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# Sensitivity of Insulated Wall and Ceiling Cavities to Workmanship

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**ABSTRACT:** This paper examines certain workmanship requirements applying to insulants in cavities. It presents previously reported measured values for the effects of edge gaps, and compares these results with new laboratory measured results for the heat transfer across insulated wall and ceiling cavities, in configurations which permit natural convection to flow around the insulant. The results show the existence of a threshold edge gap width of a few mm for the onset of convection in upward heat flow, but no threshold gap width of detectable size for horizontal heat flow. The loss of thermal performance from convection, as expected, outweighs that previously reported for non-convecting gaps.

## SUMMARY

THERE IS NOW a considerable amount of data [1-8] concerning the loss of thermal performance of structural cavities which can result from thermal bridging of various forms and degree. In many of these reports, losses of 3 to 5% of the cavity insulating value for each 1% of gap width (i.e., edge gap as a percent of cavity width), seem to be quite typical, although there are a few reports in which the loss reaches 10% or more per 1% of gap width. To give a perspective to these figures, note that a gap of 1% would mean a gap width of 5 mm when the frame spacing is at 500 mm, and so would not be difficult either to detect or to avoid.

At least one case has been reported [7] in which degradation was much more severe even than above. This is recognisably a case where convective air circulation has enabled heat to bypass the insulant. It occurred in a wall panel, where the convective circulation pressure difference may be relatively large. The corresponding condition applying in ceiling cavities, where the convective circulation pressure must be much smaller, was not reported.



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The project leading to this paper therefore began by examining, by measurement, the case of an insulated ceiling cavity. These measurements were carried out in a structure representing an actual construction of interest. It therefore contained thermal bridging paths of structural timber as well as convective gaps. Later measurements were conducted to represent the wall panel case, and in essence repeated LeCompte's [7] work.

In the following, the two new series of measured cavity thermal resistances are first described, with the procedures used to obtain them. These results are then discussed and compared with previously published measured data. The principal conclusions of the paper are (a) confirmation of LeCompte's results [7] that severe loss of insulation value accompanies even very small edge gaps in wall cavities where convection can occur, (b) that in ceilings a threshold edge gap of a few mm can be tolerated before convection is initiated, but that once initiated this convective loss is as severe as in walls.

## EXPERIMENTAL PROCEDURE

*(a) Ceiling.* For the upward heat flow case, samples of insulant were mounted in a test frame as illustrated in Figure 1. The insulant used was nominally 50 mm thick (actually 47 mm) fused bead EPS (Expanded Poly-Styrene) foam with aluminium foil facing bonded to both faces of the insulant. The R-value of the insulant was measured as 1.25 $m^2 \cdot K/W$, corresponding to a thermal conductivity of 0.0376 W/m·K, which is typical for the observed density of about 17 $kg/m^3$.

