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THE EFFECT OF AN IMPROVED WINDOW ON CONDENSATION POTENTIAL

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INTRODUCTION

Thermally upgraded houses, new and existing, tend to operate with higher humidity levels because of increased airtightness. This may benefit the health of the occupants in winter climates. However, the building envelope may not be able to accept the greater moisture content without deterioration. The most evident instance of this situation is extensive condensation on windows, normally the coldest interior surfaces in the dwelling. Damage to the sill and adjacent wall coverings, loss of transparency and of openability (if frozen shut) can result[1]. Thus, the humidity level in a house may be limited by the condensation performance of the windows.

Recently, low emissivity (infra-red reflective) films/coatings have come to be used in commercially-available windows. The significant reduction in long wave radiation through such windows makes a measurable improvement in their thermal performance[2]. The resulting increase in interior surface temperatures should allow, by simple psychrometrics, increased humidity levels before condensation becomes a problem.

A simple test facility was constructed to compare the condensation performance of a standard double-glazed window with a low emissivity double-glazed model under winter conditions. The effects of interior insect screens, wide interior window sills and outdoor wind conditions were also investigated. Further details are available in the Appendices and in reference 3.

RESULTS AND DISCUSSION

Window Type. Figures 1 to 3 show the extent of condensation on the two window types for a series of indoor relative humidities at indoor-outdoor temperature differences of 20, 30 and 38°C. The humidity levels span the range from the onset of condensation to beyond what would normally be encountered in a house. A benchmark for appropriate residential relative humidities was taken from the health guidelines being developed by Canadian governments: 30% to 55% in the winter[4]. The temperature differences cover average winter conditions throughout most of North America and design conditions for much of the United States and southern and coastal Canada. For either window, as expected, the extent of condensation increases with increasing relative humidity and with increasing temperature difference. The low emissivity model is clearly the better performer. The comparison between windows can be expressed in a number of ways:

-If a relative humidity of 50%, as suggested by Sterling et al[5], was to be maintained in a dwelling for human health reasons, and no window condensation was to be tolerated, then the results show that a standard double-glazed window can withstand a temperature difference of about 25°C (an average heating season value in a cold climate). The low emissivity model can tolerate a 30°C temperature difference. If a 40% relative humidity was to be kept (a value at the high end of what is presently found in most houses in winter), those condensation-onset values become 30 and 35°C, respectively. This roughly 5°C improvement with the low emissivity window means a significantly shorter calendar period without condensation (approximately half). If minor amounts of condensation can be tolerated for brief excursions into cold temperatures, then much lower temperatures can be withstood, even down to winter design conditions for all but the northern extremes of North America. Again, low emissivity windows are significantly better than standard models in the temperature difference extremes that they can operate under essentially condensation-free.

-If a temperature difference design condition with a given extent of condensation is to be maintained, then changing to a low emissivity window allows a higher relative humidity. For cold conditions and normal humidity levels, an increase of about 8% in relative humidity can be obtained with the low emissivity model. This can be enough to relieve problems of static electricity or respiratory health. This relative humidity increase gets larger the larger the original humidity level.

-At given temperature and humidity conditions, a change to a low emissivity window can mean a significant reduction in condensation. For example, at 52% relative humidity and a 38°C temperature difference, the standard window was 90% covered in moisture while the low emissivity model was just 20% covered.

Figure 4 gives a representative set of temperature readings for those same conditions: 38°C temperature difference, 52% relative humidity. A number of observations can be extracted from these data:

-As seen in previous studies[6], the edge of a window is colder than the center, and the bottom is colder than the top. This is as expected considering extra edge losses and free convection patterns around the window. A simple, one-dimensional calculation of surface temperatures gives values corresponding to the measurements at about mid-height (see Appendix C).

-The low emissivity model is colder on its outside surface and warmer on the inside than the standard window. This is as expected from the increased resistance to heat flow provided by the low emissivity layer. The calculation in the previous paragraph suggests the low emissivity window should be 0.9°C warmer on the inside surface than the standard model, whereas the actual value is roughly 1.1°C; the correspondence is quite close.

-By rough interpolation between the positions where temperature readings were taken to the position of onset of condensation (from Figure 3), the dew point on the standard window is about 17°C, and on the low emissivity one is about 15.5°C. The measured dew point temperatures in the warm room were 15.0 and 14.0°C for the standard and low emissivity windows, respectively. These are about 2°C colder than those from the window surface temperature measurements. Besides possible humidity control excursions and inaccuracies in the temperature measurements, including those for dew point, early condensation could be produced by dust or minerals providing nucleation sites on the window surfaces; this probably happens in real houses too.

The fundamental outcome from this series of tests is that low emissivity windows have warmer surface temperatures than standard models, and thus have significantly improved performance with respect to condensation in cold climates.

Window Design. Further tests were done to assess the effect on condensation performance of a simulated 3 m/s (7 mph) head-on outdoor wind, an interior insect screen and a 100 mm (4 in) wide interior sill. The comparisons with the base case for the low emissivity window are presented in Figures 5 to 7. These results give some design guidance concerning how the window should be positioned in its frame and in the wall in order to minimize condensation.

With an interior relative humidity of 60%, the wind increased the condensation by about half of the window area (see Figure 5). Lower humidity levels caused modest amounts of condensation with or without wind. (Note that a change to a fully automated indoor humidity control scheme from the manual method used for the series of tests on window type decreased the extent of condensation under nominally identical conditions, probably due to control overshoot in the manual case.) With wind, the outside surface temperatures showed essentially no vertical stratification and colder values than without wind. The inside surface temperatures were roughly 1°C colder with wind, except more so at the top of the window and especially in the top corners. (These latter details may be due to the non-uniform wind created by the table fan used.) Calculation of the thermal effect expected because of the 60% decrease, due to wind, in air surface film thermal resistance yields 1.2°C colder indoor surface temperatures, approximately in line with the measured results (except, of course, for the stratification). The improvements observed with the low emissivity model over the standard window are even more relevant to maintaining a given humidity level for health purposes when steady winds prevail at lower temperatures. Also, design to help shelter the outer surface of a window from the wind, for instance by setting the window in towards the interior side of the wall, would improve condensation performance of any window. (The particular window tested is only set back 50 mm (2 in) from the outside wall surface.)

