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PILKINGTON RESEARCH AND DEVELOPMENT
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Improving the thermal performance of timber framed walls

Abstract
The thermal performance of timber framed walls is increased if the main cavity is filled with mineral wool. This also builds in a large safeguard against the risk of any interstitial condensation which may have resulted from gross damage to the vapour control layer.

■ INTRODUCTION

The thermal performance of a conventional timber framed wall depends mainly on the amount of insulation fitted in the stud cavity; with 89 mm studs and full-fill, a U-value of about 0.4 W/m²K is achieved (the precise value being dependent upon the amount of timber studding). Consideration has been given to improving on that excellent performance, usually by increasing the stud depth, but that increases the overall thickness of the wall.

The possibility has, therefore, now been considered of filling the main cavity between the usual brick cladding and the timber frame with insulation, in addition to full-fill of the stud cavity; by this means, a U-value of 0.25 W/m²K can be achieved.

The filling of the main cavity is also considered as a method of upgrading existing walls where there is little, if any, insulation in the stud cavity.

Currently this construction would not be allowed by the NHBC, and certainly the hygrothermal behaviour of the wall would be significantly altered by the insulating of the main cavity. The new interstitial condensation prediction technique contained in the Draft Revision of BS 5250, the Code for the Control of Condensation in Dwellings (Ref 1) has, therefore, been used to predict the effects, and extensive experimentation has been carried out to test the predictions.

■ THEORETICAL PREDICTIONS

If the vapour control layer (vcl) in a timber framed wall is intact, all the condensation prediction techniques show, and experiments have confirmed (Ref 2), that there is no interstitial condensation risk. However, in practice, the vcl may not be perfect, if only because of penetration by services, but the new prediction technique is not applicable to local damage.

In practice interstitial condensation has not been found to exist in timber frame housing as confirmed by surveys carried out by BRE and Wimpey.

The theoretical predictions have been made using data given in the Draft Code and at the suggested average winter conditions:

external : 5°C with 95% relative humidity
internal : 15°C with 65% relative humidity

giving an internal vapour pressure of 0.3 kPa excess over external, corresponding to a dry/moist occupancy (Ref 3) and at

internal : 15°C with 85% relative humidity

giving an internal vapour pressure of 0.6 kPa excess over external corresponding to a moist/wet occupancy.

Conventional construction

The effect of any ventilation of the main cavity must be considered.

It can be shown that if there is sufficient ventilation only to reduce the cavity's vapour pressure to that of the outside air without losing the thermal insulation effect of the cladding and cavity, any potential interstitial condensation risk is reduced.

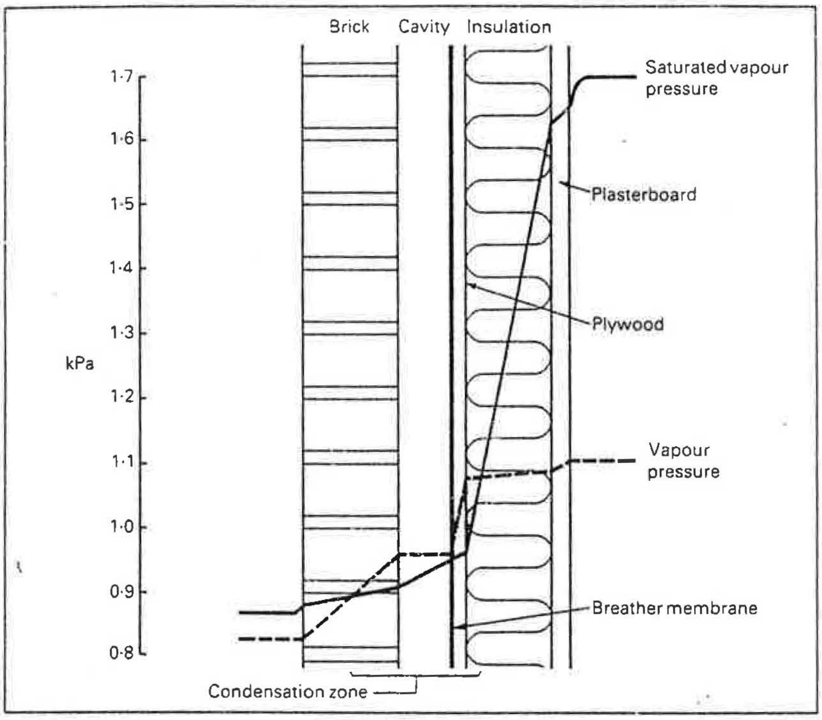


Figure 1
Timber framed wall with no vapour control layer — condensation zone prediction of BS 5250 (outside 5°C, 45% rh; inside 15°C, 65% rh).

