvented clothes drying), and the outside air temperature was 5°C (typical of New Zealand winter weather).

The house modelled was a single-storey, 10m by 10 m house with a 2.4 m ceiling height and 20 sq. m of windows. For the insulated house, thermal resistances used were R=1.9 for the roof, R=1.5 for the walls, R=1.3 for the timber floor, and R=0.17 for the window. For the uninsulated house these quantities were R=0.8 for the roof, R=0.9 for the walls, R=0.9 for the timber floor, and again, R=0.17 for the window.

Figure 1 shows the amounts of air exchange and heating energy needed to just prevent condensation on single-glazed window and other surfaces for the insulated house. The amount of heating needed to prevent condensation is shown on the vertical axis, as a function of the given air exchange rate, as shown on the horizontal axis. The curves on the figures represent the threshold of condensation for surfaces at the temperature indices shown. The shaded area on the graphs represent the conditions where condensation would occur on the wall surface, below the lowest curve marked "T.I. = 0.92 (Wall)". Condensation would occur below the higher curves, for surfaces at their temperature indices, though the areas below these curves are not shaded.

When the conditions in the house lie above the temperature index line describing the indoor heating and air exchange conditions, there should be no condensation on that surface. When the conditions in the house lie on or below this line, there is the potential for condensation. The diagonal lines stretching upwards to the right are lines of constant indoor air temperature, which occur at the heating and air exchange rates shown on the axes.

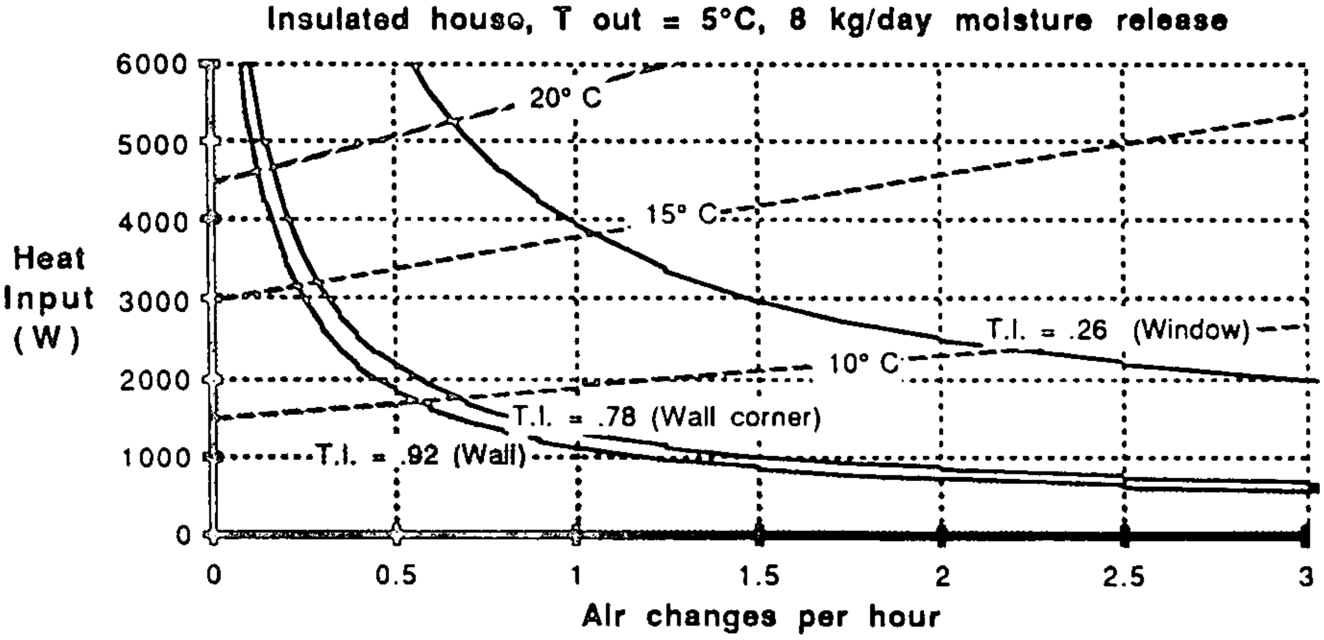

Figure 1 - Requirements to Avoid Condensation - Insulated House

Figure 2 repeats this for the uninsulated house, showing the amounts of air exchange and heating energy needed to just prevent condensation on single-glazed window and other surfaces there. The same patterns emerge, but more heating and higher temperatures are needed to avoid condensation for the uninsulated case.