As indicated in Figure 6, the insect screen increased the level of condensation by about 20% of the window area for the same conditions. The presence of the screen lowers surface temperatures about 1°C in the middle of the window and up to 3°C in the bottom corner. This suggests that the main reason for the excess condensation is not the screen itself, but its frame blocking air circulation. The effect is large enough to be important in marginal situations, such as extremely cold conditions or the high-humidity autumn season. Also, the extra air circulation around the edges of the window without the screen would aid the natural drying of any condensation as conditions fluctuate. It is thus recommended that insect screens be removed for the winter to improve window condensation performance.

The effect of the wide sill, shown in Figure 7, is quite slight: an increase of less than 10% of the window area in the level of condensation. It is possible that the blocking effect of the sill is already fully created by the 90 mm (3.5 in) inset of the window. No significant change from the no-sill case was observed in the window surface temperatures.

The above series of tests suggest that setting a window back from the external wall to provide some shelter from the wind, and close to the interior wall surface without a significant sill to enhance the effect of free convection, will improve the condensation performance of any type of window. Minimizing any blockage of the interior window surface, for example by an insect screen, will help as well.

CONCLUSIONS

1. Low emissivity windows have significantly improved condensation performance over standard models. For the same level of condensation, they can withstand about 5°C colder outdoor temperatures at similar humidities; alternately, they can tolerate 8% higher relative humidities at similar temperatures.

2. Wind, interior insect screens and wide interior sills (or inset windows) all increase condensation for a given set of conditions. The effect is modest for the latter two parameters.

3. The pattern and extent of condensation on a window seems to be defined by free convection, edge effects and possibly dust nucleation, as well as one dimensional heat flow.

RECOMMENDATIONS

1. Low emissivity windows should be promoted for their ability to help alleviate condensation problems or allow more healthful humidities in houses as well as for their improved thermal performance.

2. Increased susceptibility to window condensation because of exposure to the wind or because of interior sills (or window inset) should be taken into account in window design in houses.

3. Suggestions for wise house operation could include removal of inside insect screens for the winter to reduce window condensation.

4. Further research could be conducted with a heater placed under the window to enhance the free convection over the window (and more closely simulate a real house situation). Testing with a forced warm air register under the window would also show the effect of such an air flow both on the level of condensation and on the dynamic effects (eg drying) as humidity conditions change.

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ACKNOWLEDGEMENTS

The long hours of work put in by Ron Mason to construct the apparatus and perform the first series of tests are gratefully acknowledged. This work constituted his third year thesis for the course in Energy Conversion Technology at George Brown College. The subsequent work of Bruce Howell to enhance the apparatus and complete the testing program is also appreciated.

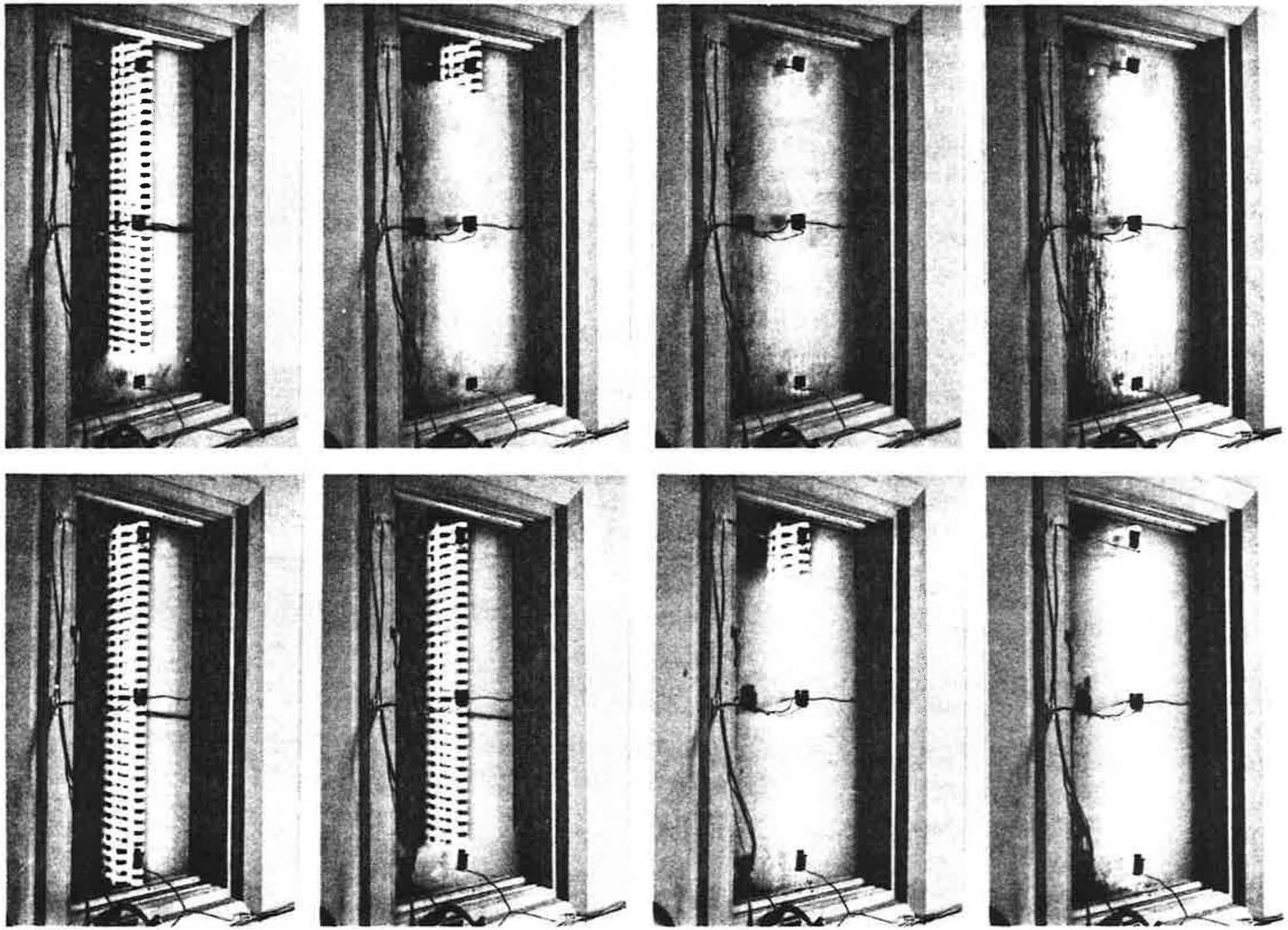

Figure 1 - Condensation Comparison for 20°C Temperature Difference

standard window on top; low emissivity model on bottom
relative humidities (from left): 63%, 72%, 81%, 98%