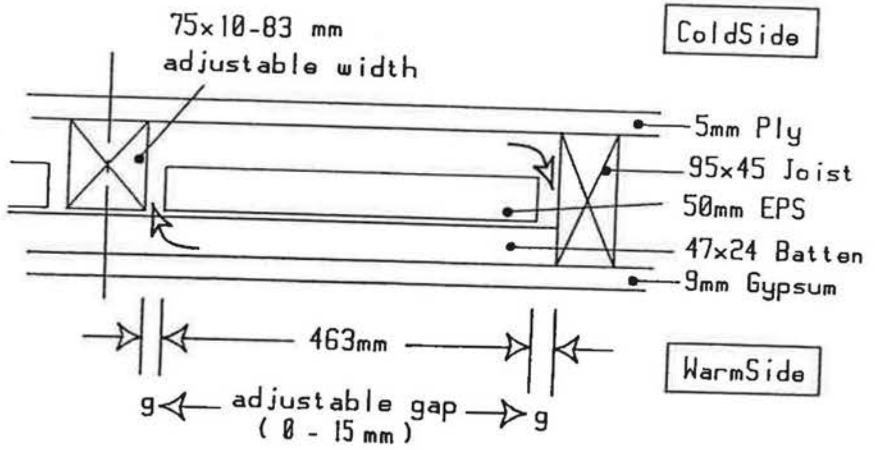


**FIGURE 1.** Detail of insulated ceiling cavity tested.

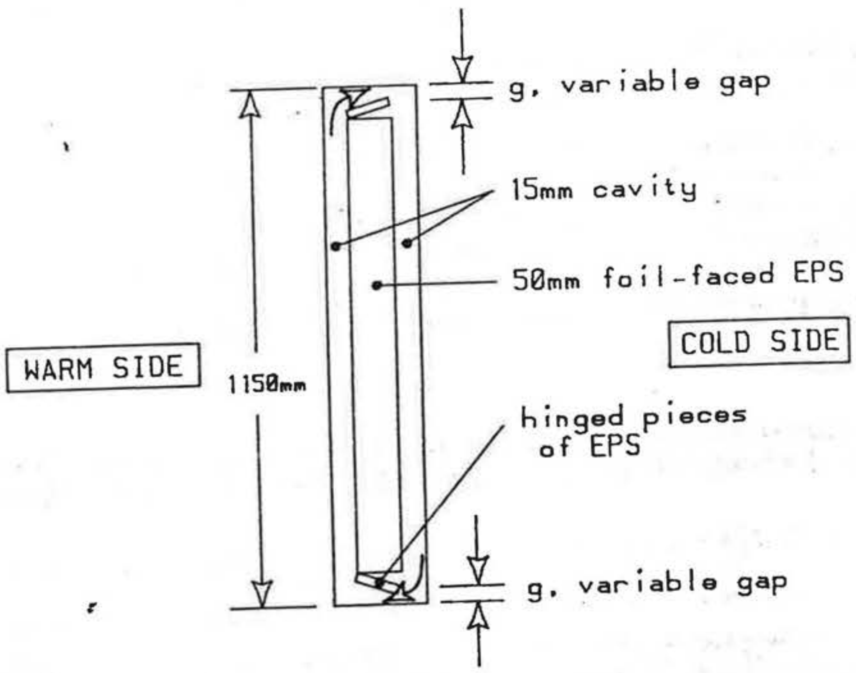


FIGURE 2. Detail of wall cavity tested.

The two pieces of insulant were unchanged during the entire series, and the gaps were adjusted by removing or inserting strips of material from the central joist. The gaps were made all equal except in the last two runs.

*(b) Wall Panel*. In the horizontal heat flow case, Figure 2, no framing was present, and the edge gap was varied by hinging an edge strip of the EPS insulant, about 10 mm wide. The insulant was the same as for the ceiling case.

It will be noted in both Figures 1 and 2 that any edge gaps will permit natural convective air circulation around the insulant. In the ceiling case, Figure 1, convection could take place either clockwise or anticlockwise.

All heat flow resistances were measured using a procedure following ASTM C 236-80, except that in the ceiling series the R-value was determined across the entire panel in the usual way, whilst in the wall series the R-value obtained was measured across the insulant and its surrounding cavities only. The ceiling results were then modified to correspond to those for the wall, in the following way. First the thermal resistances of the outer surfaces (0.12 m²·K/W) and the surrounding lining and cladding (0.05 m²·K/W) were subtracted from the total resistance, to give the "cavity thermal resistance" in Table 1. Then the effect of the timber framing was de-



ducted, using the method of Isothermal Planes, to give the "estimated cavity resistance" in Table 1. This procedure is an approximate one, but is believed to be adequate for the purpose.

The direct thermal resistance measurements are believed to be accurate to within ±3%. The surface and cladding resistances used to convert the ceiling resistances are accurate to within about ±10%. The Isothermal Planes conversion to "normalise" the ceiling results has in previous similar situations been estimated [1,4] to be also within about ±10%. Errors are zero when the edge gap is zero, and [1,4] must be a smooth function of gap width for other values.