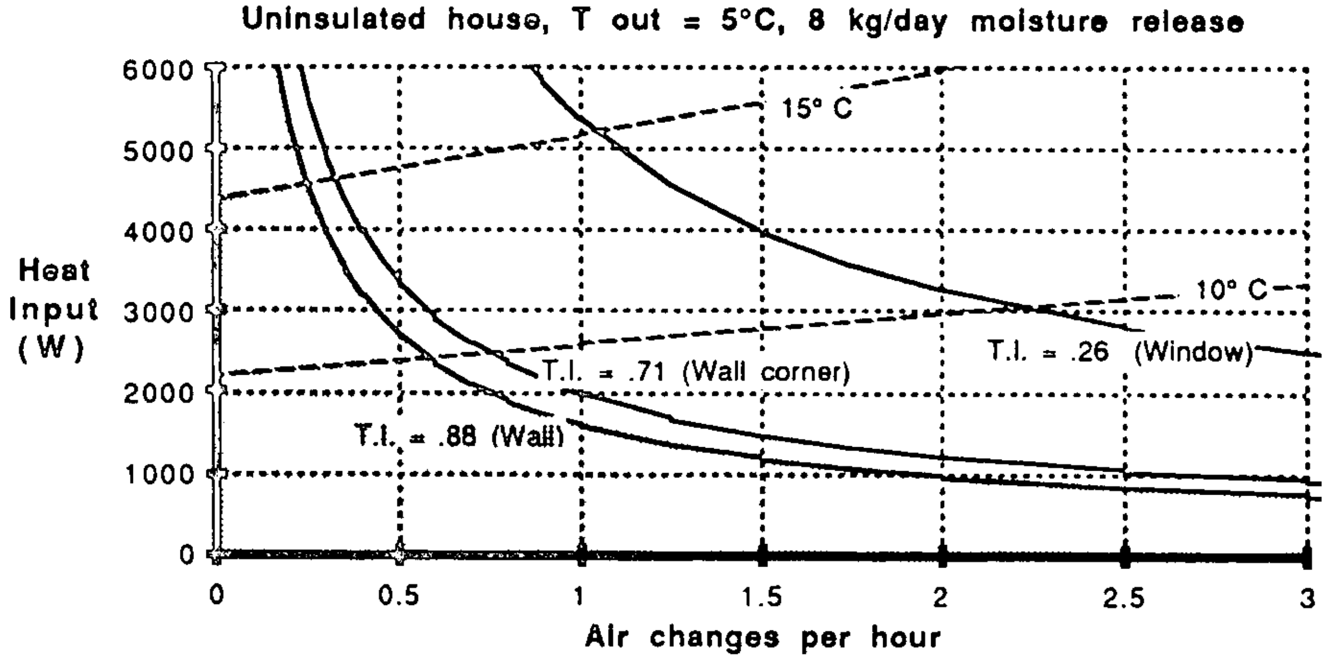

Figure 2 - Requirements to Avoid Condensation - Uninsulated House

The shape of these figures are their most important features. In the upper left of the graphs, condensation is controlled by air exchange. Under these conditions of moderate heating but very low air exchange, only small additional amounts of air exchange are needed to cross the lines and avoid condensation, but much additional heating would be needed to achieve the same result.

Likewise, in the lower right of the graphs, condensation is controlled by heating. At high air exchange but low heating rates, little additional heating is needed to cross the line and avoid condensation, but sometimes even unlimited amounts of extra air exchange will not achieve this.

For a bedroom at night, with moisture releases typical of the respiration of two occupants, the combinations of heating and air exchange needed to prevent condensation are shown in Figure 3. The two curves on this graph are for the temperature indices calculated for insulated walls and uninsulated corners as in Table 2. The outdoor conditions are the same as in Figures 1 and 2: 5°C at saturation humidity.