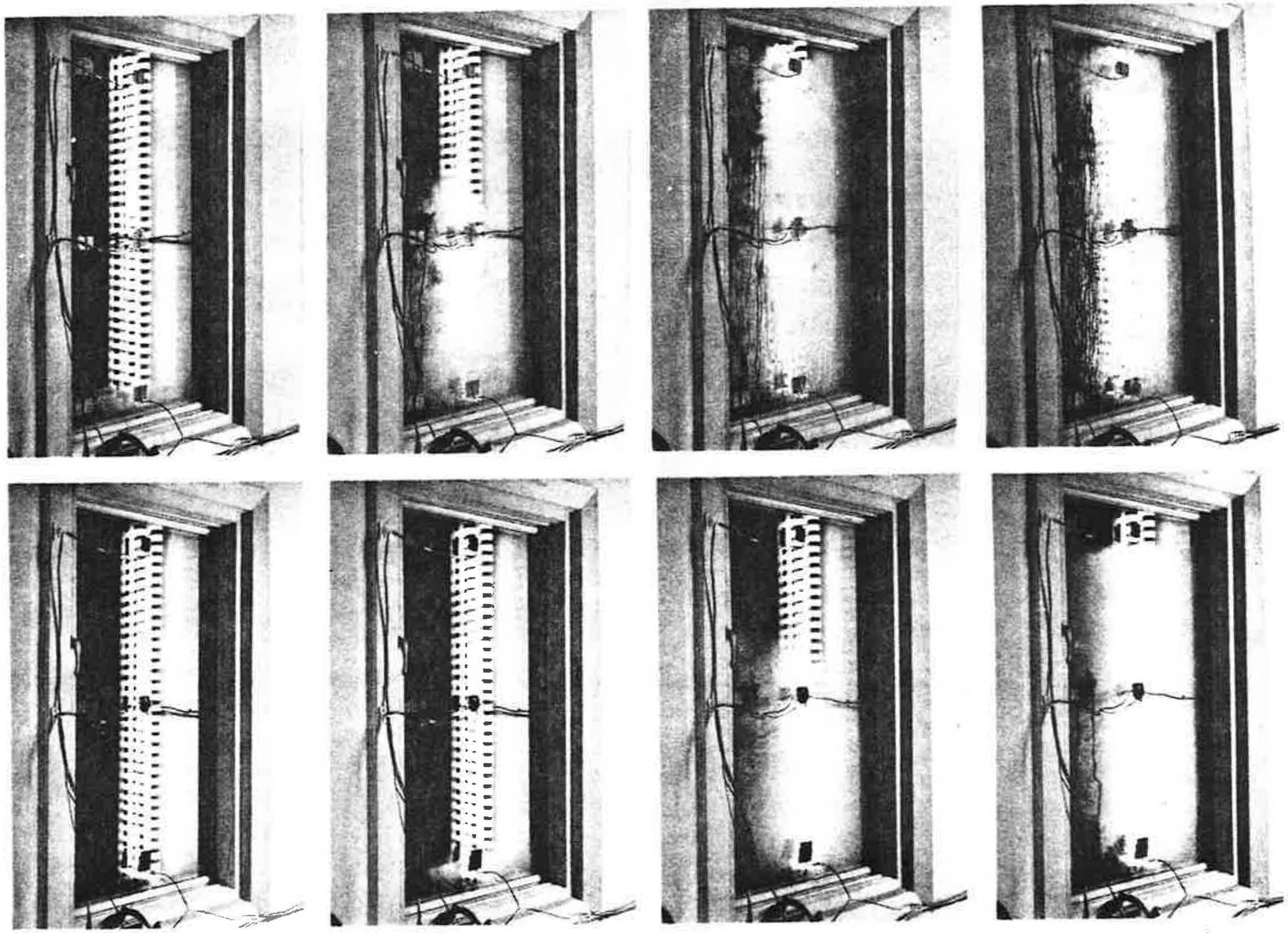

Figure 2 - Condensation Comparison for 30°C Temperature Difference

standard window on top; low emissivity model on bottom
relative humidities (from left): 47%, 55%, 66%, 78%

