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PILKINGTON RESEARCH AND DEVELOPMENT
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The calculation of interstitial condensation risk

Abstract
—The British Standard Code of Practice for the Control of Condensation, BS 5250: 1975, has been revised and was published in June 1989[1]. It contains the combined latest knowledge and best views available on the subject and its 120 pages should prove to be much more useful than the 1975 version of only 27 pages. One considerably expanded section is the appendix dealing with the prediction of interstitial condensation risk during winter conditions, replacing the existing procedure which predicts condensation zones and which can be very misleading.

The procedure laid down in BS 6229, the Flat Roof Code[2] and the procedures given in the CIBSE Guide A10[3] differ from the revised version of BS 5250 but are retained as current methods.

This article illustrates the use and difficulties of the BS 5250: 1989 procedure and shows that the others will give very misleading results in some circumstances.

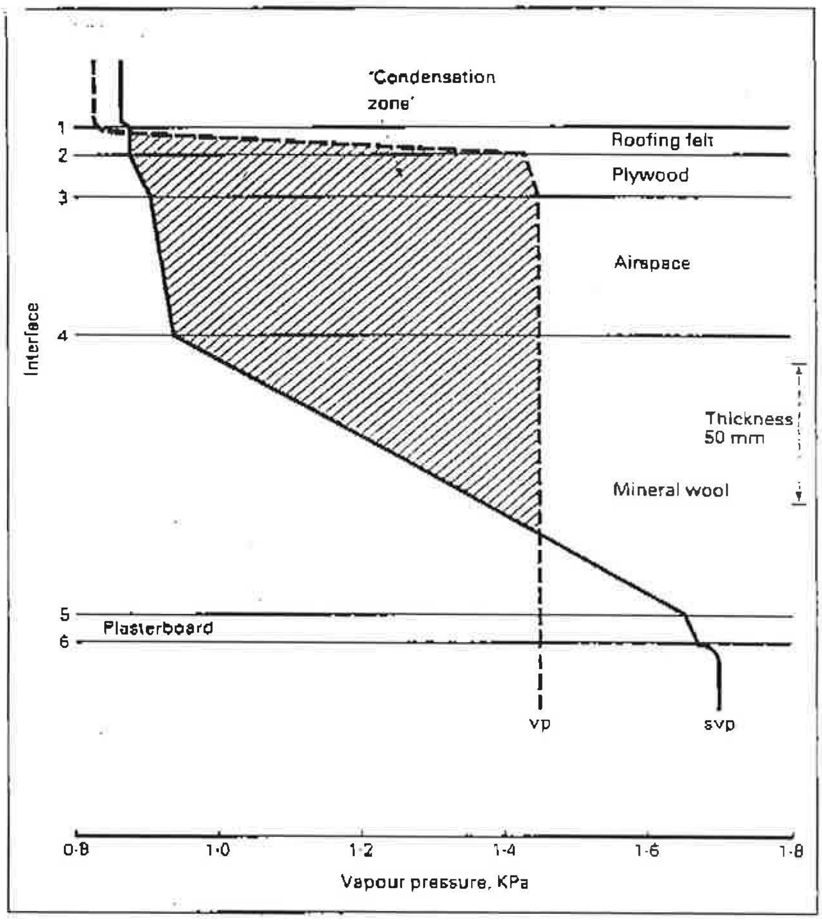


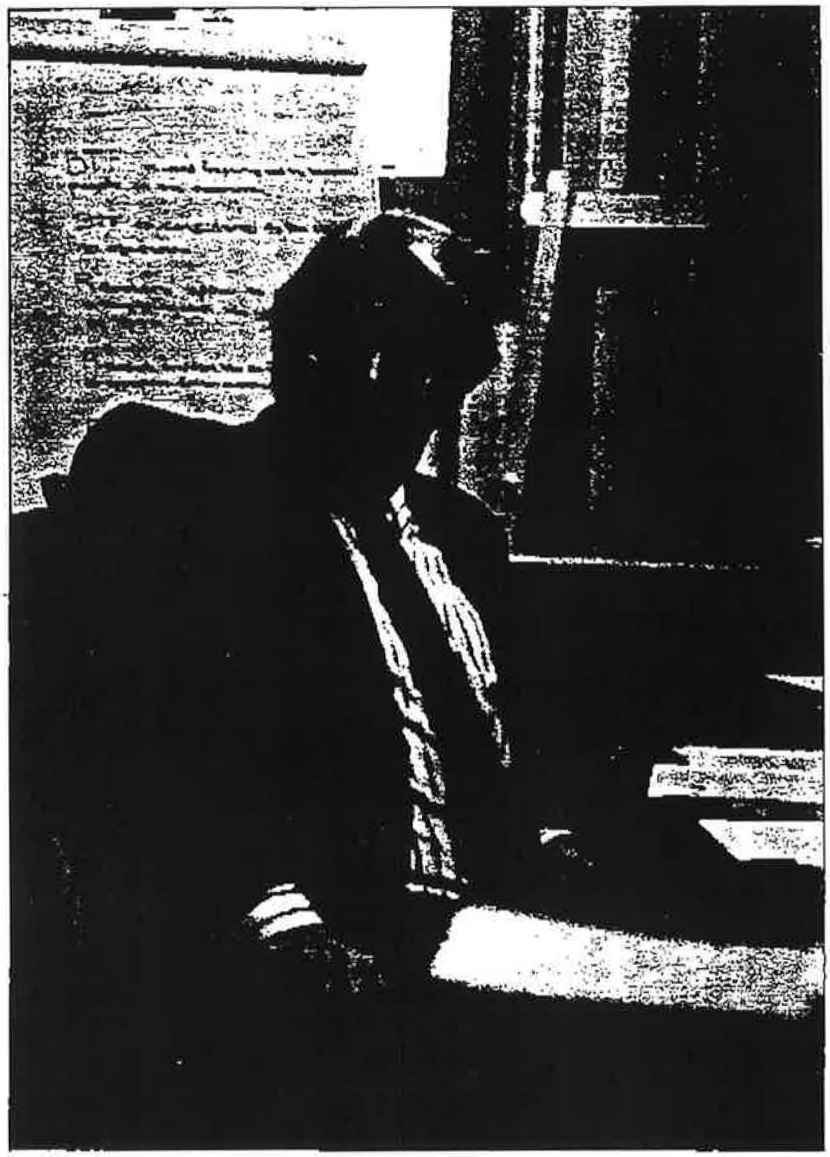
Figure 1
svp and vp curves from BS 5250 : 1975.

■ OUTLINE OF CALCULATION PROCEDURES

All procedures start with the method given in BS 5250: 1975[4], namely the calculation of the temperature and dew point profiles through the construction. The trend now is to use saturated vapour pressure (svp) instead of temperature, and vapour pressure (vp) rather than dew point: the diagrams produced are identical but with different units, eg. see Figure 1.

If the vp is below the svp throughout the construction, there is no condensation risk and all the methods of prediction listed above are in agreement. If there is an overlap of the profiles producing the original BS 5250 "condensation zone", again there is agreement that there is an interstitial condensation risk. BS 5250: 1975 indicated that any material within this zone would be at risk, but that idea is now generally considered wrong and many papers have been published[5] explaining this.

The construction will often consist of a number of layers of materials and it is usually only at the interfaces between these layers that condensation will occur. If



Dargan Bullivant's opinion is that "since 1979, under European law, there are no technical barriers to trade."

France, West Germany and the UK but the test methods are different."

This was the right approach for CEN to adopt, said Chemillier.

Ivan Dunstan said there was no reason why CEN could not adopt a flexible approach by say, employing a consultant to undertake the first draft of the European standards.

Finally Peter Hewlett was asked if he was encouraged by the responses from the Advisory Panel.