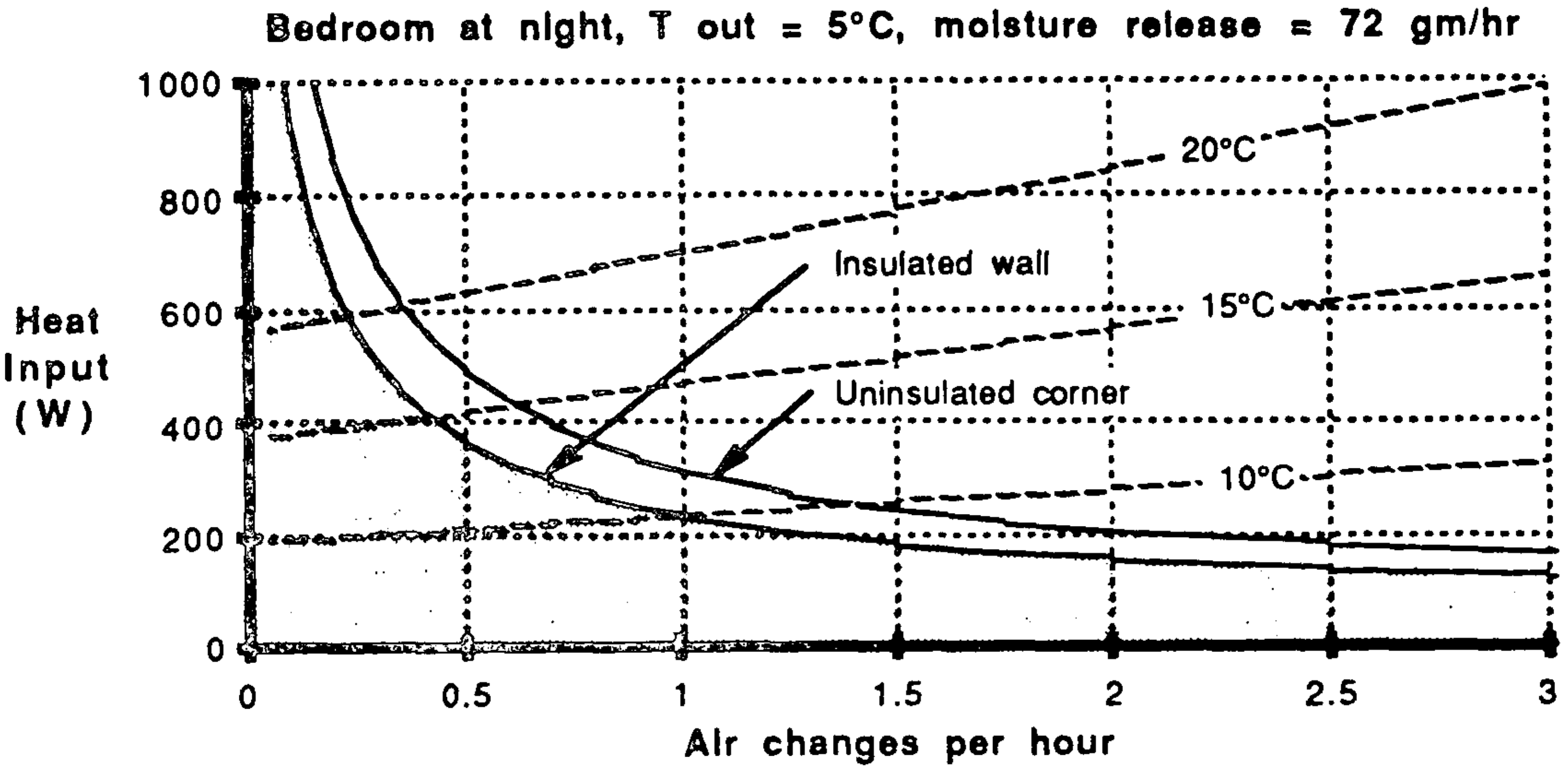

Figure 3 - Requirements to Avoid Condensation - Insulated Bedroom

This figure is notable in that it displays the same pattern as seen in Figures 1 and 2, but additionally shows the results of having different insulation levels as different temperature indices. As can be seen, with increasing insulation levels, the more resistant the wall is to condensation, as its interior surface temperatures will be higher.

For a kitchen with indoor moisture release rates typical of cooking, the heating and air exchange combinations needed to prevent condensation are shown in Figure 4, with the same temperature indices as the previous figure. Note the much higher required heat inputs, and consequent high temperatures for this case. It can be seen that there are almost always conditions where condensation will occur in kitchens, and that the amounts of air exchange, insulation, and heating needed to reduce the impact of this are greater, but similar in pattern to that required in other rooms.