This is referred to subsequently as a vented cavity. Since any further ventilation would also reduce the temperature in the cavity, that would increase any risk. It is thought that the beneficial effect of open perpends required in timber framed walls is achieved because effectively a vented condition is produced.

The predicted minimum internal humidity to initiate condensation at the sheathing is given in Table 1.

The necessity for the vcl is clearly shown, but it must be remembered that the figures for the construction with no vcl will not be achieved in practice unless there is gross damage to the membrane; the figures serve mainly as comparisons. Such a small advantage calculated for the effect of venting the cavity is surprising.

Vapour control layer	Cavity	Predicted minimum internal humidity for condensation at sheathing
Yes	Unvented	No condensation at 100%
Yes	Vented	"
Yes	Insulated	"
No	Unvented	58%
No	Vented	59%
No	Insulated	71%
Conditions: external 5°Cm, 95% rh internal 15°C		

Table 1: Condensation prediction.

Figures 1 and 2 show the interrelationship of vapour and saturated vapour pressures for the unvented conventional construction with no vcl calculated according to the current BS Code (Ref 4) and the new Draft Code respectively. The extensive condensation zone is replaced by a single condensation plane, although it can be seen in the latter case that the humidity at the brick/cavity interface is very high.

Modified construction

The addition of mineral wool insulation to the main cavity obviously improves the thermal performance of the wall, but in addition it increases the temperature of the plywood sheathing. Figure 3 shows the predicted effect of this, again for a wall with no vcl.

The saturated vapour pressure at the sheathing rises significantly; the vapour pressure also rises, for although the extra insulation hardly alters the vapour resistance of the cavity, the vapour pressure is no longer held down by the saturated vapour pressure. Table 1 shows that the net effect is the removal of any risk of condensation at the sheathing at the lower standard environmental conditions even with no vcl. Condensation is now predicted on the brick cladding which is considered inconsequential (as in the case of masonry walls with insulated cavities).

It is not suggested that the vcl is omitted. Table 1 shows that condensation would be expected on the sheathing if the internal humidity rose to 71%, that is, at less than that often found in practice. However, the 12 percentage points difference in internal humidity to create condensation between the normal vented construction and that with the extra insulation indicates the enormous safety margin which should be created for walls with a vcl with only the normal small amounts of damage.

■ EXPERIMENTS TO VERIFY PREDICTIONS

Construction of test rig and test panels

The hygrothermal test rig comprises internal and external environmental chambers with the experimental wall between them. The wall has external brick cladding and a full height timber frame complete with a section of floor and intermediate floor (see

Figure 4a). The frame has three 600 mm wide test panels side by side separated from each other and from the rig walls by guard panels 300 mm wide (see Figure 4b). The main cavity between sheathing and cladding is subdivided into three to correspond to the test panels by means of conventional cavity barriers.

Throughout the tests, the aim has been to compare, for each environmental condition, a panel built with an unventilated cavity with one built conventionally (with an open perpend at dpc level) with one which has the outer cavity filled with mineral wool (Pilkington Dritherm batts). These are subsequently referred to as unvented, vented and insulated. As a preliminary to the tests proper, the rig was run with all three panels in unvented form and with similar damage to the vcl in each panel to check that there were no inconsistencies between them: differences were negligible.

A major difficulty is choosing some form of vcl damage. Omitting the vcl altogether gives totally unrealistic conditions, and fitting one of low vapour resistance would not reflect the localised nature of tears and holes. In addition, if the real damage is in the form of a hole through the plasterboard and the vcl at the same point (for example around an electrical socket outlet), then moisture would be carried through in any airflow resulting from an overpressure at the internal environment, in addition to that diffusing through the construction.