## RESULTS

Results for heat flow upward through a horizontal ceiling assembly are shown in Table 1, and illustrated in Figure 3. The immediately evident be-

*Table 1. Summary of thermal resistance across cavities with convection bypassing insulant.*

| Ceiling—See Figure 1 | | | | |
|---|---|---|---|---|
| Mean Edge Gap Width mm | Air-to-Air Thermal Resistance m²·K/W | Cavity Thermal Resistance m²·K/W | Estimated Cavity Thermal Resistance m²·K/W | Estimated Minimum Air Speed mm/s |
| 0 | 1.77 | 1.58 | 2.1 | — |
| 0.5 | 1.78 | 1.59 | 2.1 | 1.8 |
| 2.4 | 1.80 | 1.61 | 2.1 | 1.5 |
| 3.5 | 1.73 | 1.54 | 1.98 | 2.0 |
| 4.3 | 1.70 | 1.51 | 1.93 | 2.1 |
| 5.1 | 1.39 | 1.20 | 1.45 | 4.1 |
| 7.6 | 1.25 | 1.06 | 1.25 | 5.3 |
| 15.3 | 0.96 | 0.77 | 0.87 | 9.4 |
| **Wall—See Figure 2** | | | | |
| Edge Gap Width mm | | | Cavity Thermal Resistance m²·K/W | Estimated Minimum Air Speed mm/s |
| 0 | | | 2.10 | — |
| 1 | | | 1.80 | 1.1 |
| 2 | | | 1.35 | 2.8 |
| 3 | | | 1.14 | 6.4 |
| 5 | | | 0.94 | 7.7 |
| 10 | | | 0.82 | 10.0 |

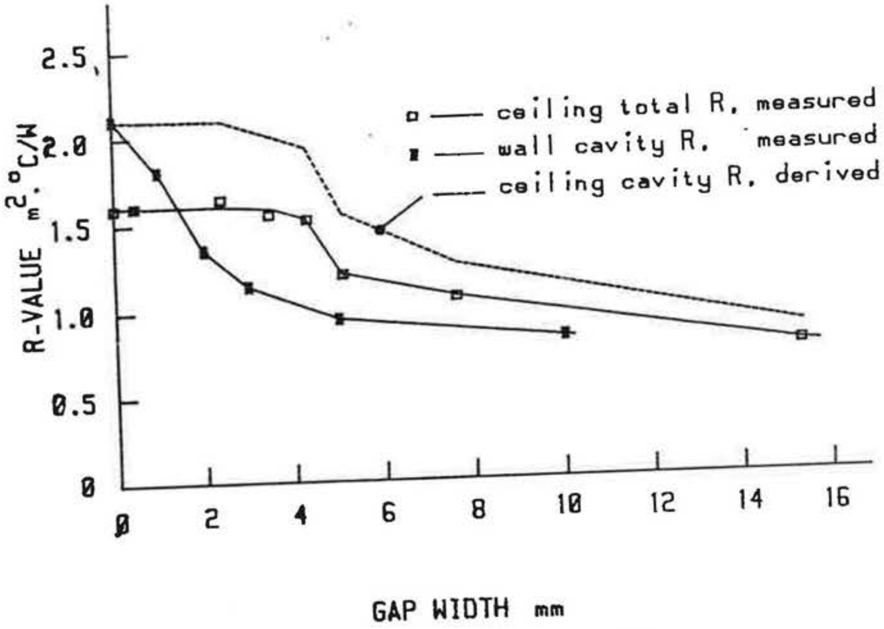


FIGURE 3. R-value with convective gaps.

haviour observed for this case was that no significant loss of thermal performance occurred until the width of edge gap exceeded 4 to 5 mm, at which point there was a fairly sudden and major drop of some 25% in the R-value. This feature is equally prominent in both as-measured resistance and the "estimated cavity resistance values in Figure 3. Further widening of the gap resulted in progressive further lowering of the thermal resistance. This continued up to the largest gap width tested, about 15 mm, at which point the resistance was some 40% of the initial value.

The last stage of this case involved respectively the use of non-equal gaps to the two edges of the insulant, and the provision of a slope angle (which happened to be 4.1 degrees to the horizontal) to the panel. These conditions were set up with a gap width chosen at 3.5 mm, just a little below the threshold level. Both actions decreased the thermal resistance, but appear not to have caused the system to move over the threshold.

The results for horizontal heat flow through a vertical panel are shown in Table 1, and illustrated in Figure 3. No threshold effect is visible in these results. A sharp fall in thermal resistance is evident even for the smallest edge gap width (1 mm).



## DISCUSSION

It is evident in Figure 3, in spite of the influence of the structural bridging effects, that a threshold effect is present for the ceiling case. This permits small fitting errors without significant loss of insulation value. However in the wall panel case no such threshold is present and there is no tolerance for workmanship imperfection.