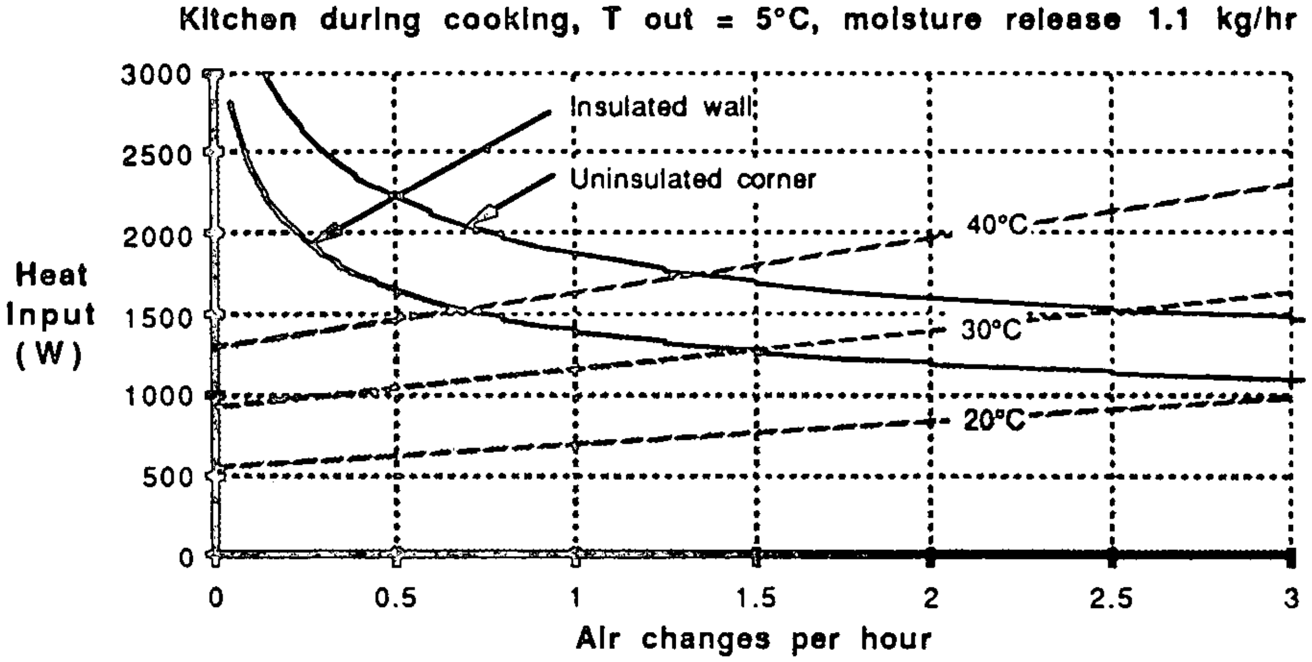

Figure 4 - Requirements to Avoid Condensation - Insulated Kitchen

The effect of variations in outdoor temperature on the whole-house heating and air exchange conditions needed to prevent wall surface condensation are shown in Figure 5. As is seen, at lower outdoor temperatures and similar air exchange rates, more heating is needed to prevent condensation. This is because the effect of colder wall surfaces outweighs the effect of the drier, colder outside air being exchanged.

The effect of variations in moisture release rate in the building are shown in Figure 6. They range from half to double the assumed "base case" moisture release rate of 8 kg/day. As expected, with higher rates of moisture release, more heating and air exchange are needed to prevent

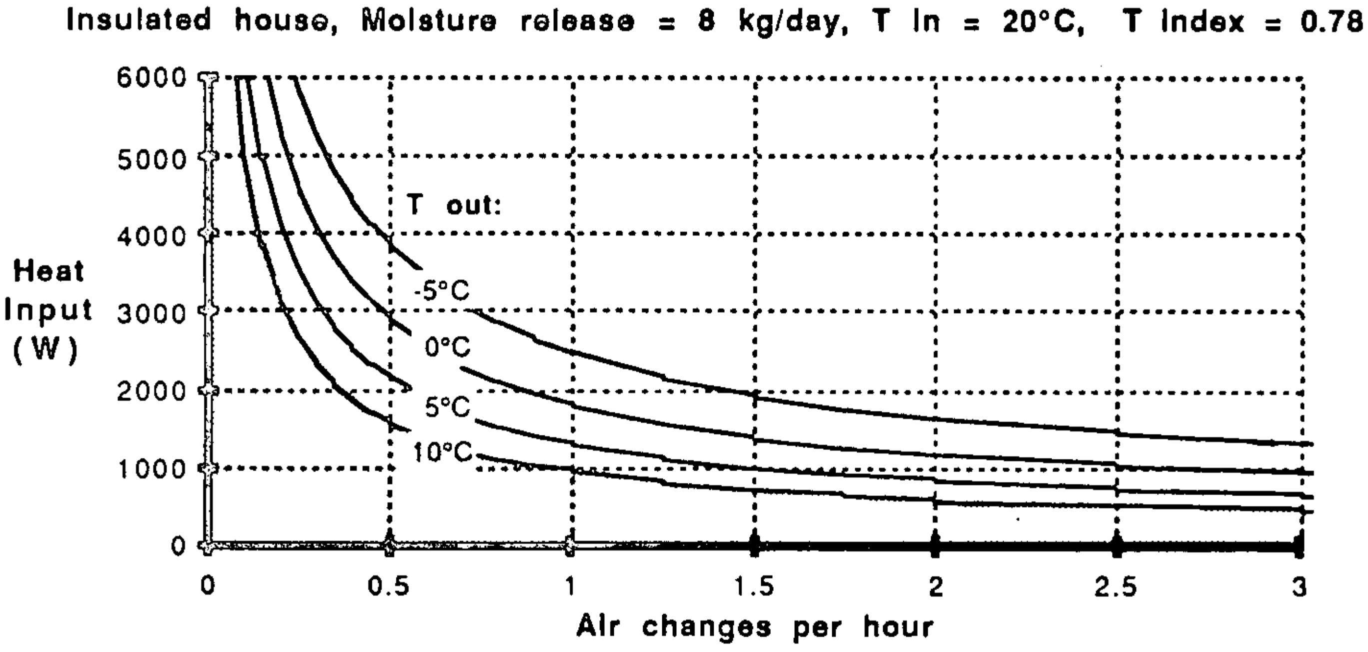

Figure 5 - Effects of Variations in Outdoor Temperature

condensation in room corners. Also note that the variation in the heating/air exchange lines due to these moisture release rate changes is similar in magnitude to those due to variations in outdoor temperature or surface temperature index.