His answer was affirmative but cautioned. "I don't think there is any room for complacency. I am encouraged that CEN is being managed and is being driven by industry.

"There are going to be products which could go to CEN but this may not be possible for several years and therefore they will have to go along the technical approvals route.

"Therefore the organisations responsible for these options have got to be in place and set up in such a way that they harmonise with one another. What however, is rather sad, is that there is no push nor any demands being made for this alternative other than from self-interested groups such as the BBA who seek commercial opportunity and are driving the process along and offering a service which is going to be needed. Perhaps that is sufficient.

"But I feel we in turn should be driven ourselves" said the BBA director "and therefore I question whether there is, as yet, a cohesive national strategy. We are at a very formative stage.

"What I would like to see is a schedule of events to take us up to at least 1992 so that we can see where there is completion, where there is an alternative option, where there is a gap, and what is the fallback position.

"The industrial base, I am sure, would welcome that because it would give them a framework on which to respond. At the moment, much of what we have discussed is really the private knowledge of a very few people."

only one of the interfaces corresponds to the predicted condensation zone then that is where the condensation will occur and all the methods will predict the same quantity of condensate except BS 5250: 1975 which does not have a quantitative procedure.

If the condensation zone contains more than one interface, differences in the methods appear and show up fundamental problems in the BS 6229 and CIBSE A10 procedures. Accordingly, the example chosen to illlustrate the calculation methods is a cold deck flat roof with no vapour control layer (vcl) nor ventilation.

This is considered under conditions corresponding to a moist/wet occupancy as suggested in BS 5250: 1989. One would be ill advised to build such a roof, but it is chosen because the svp and vp profiles overlap indicating some interstitial condensation risk. There are three interfaces corresponding to the overlap, which must be considered as potentially at risk, Figure 1.

The calculation methods are now dealt with separately, followed by some comments on the use of the latest method.

BS 5250: 1989

The new Condensation Code suggests a four-stage procedure:

1) calculation of thermal and vapour conditions at interfaces (effectively as BS 5250: 1975);
2) determination of planes of condensation using a graphical technique;
3) calculation of condensation rates;
4) assessment of results.

1) A worksheet is provided and Table 1 shows this completed for the chosen example. Values for resistivity or resistance are taken from the Code. Where necessary, resistances are calculated from resistivities by multiplicating by the material widths. Interface temperatures are calculated from the formula for the nth interface:

$$tn = te + \frac{(ti - te).\ Rtn}{Rt}$$ (symbols as per the worksheet)

Table 1: Calculation worksheet

CONSTRUCTION	UNVENTILATED COLD DECK FLAT ROOF WITH NO VCL

EXTERNAL CONDITIONS	(te) 5°C
INTERNAL CONDITIONS	(ti) 15°C

INTERFACE	MATERIAL	WIDTH m	THERMAL RESISTIVITY mK/W	THERMAL RESISTANCE m²K/W	CUMULATIVE THERMAL RESISTANCE	INTERFACE TEMPERATURE °C	SATURATED VAPOUR PRESSURE kPa
EXTERIOR					0	5.00 te	0.87 pse
	EXTERNAL SURFACE			0.04			
1					0.04 Rt1	5.13 t1	0.88 ps1
	ROOFING FELT	0.010	2.00	0.02			
2					0.06 Rt2	5.20 t2	0.88 ps2
	PLYWOOD	0.015	7.00	0.11			
3					0.17 Rt3	5.57 t3	0.91 ps3
	AIRSPACE	0.050	—	0.17			
4					0.34 Rt4	6.13 t4	0.94 ps4
	MINERAL WOOL	0.100	25.00	2.50			
5					2.84 Rt5	14.47 t5	1.65 ps5
	PLASTERBOARD	0.010	6.00	0.06			
6					2.90 Rt6	14.67 t6	1.67 ps6
	INTERNAL SURFACE			0.10			
INTERIOR					3.00 ∑Rt	15.00 ti	1.70 psi

Corresponding svp's are then found from tables.