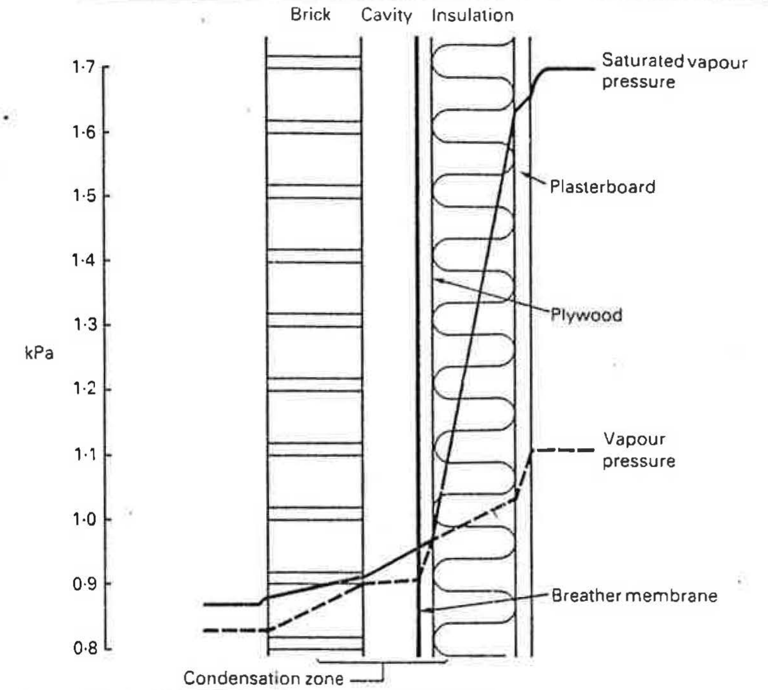
A 19 mm diameter hole cut through the plasterboard and vcl was chosen as the standard damage, which should represent worse conditions than would be found in practice. An overpressure of about 1—2 Pa was maintained at the interior environment compared to the exterior to create some air flow, although this was expected to be limited in extent because there was no obvious air path out of the stud cavity (0—10 Pa overpressure would be typical in a house). No predictions were made of the effects of these airflows.

Test conditions

For practical reasons and to accelerate the tests, the external conditions were maintained by nominally 5°C and 85% relative humidity (with a uniform airflow of about 2 m/s maintained down the outer face of the brick cladding) and the internal temperature at nominally 25°C; the internal humidity was used as the main variable.

Environmental temperatures were generally maintained at ± 1°C or better of the set point. Humidity control is difficult and there were problems of short term fluctuations and drifting of calibrations: in view of the relatively slow response of the system to moisture conditions, the average values which are quoted are considered to reflect appropriate conditions. Temperatures and humidities were monitored within the constructions and the vapour pressure figures are derived from these. Timber moistures were monitored by measuring electrical resistances.

In the main tests, the internal humidity was increased in a series of steps to determine



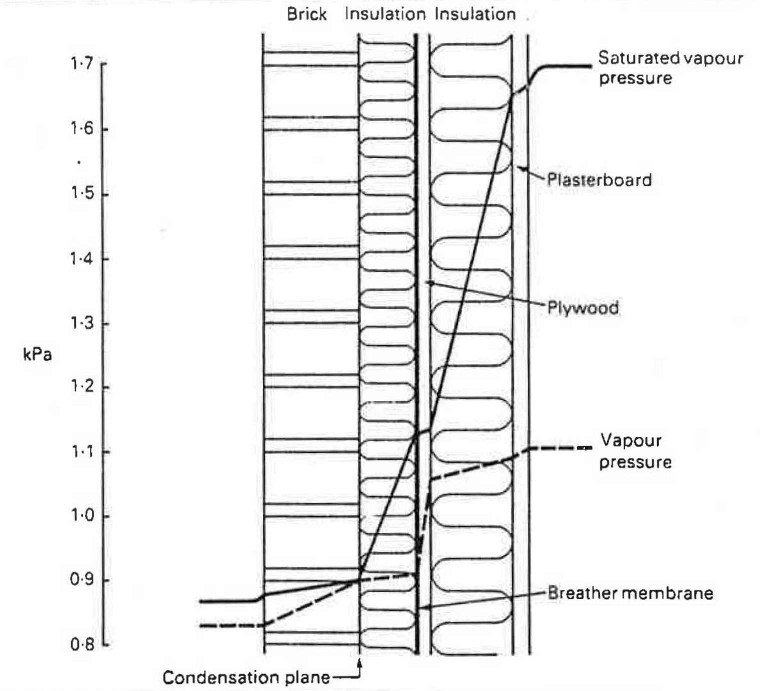


Figure 2 (top)
Timber framed wall with no vapour control layer — condensation plane prediction of draft code (outside 5°, 95% rh; inside 15°C, 65% rh).

Figure 3
Timber framed wall with no vapour control layer, but with extra insulation in cavity — condensation plane prediction of draft code (outside 5°C, 95% rh; inside 15°C, 65% rh).