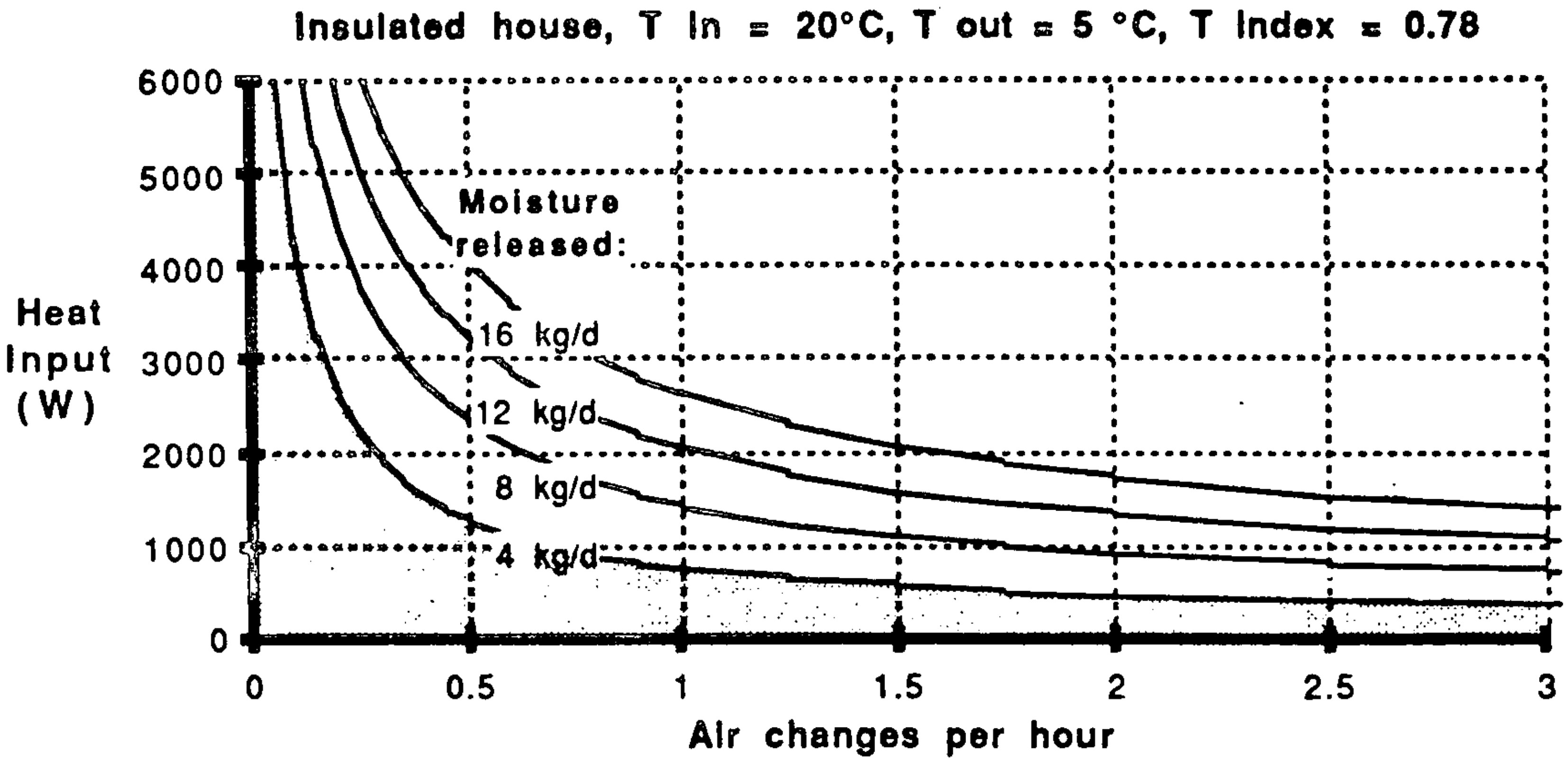

Figure 6 - Effects of Variations in Moisture Release Rate

These analyses generally follow an early BRANZ paper entitled "The Theory of Mould and Mildew"[3] which was published in 1972. It calculated the air exchange rates needed to avoid this 90% relative humidity level at building surfaces for various conditions of water vapour generation, and heating and insulation level.

Simplifications included in the analyses presented here include neglecting the fact that moisture damage begins before condensation occurs, and assuming a "ventilation efficiency" of 100%. Also, moisture transfer by mechanisms other than air exchange was neglected.

One of the most prevalent types of moisture damage is mould. Mould grows before condensation occurs due to the hygroscopic effects of most building materials, whereby they absorb moisture directly out of the air (and potentially feed mould and mildew) as a function of relative humidity, typically between 70% and 90% relative humidity.[8]

"Ventilation efficiency" is an empirical coefficient describing the effectiveness of pollutant removal by the ventilation air.[9] This coefficient is equal to unity when the ventilation air dilutes the pollutant concentration at the same rate as it dilutes the air in the space. However, for source ventilation of specific pollutants, the ventilation efficiency can be much higher than one, as when the pollutant is ventilated directly out of the building, and carried off much more quickly than the air of the whole building changes. And for whole-house air exchange the ventilation efficiency is often much lower than one, as the ventilation air dilutes a concentrated pollutant less effectively than it changes the air of the whole space.