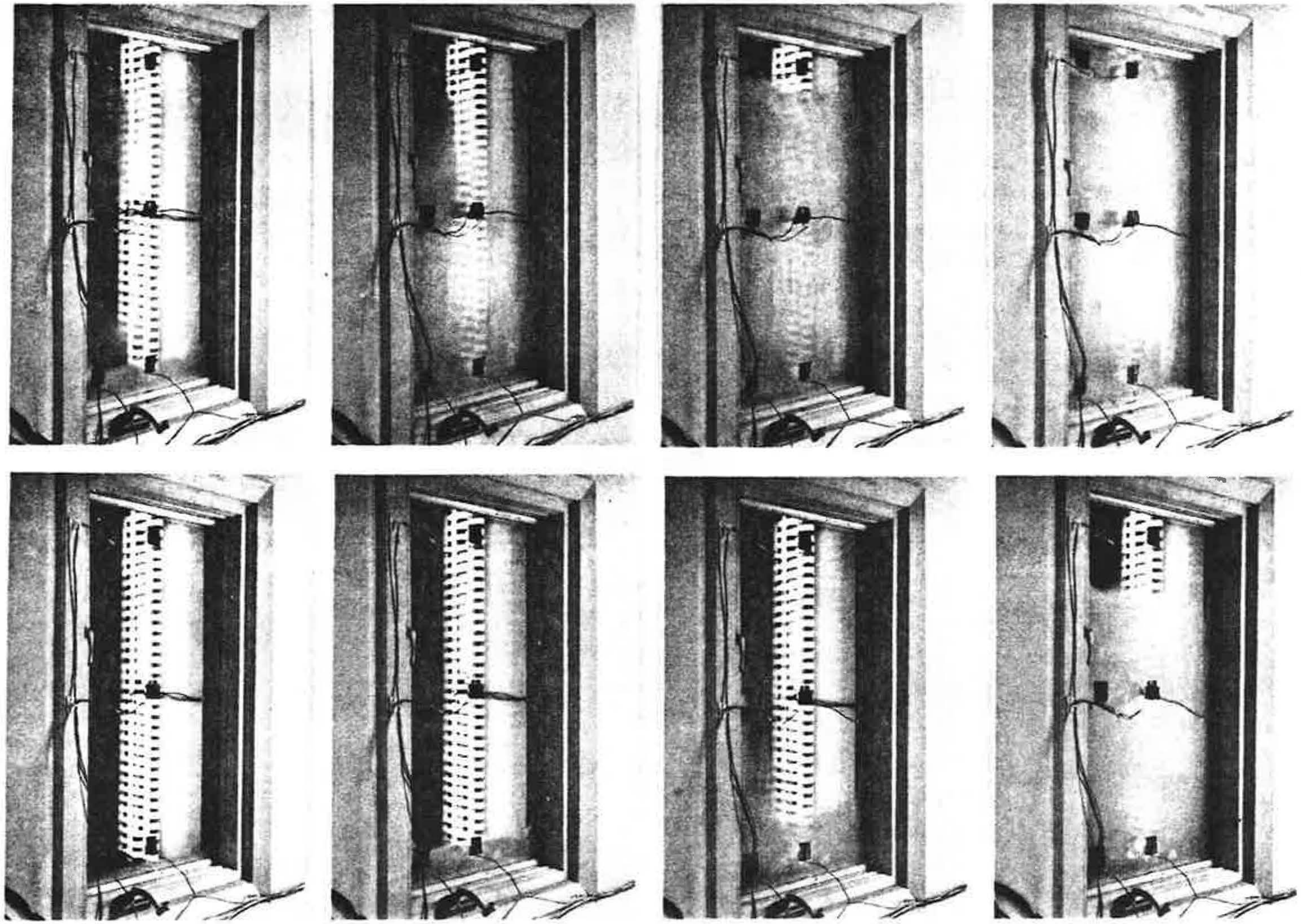

Figure 3 - Condensation Comparison for 38°C Temperature Difference

standard window on top; low emissivity model on bottom
relative humidities (from left): 40%, 47%, 52%, 59%

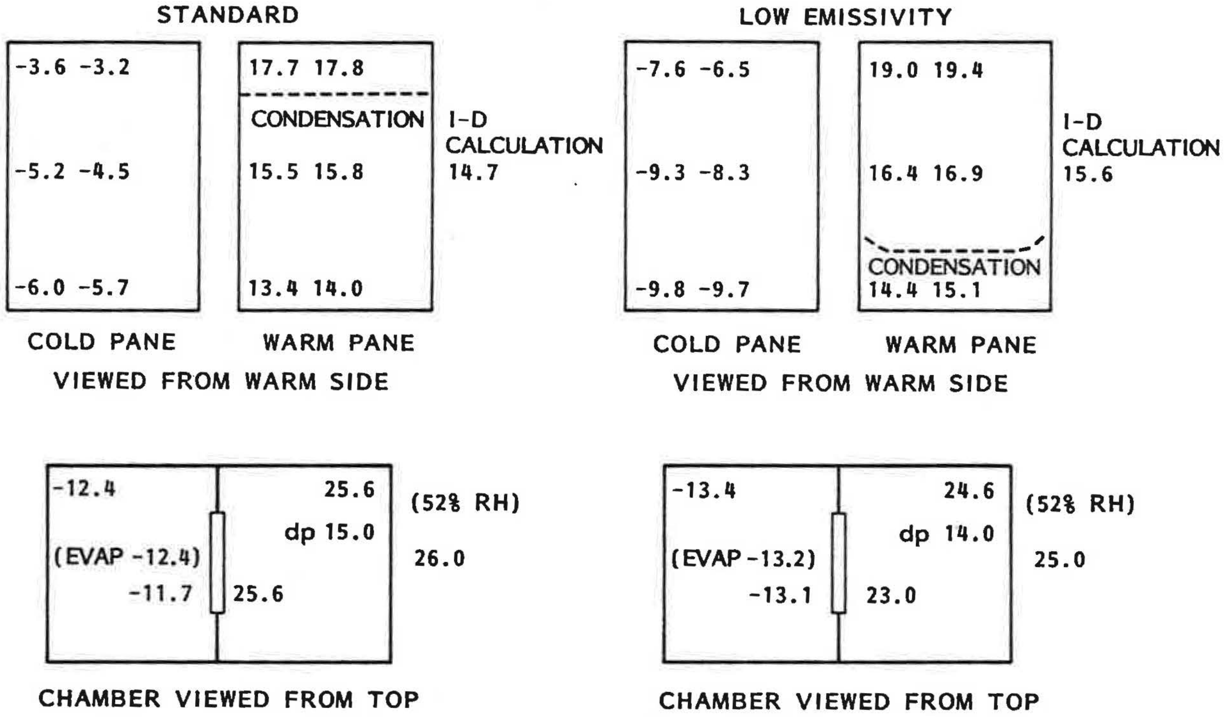

Figure 4 – Temperature Readings in °C for ΔT = 38°C
(Evap = Evaporator; dp = Dew Point)