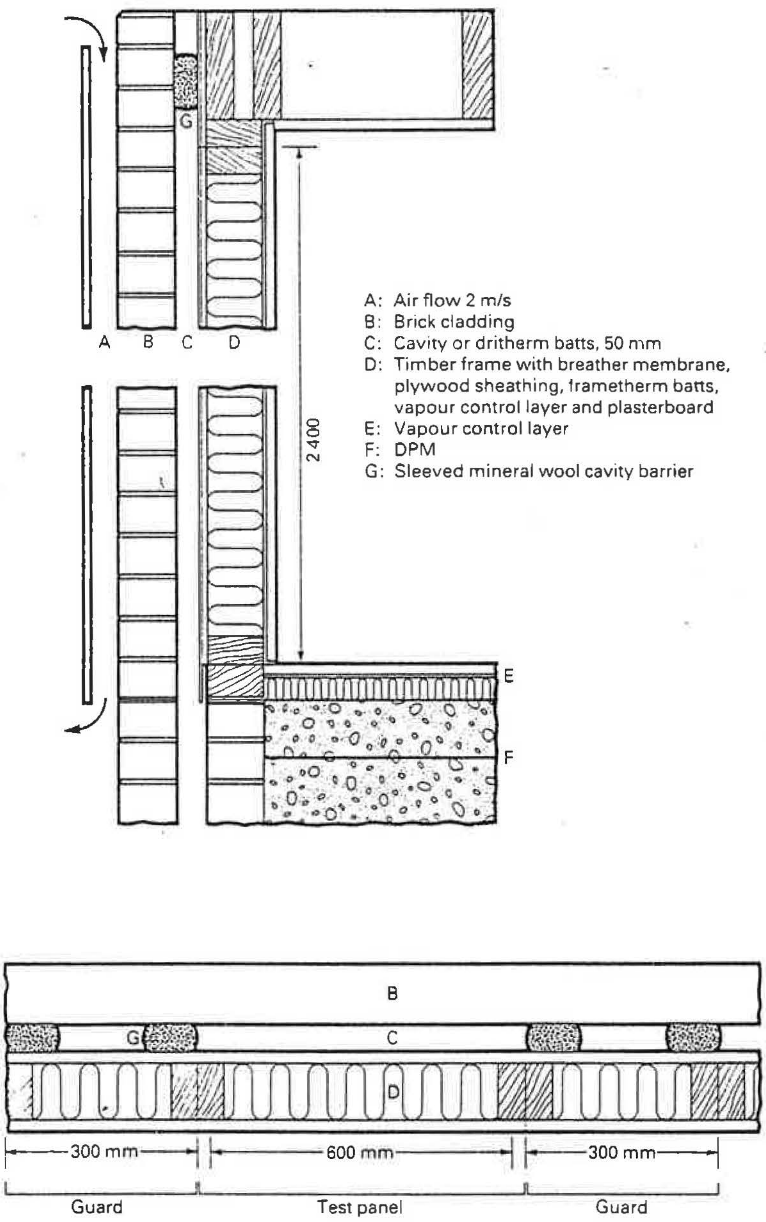


Figure 4a
Cross section of test wall.

Figure 4b
Plan view of test wall.

the humidity corresponding to the onset of condensation at the plywood sheathing (that is, 100% just reached) for each of the three constructions. This was carried out over a long time scale (20—30 days per step) so that near equilibrium was obtained for each step, that is, to a point where change was no longer obvious.

Each of the three panels in the above tests had the plasterboard/vcl damaged in the standard form at a position two-thirds up from floor to ceiling.

Following the main tests, the severity of the environmental conditions was reduced for a period prior to stripping and inspection of the wall.

■ RESULTS OF EXPERIMENTS

Vapour control layer intact

A run was carried out before the main tests to determine if the different constructions would have any effect on the conditions in the wall with a perfect vcl. The internal humidity was 38% and changes within the wall were slow, equilibrium not being attained after 35 days. By that time, however, there were marked differences in performance of the three panels. Results are plotted on the left hand sides of Figures 5—7.

Figure 5 shows that at the plywood sheathing, the relative humidity (rh) had reached 60% in the unvented and vented panels and was still rising, but it had reached only 48% in the insulated panel.

Figure 6 shows that the plywood moisture levels reflected the humidities with 12, 12 and 9% (by weight) respectively. The soleplate moistures (Figure 7) also reflected those trends.

Vapour control layer plasterboard cut

Figure 5 shows the levels of internal humidity which were necessary to achieve just 100% rh at the plywood sheathing for each of the three constructions: 40% for the unvented construction, 48% for the vented, and 58% for the insulated construction. These correspond to vapour pressure differences across the wall of 0.50, 0.62 and 0.99 kPa respectively. This figure also shows that for any internal humidity, the humidity produced at the plywood in the vented panel was much lower than that in the unvented panel, and very much lower in the insulated panel compared to that in the vented one; for example, at 40% internal rh, humidities at the plywood opposite the damage were 100, 85 and 63% respectively.