For ventilation efficiencies lower than unity, higher air exchange rates than shown in the preceding figures would be required to prevent condensation; for more efficient ventilation, a lower total flow rate would be needed. And to reduce indoor relative humidity rates below the 100% assumed on the curves in the figures, proportionally more air exchange would be required.

THE NEED FOR VENTILATION

Air infiltration is the uncontrolled leakage of air into a building. It reduces the levels of water vapour in the air to approach equilibrium with the outside air. Historically, infiltration combined with the practice of "airing out the house" by opening windows kept the water vapour and pollutant concentrations at a low enough level to usually avoid problems. However, as the airtightness in buildings continues to improve, infiltration is often drastically reduced.

The driving forces of air infiltration theoretically include both wind and temperature difference (thermal buoyancy or stack effect), but practically, the temperature difference has a minimal effect on infiltration rates. In New Zealand, with low indoor/outdoor temperature differences and building heights, stack effect only accounts for a small fraction of typical infiltration rates.

Figure 7 shows the percentage of wind induced driving force produced by thermal (stack) temperature differences given for varying wind velocities. Typical average wind speeds encountered in New Zealand are in the 5 tc 10 m/sec range, so the stack effect usually provides a force about 1/10 that of the wind.

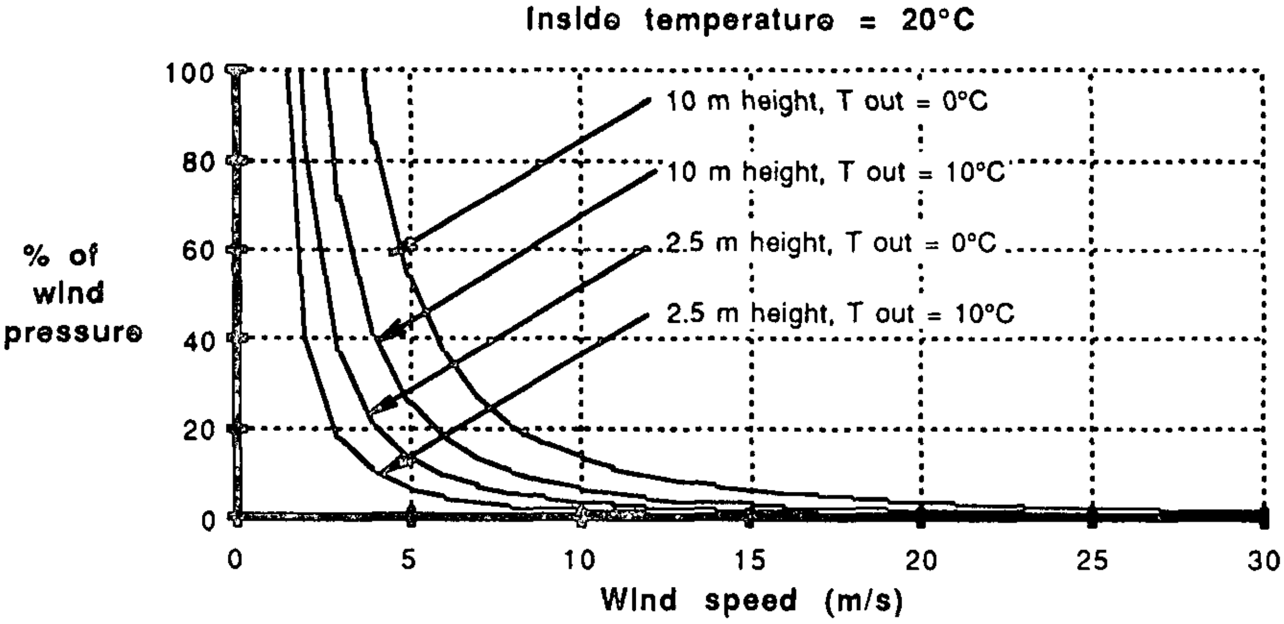

Figure 7 - Thermal (Stack) Pressure as Percent of Wind Pressure

The importance of this is that the colder temperatures experienced in winter do not in general lead to increases in the infiltration rate, although the rate of natural ventilation is much reduced then (due to people keeping their windows closed to conserve heat).

Figure 8 shows the results of measurements made in a typical Lower Hutt house,[10] where infiltration rates were continually monitored with tracer gas and correlated with wind speeds and temperature differences. Note that although there is a good correlation between wind speed and infiltration rate, there is not with temperature. Also note that the house was more airtight than the national average, with measured infiltration rates of typically 0.25 ACH or less.