These results, along with previously reported measurements from various sources [2,3,5–8] are illustrated in Figure 4, as percentage drop in cavity thermal resistance against percentage gap edge width. This is present on a log scale to allow easier visualisation of the whole range of influence.

From Figure 4 it may be seen that the present results, except for the below-threshold region in the ceiling case, show extreme sensitivity of thermal performance to very small edge gaps, compared with the results reported by Johns-Manville [5], Owens-Corning [6], and C. Bankvall [3]. Those all specifically exclude convective bypassing of the insulant. However results reported by LeCompte [7], which specifically included convective bypassing, agree in this acute sensitivity and his data and the present are almost identical.

McCaa [9] does not describe the type of edge gap occurring in his data.

It might be conjectured that the Johns-Manville, Owens-Corning, Bankvall, and McCaa data, along with the below-threshold portion of the ceiling data in this paper, might form one family for the nonconvecting gap case,

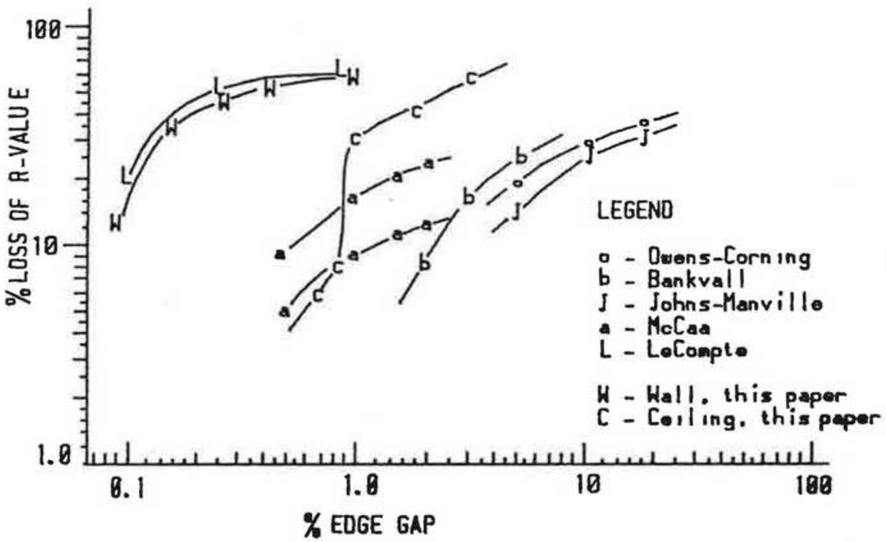


FIGURE 4. A comparison of measured insulation loss for various gap ratios.

whilst that from the above-threshold results here, along with LeCompte's data, form another family for the convective bypass case.

The behaviour reported by Berlad et al. [2] for wall cavities should be considered here also. That study showed that with typical porous insulants it is not even necessary to have an edge gap to suffer severe convective loss, if there are cavities on both faces of the insulant. The convective pressure is large enough that circulation will penetrate through the insulant in that case.

The air circulation rates cited in Table 1 are derived from simple energy considerations, as the rate required to carry the apparent convective heat flow at the trans-cavity temperature difference. They are intended as indicative only, to show that the amount of air circulation required is very small. These values are of similar size as can be calculated using simple classical laminar flow fluid mechanics.

## CONCLUSIONS

For both upward and horizontal heat flow, any occurrence of convective circulation around the insulant causes major loss of performance with very small edge gap widths.

However for vertical heat flow upward through a horizontal ceiling, the loss exhibits a threshold of gap width below which convection does not occur. For the conditions used here, this threshold gap width was 4 to 5 mm. At this point a sudden major drop of about 25% in resistance was observed.

For horizontal heat flow through a wall panel there is no apparent threshold, or if so then it is less than 1 mm.

In both cases thermal resistance continues to fall as the gap width increases beyond the threshold width. No limit was found to this loss in these tests, which continued to about 60% loss in total cavity thermal resistance in this series of tests.

In practical building terms, these results mean that for ceiling insulant having cavities both above and below the insulant, it is possible to get substantially full insulation value with achievable standards of good workmanship of a few mm, but in the case of walls this is not so. Even "good" workmanship is not enough in that case, and gaps of less than visible width ($\sim$1 mm) are likely to drastically undermine the insulation value.

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