Figures 6 and 7 show that the moisture contents in the sheathing and soleplates reflected these humidities; for example, at an internal rh of 58%, the moisture content of the plywood sheathing opposite the damage was in excess of 30% by weight for the unvented and vented panels, and only 19% in the insulated panel.

Inspection of the test panels

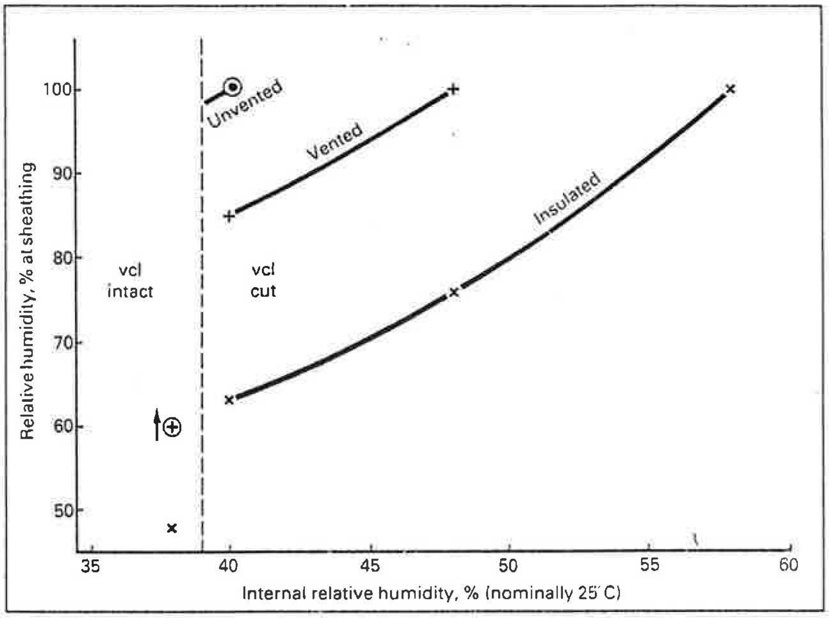
Following the main tests, the internal rh was reduced to 53% which represents a vapour pressure difference of 0.84 kPa, just greater than the maximum found in a limited study of occupied dwellings (Ref 3). The purpose was to demonstrate the differences between the three constructions, including visual differences, at this extreme of practical conditions. It was accepted that there might be some hysterisis effects from the more severe conditions and some results confirmed that equilibrium had not been fully established in that previous test. However, the general trends reported above were confirmed.

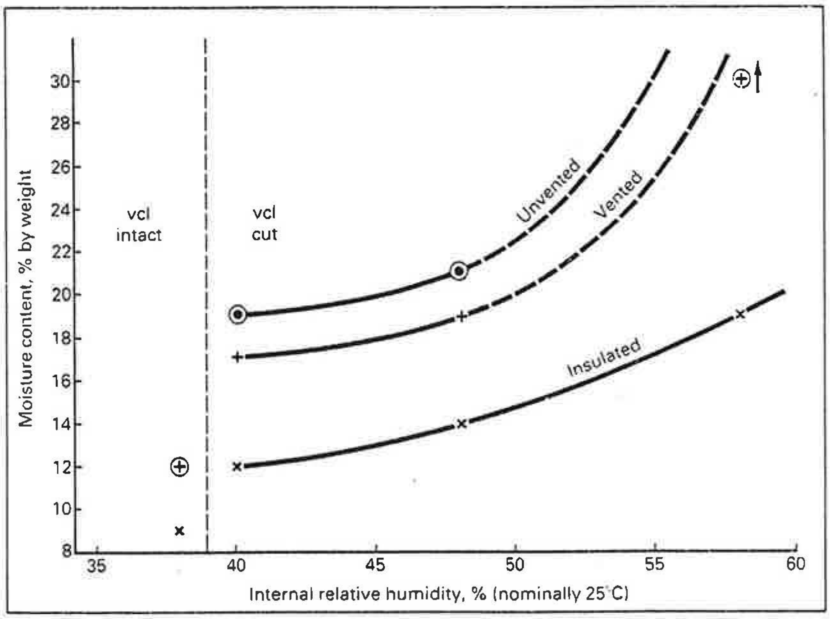
Relative humidities at the plywood sheathing opposite the damage remained at 100% in the unvented and vented panels, but dropped to 85% at the insulated panel. Cavity humidities remained at 100, 100 and 84% respectively. The final moisture contents of the sheathing reflected these humidities with values of greater than 30% by weight for unvented and vented and of 17% for the insulated panels. Final moisture contents of the soleplates were 23, 21 and 17% and for the header joists were 16, 14 and 14% respectively.