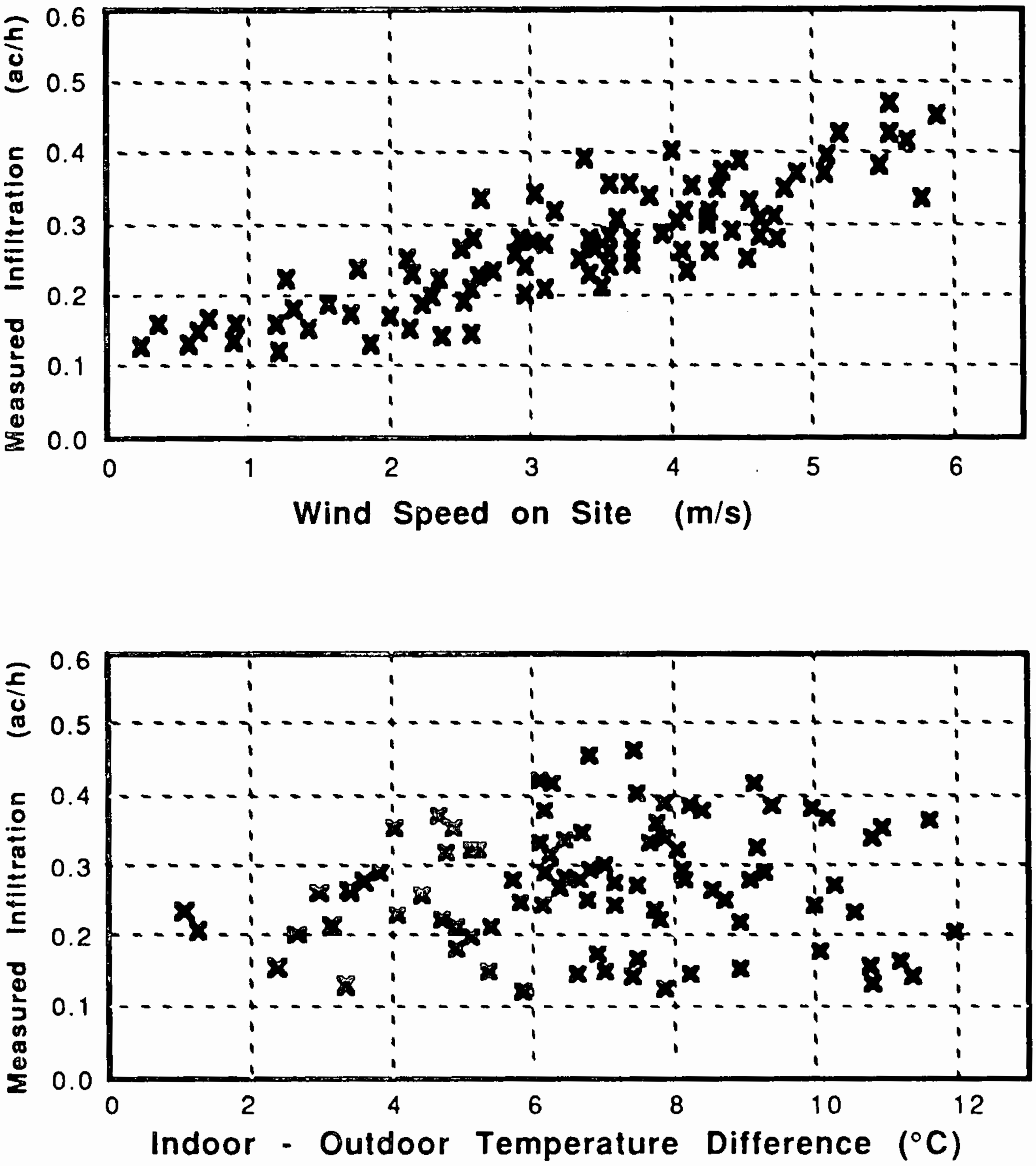

Figure 8 - Measured Infiltration Rates and Correlations

Based on this data, infiltration in New Zealand houses can adequately be treated as a function of wind speed only. The problem with this is that sufficient wind is not always present to drive infiltration when moisture must be ventilated.

NATURAL VENTILATION POTENTIAL

Because there is a need for ventilation, and since most New Zealand buildings do not have purpose-built ventilation systems, an obvious solution is to include provisions for natural ventilation, by manual opening of windows. As the leakage areas are so much larger when doors and windows are opened than the natural ones occurring in the fabric of a building, the amounts of air flow are consequently much higher than for infiltration.

But, as excess ventilation causes extra heating loads, as well as reducing comfort due to cold drafts, it is necessary to be able to estimate how far windows should be opened to provide sufficient ventilation.

Thus, Figure 9 has been calculated from standard aerodynamics to show the amount of ventilation achievable by opening one meter wide windows on the up-and down-wind sides of a house to the same amount. It assumes a 100 sq. meter house with infiltration leakage sites similar to the house in Figure 8, minimal internal flow resistance in the house, shielding coefficients of +1.0 on the upwind face of the building and -1.0 on the downwind face, and wind speeds as experienced at ceiling level.