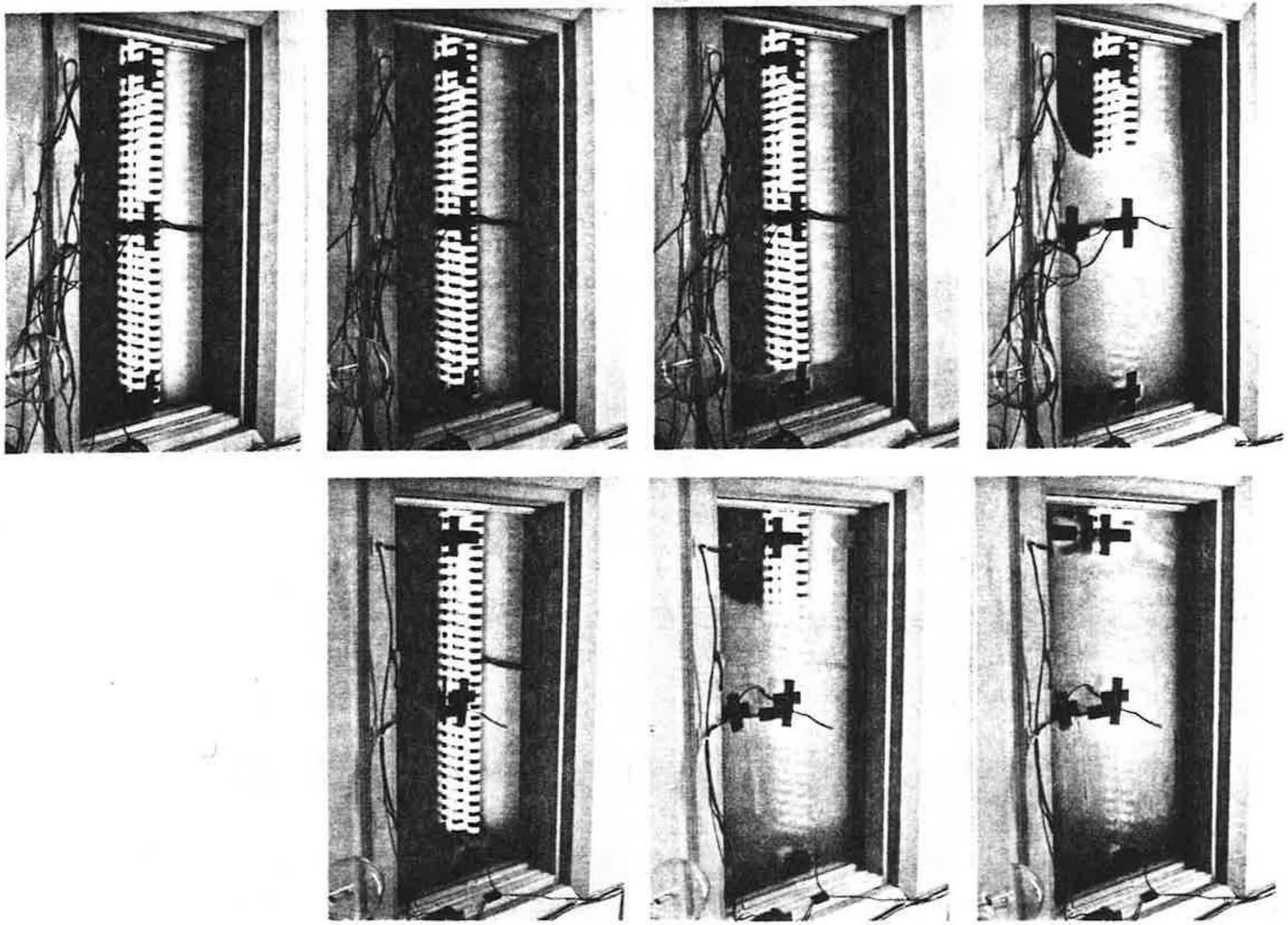

Figure 5 - Effect of Wind on Condensation for Low Emissivity Model at 38°C Temperature Difference

no wind case on top;   wind case on bottom
relative humidities (from left):   top   42%, 52%, 62%, 73%
bottom   48%, 60%, 70%