The plywood sheathings in the unvented and vented panels both had an area of about 450 mm diameter opposite the damage which was visibly wet, whereas that of the insulated panel showed no signs of damage or dampness.

The interior face of the brickwork in the unvented cavity was generally wet, that of the vented construction looked dry and that of the insulated construction was dry, except for an area of about 300 mm diameter centred on the damage position which was wet with globules of water.

Soleplates looked dry, but there was a considerable quantity of water between the dpc and the oversite dpm corresponding to





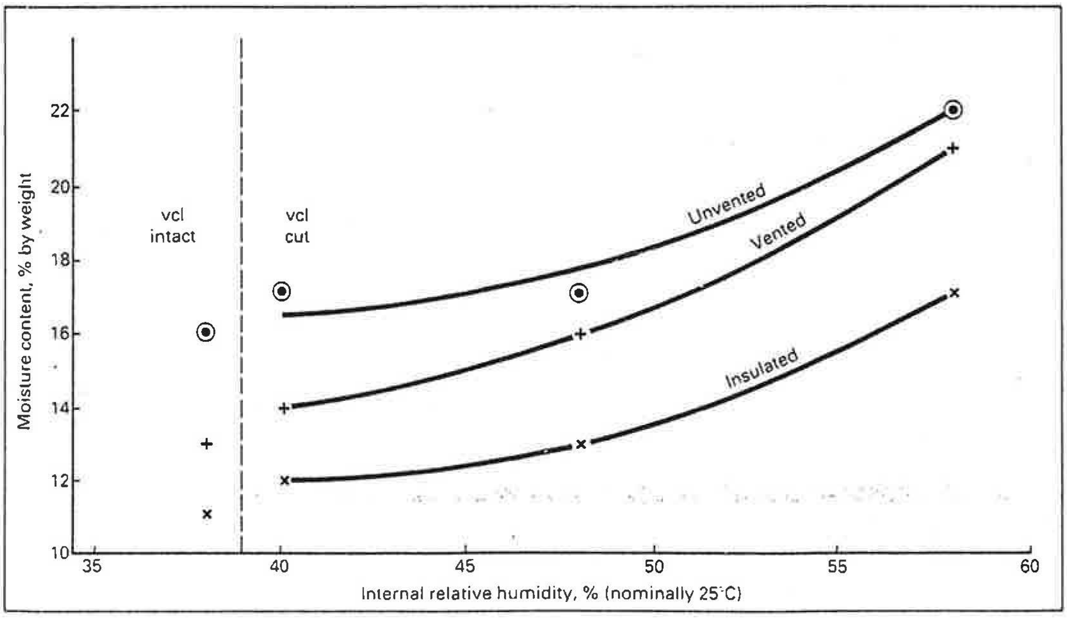


Figure 5 (top)
Effect of internal relative humidity on humidity at sheathing opposite damage for various constructions.

Figure 6 (above)
Effect of internal relative humidity on moisture content of sheathing opposite damage for various constructions.

Figure 7 (left)
Effect of internal relative humidity on moisture content of soleplate for various constructions.