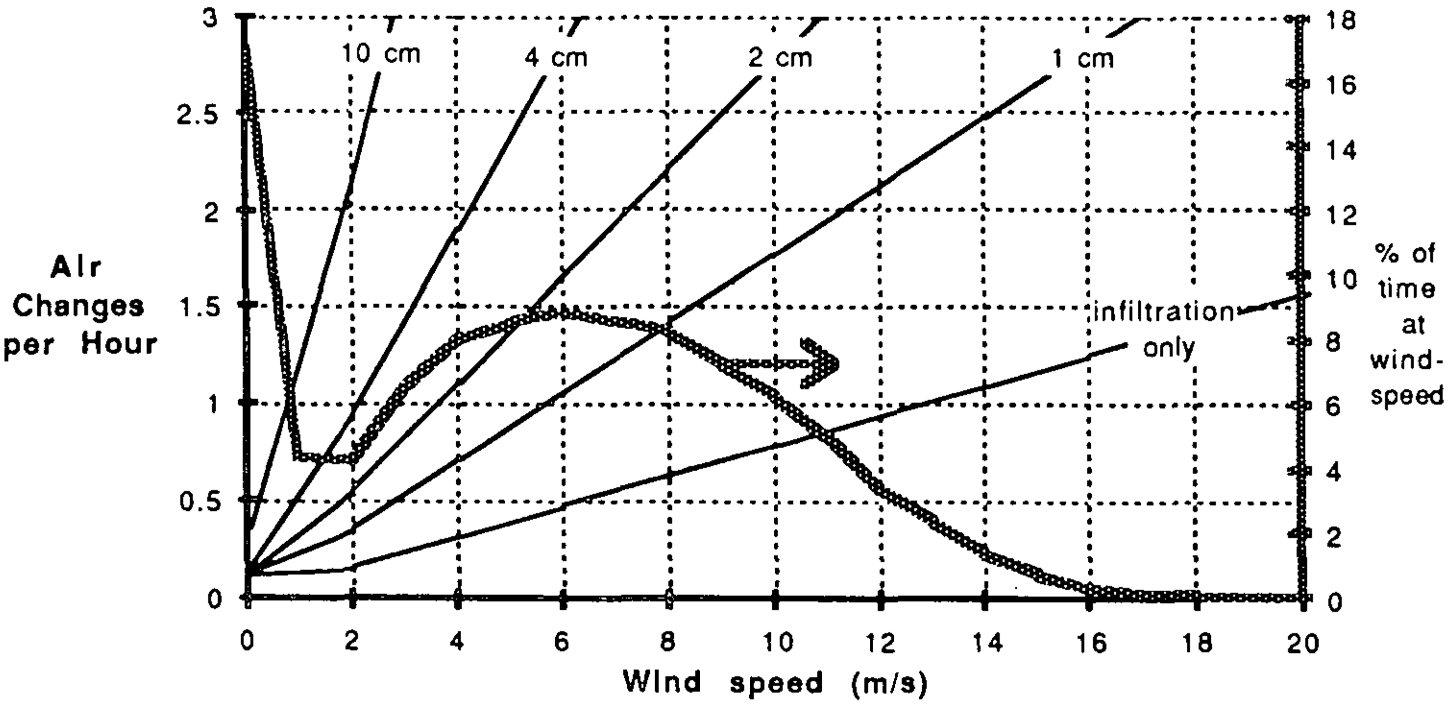

Figure 9 - Potential Natural Ventilation Rates and Windspeed Distribution

As can be seen from Figure 9, high natural ventilation rates can be achieved at relatively narrow window openings, even at quite moderate wind speeds. The distribution of windspeeds measured in Wellington are also included on this figure, with the vertical axis on the right side of the graph indicating the percentage of time the wind is measured at each speed.[11]

The purpose of this graph is to "calibrate the intuition" of homeowners and designers, to offer guidance, in conjunction with the previous figures showing the requirements for air exchange.

A final technique for moisture and pollutant control is that of mechanical ventilation, most common in commercial buildings (especially kitchens). Exhaust fans in kitchens above stoves are common fixtures, used to remove the excess moisture and fumes of cooking. In some of the more modern, low energy houses in cold climates throughout the world, where they are built very airtight, whole-house mechanical ventilation is provided, often with heat recovery. It is notable, though, that for mechanical ventilation to work effectively, the building must be quite tight to infiltration to begin with, or the mechanical ventilation system will be "swamped" by the infiltration under certain conditions.[12]

CONCLUSIONS

Condensation has been shown to be alleviated by a combination of air exchange and heating. Neither will solve the problem alone.

For very low heating rates, as in the case for many New Zealand houses, simply increasing the air exchange rate does not reduce the indoor relative humidity enough to avoid condensation. Some heating is required for this, often quite a small amount.

Likewise, on very still nights, when air change rates are very low, simply adding heating will not reduce condensation. Some form of added ventilation is needed to accomplish this.

A favoured technique to achieve this is natural ventilation, by opening windows on two sides of the house, and encouraging a slight draught or breeze through it. A method is included in the text to approximate the amount of ventilation that can be achieved by this technique at various window openings, depending on outside windspeed.

Ventilation is an important contributor to reducing condensation and indoor air pollution. With a better understanding of the mechanisms and driving forces of infiltration and natural ventilation, New Zealand designers should be able to accommodate this need by placing windows where they can catch prevailing winds, and not trying to provide "high and low" ventilator combinations.

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