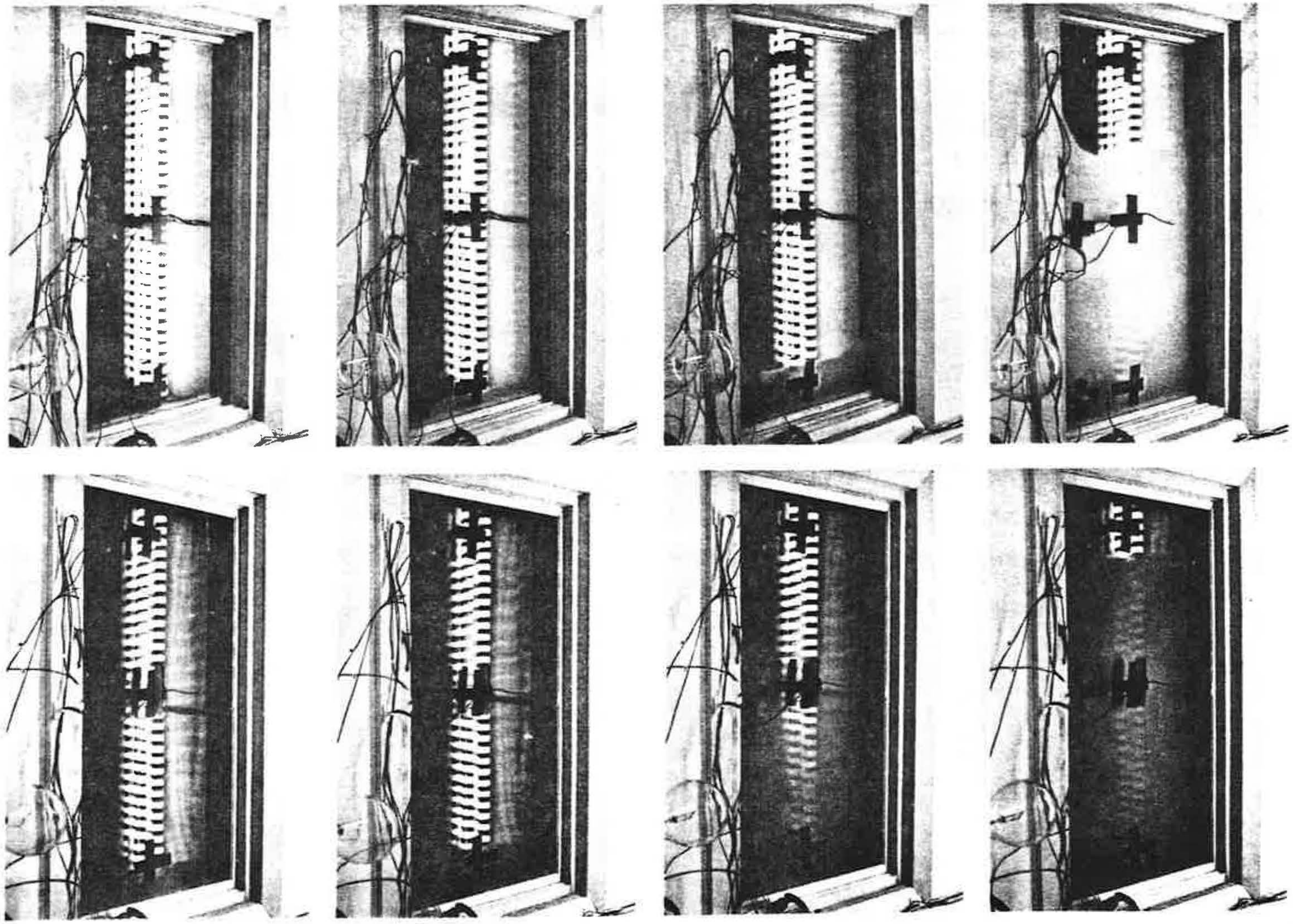

Figure 6 - Effect of Insect Screen on Condensation for Low Emissivity Model at 38°C Temperature Difference

no screen case on top; insect screen case on bottom
relative humidities (from left): top 42%, 52%, 62%, 73%
bottom 40%, 50%, 60%, 70%

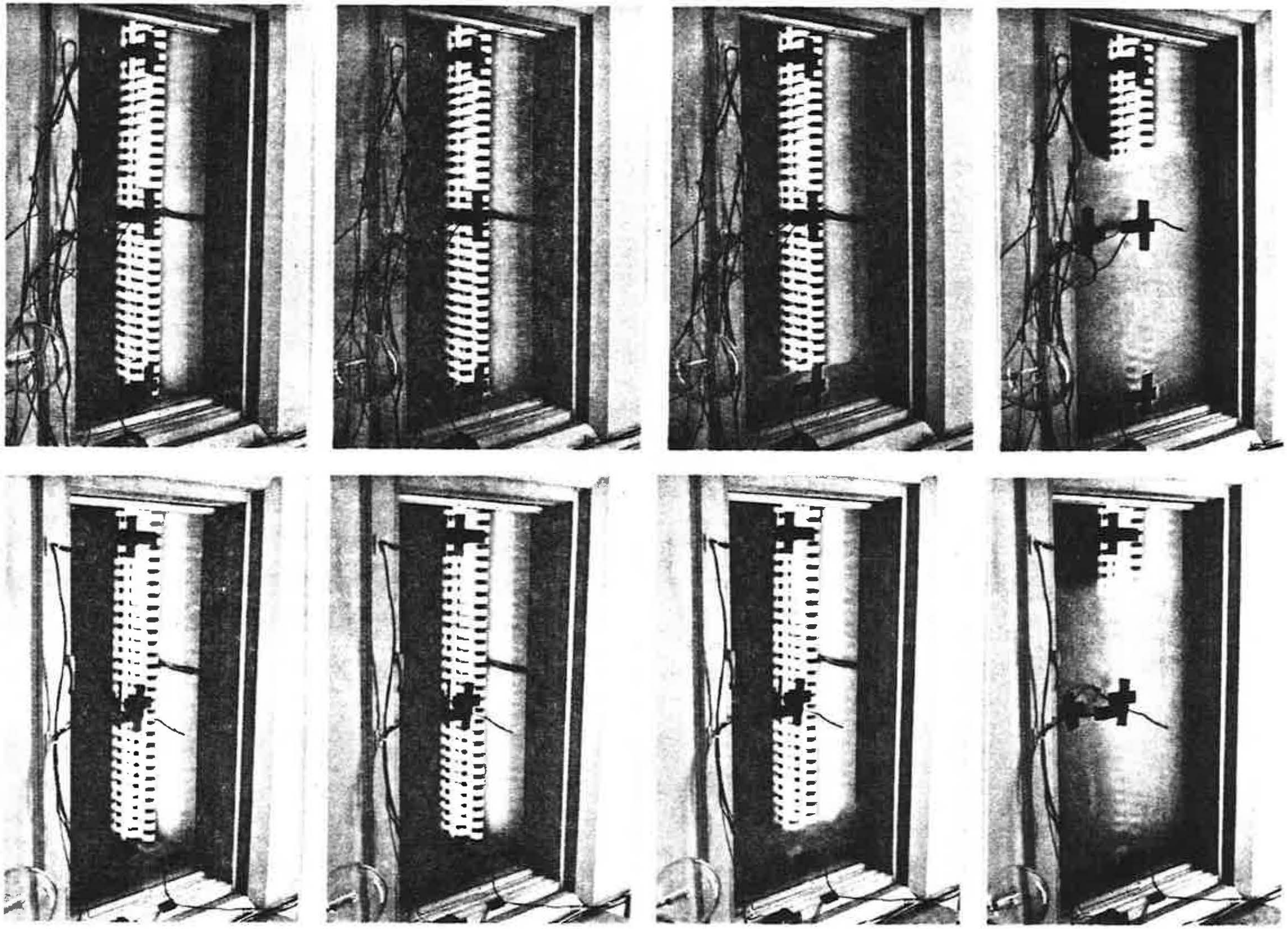

Figure 7 - Effect of Wide Sill on Condensation for Low Emissivity Model at 38°C Temperature Difference

no sill case on top; wide sill case on bottom
relative humidities (from left): top 42%, 52%, 62%, 73%
bottom 46%, 50%, 60%, 70%