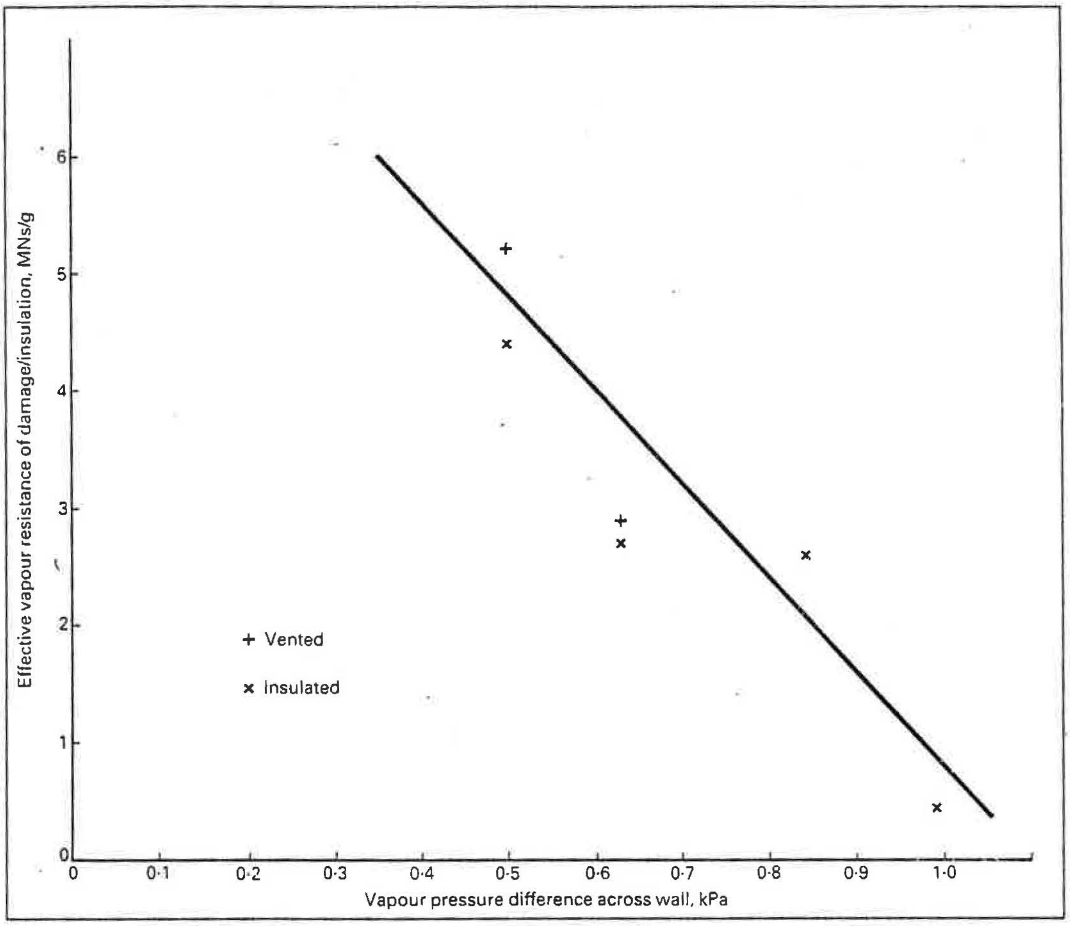


Figure 8
Effect of vapour pressure on effective vapour resistance of damage/insulation.

the unvented and vented panels; all was dry around the insulated panel soleplate area.

At the header joist positions, all appeared dry except for a quantity of water trapped between the cavity barrier and the breather paper at the unvented panel.

■ DISCUSSION OF THE RESULTS

The results show that there are no interstitial condensation problems created by decreasing the U-value of the wall by filling the main cavity with mineral wool; in fact, a large safety margin is built in as regards moisture problems. In the case of serious damage to the vcl and plasterboard, any risk of interstitial condensation is dramatically reduced and, whether or not there is damage, the humidity levels which the timber is exposed to are similarly reduced. The net result is lower moisture levels in the timbers.

Although a big safety margin is produced by the insulating of the main cavity, it is difficult to relate the results of the accelerated tests directly to more normal conditions. Thus an attempt has been made to translate the results to the Draft Code conditions.

Analysing the effects of damage to a vcl is complex. The temperature gradient is distorted in the vicinity of the hole, probably due to airflow because of the pressure difference across the wall; the proportional conversion should be approximately correct for a wall with a similar pressure difference.

From the measured equilibrium vapour pressures at the sheathing and a knowledge of the vapour resistance of the exterior part of the wall, an effective vapour resistance for the damaged vcl/plasterboard/insulation can be calculated appropriate to the conditions at the sheathing opposite the damage, for each interior vapour pressure. Figure 8 shows the results of this from all suitable experiments.

The resistance is not constant but there appears to be a relationship between it and the vapour pressure drop across the wall. It shows that at high vapour pressure differences, the standard damage is equivalent to the extreme of having no vcl (but intact plasterboard) as regards the sheathing opposite the damage. At lower vapour pressure differences, the effect is only a little less serious.

Using the resistance/vapour pressure relationship and the temperature gradient conversions, internal humidities have been calculated for various humidities at the sheathings for the Draft Code conditions of 5°C, 95% rh outside and 15°C inside. Figure 9 gives the results of the calculations.

The very clear safety margin is again shown as a result of improving the thermal performance: a 15 percentage points of interior relative humidity safeguard over the conventional vented construction.

It must be stated again that in no way is it suggested that the vcl is omitted, even though the insulated construction would be satisfactory without it with reasonable moisture levels in a house.

Because of variations in interior moisture levels and because of the hygroscopicity of timber in high humidity conditions, the vcl still serves a major role in controlling moisture flows.

Figure 9 shows that with the standard damage the internal humidities necessary to produce a particular condition at the sheathing do lie between those expected for no vcl and for a perfect vcl.

Moisture and condensation in the main cavities

The temperatures measured in the unvented and vented cavities were similar for the same environmental conditions. The vapour pressures in the vented cavity were less than in the corresponding unvented cavity (unless 100% rh was achieved), but were generally greater than the external value — thus conditions encountered in the vented cavity were somewhere between those defined for vented and those calculated for unvented constructions.

Thus, the large difference found between unvented and vented constructions in the experiments is even more surprising than indicated by the initial predictions. Certainly, venting of the cavity looks essential in the absence of the extra insulation, although the magnitude of the effect at normal conditions is not known.

The wet sheathing and condensate on the brickwork of the unvented panel confirm that two planes of condensation, as predicted by calculation, can exist in practice. The dry sheathing and the condensate on the brickwork of the insulated panel confirm the indications of the calculation procedure.

Moisture in the soleplates

The tests showed that soleplate moistures are much lower when the extra insulation is included as compared to the conventional vented construction, with a reduction of up to four percentage points by weight.

The water found between the dpm and the dpc in the unvented and vented panels is of prime concern here. It would be formed by a combination of the cold bridge effect of the solid floor and the fact that there is a route between the wall and floor vcl's through which moisture vapour can flow (either by diffusion or by transport in a moist air flow). The beneficial effect of the extra insulation is because of the reduction in the cold bridge, but consideration must also be given to limiting the vapour flow by overlapping and sealing the vcl's.

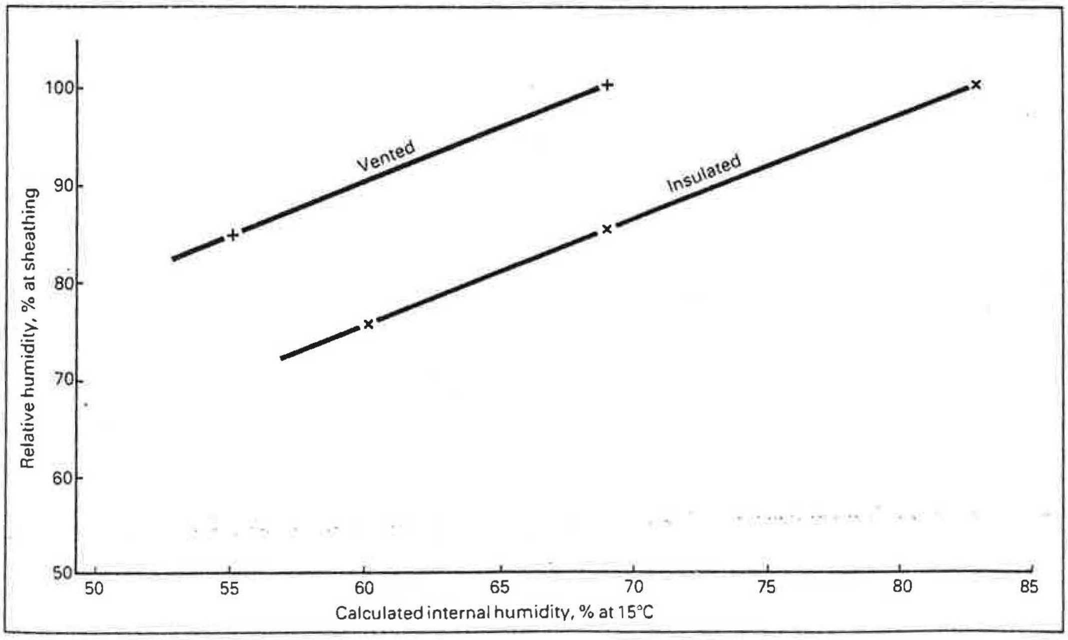


Figure 9
Predicted relationship between relative humidity at sheathing opposite damage and internal humidity for various constructions.

It is thought that the condensate found would not affect the timber moistures in the experimental rig, but in practice, when the soleplates are bedded in mortar which is likely to overlap the dpc, that could act as a direct wick from dpm to timber. This could be the mechanism responsible for some high moisture levels in soleplates which have not been previously explained (Ref 5).

Header joists

High moisture contents do not seem to be a problem in practice. This is borne out by the experiments, but under very adverse conditions the extra insulation could be beneficial.

The extra insulation would remove the necessity to install cavity barriers at this level, which would in turn remove any possible condensation risk associated with the polythene sleeving.

Upgraded Scottish houses

The experimental results support the findings of the BRE (Ref 6) which examined timber framed houses which had been upgraded by insulating the main cavities, contrary to NHBC rules. It found that the upgrading had made the houses easier to heat and had reduced surface condensation problems; it found no evidence of disadvantages resulting from the cavity fill.

■ CONCLUSION

The addition of mineral wool insulation to the main cavity of a conventional timber framed construction to improve its thermal performance also builds in a large safeguard against interstitial condensation which might result if there were serious damage to the vcl. Local humidities in the structure and moisture contents of sheathing and soleplates are reduced.

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