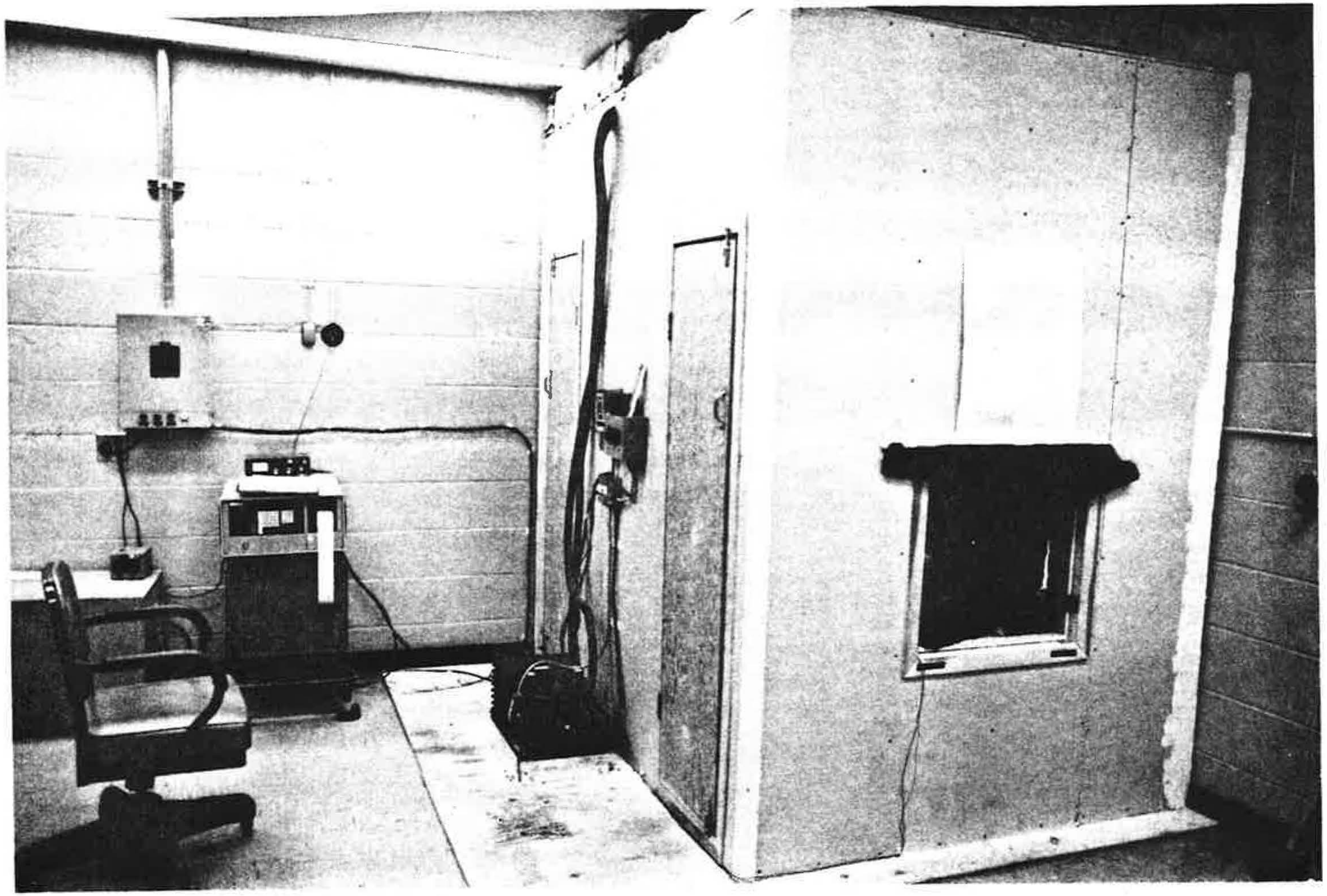

Figure 8 - Window Condensation Test Chamber

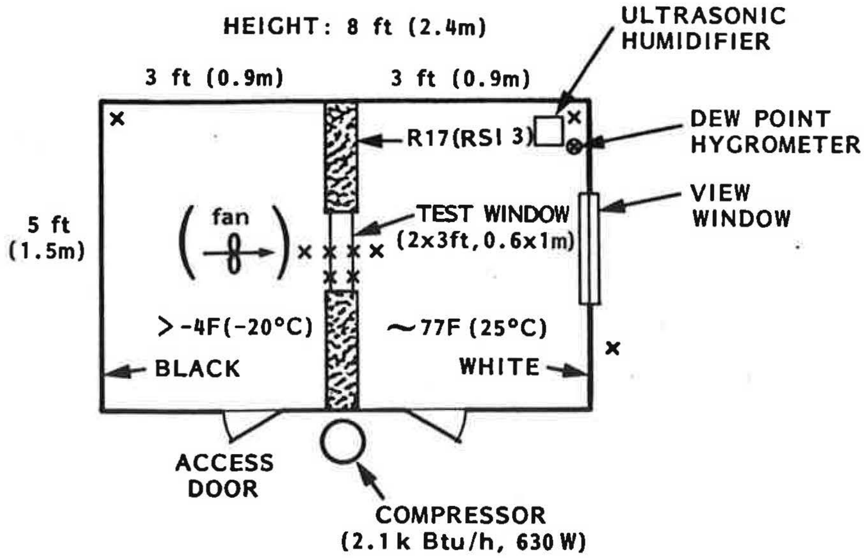

Figure 9 – Window Condensation Test Facility, Plan View
x : Type T Thermocouples

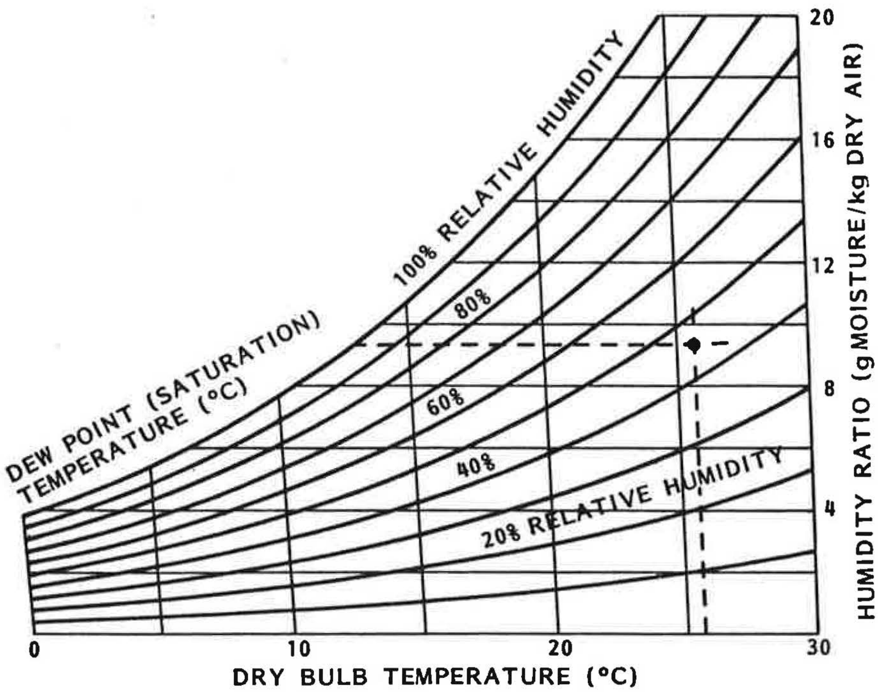

Figure 10 – Psychrometric Chart Example

To Set Initial Humidity Conditions:
Warm Room Dry Bulb Temperature = 25.6°C
Window Surface Temperature = 13.4°C
(≡ Dew Point Temperature for Condensation Onset)
∴ Initial Relative Humidity ≤ 47%

Appendix A
Test Facility

The test window was installed in a standard-construction, RSI 3 (R 17) wall in the chamber illustrated in Figures 8 and 9. The chamber consists of an outdoor and an indoor section, both 1 x 1.6 x 2.5 m (3 x 5 x 8 ft). The outdoor section was made well-insulated and airtight to allow the 630 W (2150 Btu/h) refrigeration unit to cool it to -20^{o}C (-4^{o}F). The defrost heater was thermostatically-cycled to give a range of outdoor temperatures. The interior of this section was painted flat black to simulate a winter night. A table fan was used to simulate elevated wind conditions. (For the no-wind tests, a slight air motion vertically across (parallel to) the window was induced by the fan of the evaporator coil of the refrigeration unit.) The indoor section was insulated and made airtight for isolation from the laboratory ambient. It was painted white and given a tile floor, like a bathroom. Indoor temperature was controlled using a lightbulb. Humidity was introduced with an ultrasonic humidifier fed with demineralized water.

The test window was 0.6 x 1 m (2 x 3 ft) with a fixed outer lite and (21 mm (13/16 in) apart) interchangeable inner panes, one standard glass and the other with a pyrolytically applied low emissivity (thin metal oxide) coating intrinsic with its exterior surface. The window was instrumented to give surface temperatures using copper-constantan thermocouples placed 50 mm (2 in) from the window frame in the pattern shown in Figures 1 to 7^{6}. The thermocouple grid was made asymmetric so that any disturbance of the condensation pattern could be ascertained. No significant anomalies were observed. Further thermocouples gave room temperatures (see Figure 9). A one-point calibration (ice bath) was performed on all the thermocouples. A dew-point hygrometer gave relative humidities and was made part of the humidity control scheme.

Appendix B
Test Procedure

The test procedure consisted of setting the required temperature difference between the indoor and outdoor rooms, setting the indoor relative humidity, waiting for stable conditions and then photographing the resulting extent of condensation and noting the temperature readings.

The indoor temperature was controlled just above that occurring naturally as a balance between the heat gain from the lab ambient (normally 25^{o}C) and the heat loss into the cold section. Then the defrost heater was used to counteract the refrigeration unit's cooling capacity to give the specific temperature difference needed. The humidifier's humidistat was disconnected and control given over to the dew-point hygrometer for increased accuracy. The humidification rate of the humidifier was controlled manually to achieve stable conditions for a given humidity level. To set the initial humidity conditions, the onset of condensation was predicted from the monitored window surface temperatures as shown on the psychrometric chart in Figure 10. The lab ambient conditions were not well controlled, so that absolute temperatures of tests being compared could not always be maintained the same. But identical indoor-outdoor temperature differences were set to ensure that identical relative temperature regimes were tested. The only situation not fully covered in this way was the transition from condensation to frosting; but the interior window surface temperatures for these double-glazed models never approached freezing even for the coldest outdoor temperatures investigated. In a few cases, relative humidities lower than that obtainable from the lab ambient were needed; a tray of dessicant was employed.

A period of half an hour was used to ensure stable conditions. Longer term tests confirmed that no change in the condensation pattern occurred after the initial period. (There was a natural shift from a light mist to heavy rivulets in the condensation region over time.) Constancy of the temperature readings also indicated steady state. The level of condensation for a given set of temperature difference and relative humidity conditions was recorded by photographing the window from an angle under illumination by a zebra-patterned long fluorescent tube (see Figures 1 to 3 and 5 to 7).

Appendix C
Surface Temperatures

The calculation of surface temperatures for comparison with the measured values in Figure 4 used the air temperatures close to the window and standard assumptions about component thermal resistances and one dimensional heat flow. This latter assumption doesn't allow simulation of the stratification observed in Figure 4, but the calculated values (14.7 and 15.6^{o}C for the standard and low emissivity windows, respectively) do correspond roughly to those measured in the middle of the windows. The comparison may also be prone to measurement errors due to the means of thermocouple attachment.