2) The svp for each interface is plotted against the cumulative vapour resistances of the materials (not their thicknesses), Figure 2. A straight line is then drawn from the internal to the external vp. In this case the line overlaps the svp line, therefore a risk exists. Next, this vp line is redrawn by "a series of straight lines of minimum length without crossing the svp line". This clearly touches the svp line at interface 2.

That interface between felt and plywood is considered to be at risk. The vp line also touches the svp line at one or more of the interfaces 3, 4, 5 and 6, but since these are virtually coincident on the diagram, it is not possible to determine which. (Figure 1 has already indicated that there is no risk at interfaces 5 and 6.)

The next stage is to redraw the right hand part of Figure 2 in enlarged form as shown in Figure 3. The redrawn "minimum length" vp line touches the svp line at interfaces 3 and 4, in addition to the already identified

95 %RH	VAPOUR PRESSURE (pe)	0.83 kPa

85 %RH	VAPOUR PRESSURE (pi)	1.45 kPa

VAPOUR RESISTIVITY MNs/gm	VAPOUR RESISTANCE MNs/g	CUMULATIVE VAPOUR RESISTANCE	INTERFACE
		0	EXTERIOR
	0		
		0 Rv1	1
—	1000		
		1000 Rv2	2
2000	30		
		1030 Rv3	3
5	0.25		
		1030.25 Rv4	4
7	0.70		
		1030.95 Rv5	5
60	0.60		
		1031.55 Rv6	6
	0		
		1031.55 $\sum Rv$	EXTERIOR

interface 2. Thus condensation is predicted at the felt/plywood, plywood/airspace and the airspace/insulation interfaces. It should also be noted that the svp and vp lines are coincident across the thickness of the plywood (and the airspace) which means that condensation can be expected within the thickness of the material — this is unusual in practice and is discussed later.

3) The condensation rates are then calculated for each of the three interfaces using the formulae given in the Code, repeated below. Symbols again are as per the worksheet and calculated rates are in g/m^2. 60 days.

$$QA - 5184 \left(\frac{psB - psA}{RvB - RvA} - \frac{psA - pe}{RvA}\right)$$

$$QB - 5184 \left(\frac{psC - psB}{RvC - RvB} - \frac{psB - psA}{RvB - RvA}\right)$$

$$QC - 5184 \left(\frac{pi - psC}{\sum Rv - RvC} - \frac{psC - psB}{RvC - RvB}\right)$$

Condensation is predicted at interfaces 2, 3 and 4, thus A=2, B=3, C=4. Hence:

$$Q2 - 5184 \left(\frac{0.91 - 0.88}{1030 - 1000} - \frac{0.88 - 0.83}{1000}\right) - 5g/m^2.\ 60\ days$$

$$Q3 - 5184 \left(\frac{0.94 - 0.91}{1030.25 - 1030} - \frac{0.91 - 0.88}{1030 - 1000}\right) - 617g/m^2\ 60\ days$$

$$Q4 - 5184 \left(\frac{1.45 - 0.94}{1031.55 - 1030.25} - \frac{0.94 - 0.91}{1030.25 - 1030}\right) - 1412g/m^2\ 60\ days$$

4) It is very obvious that this construction is unacceptable with condensation levels as above predicted at both sides of the plywood and on top of the insulation.

There are two important claims for the validity of this method. The first is that all vapour flows, vapour pressures and vapour resistances are in balance and are consistent with each other throughout the construction. The second is that the vp is always below or equal to the svp at any point. These claims cannot always be made for the other methods described in this paper.

■ BS 6229

In the following example, the values used for internal and external conditions are again those suggested in BS 5250: 1989 rather than those in BS 6229 because of the need for comparison of the methods. The procedure is again in four stages:

1) determination of svp and vp curves for winter conditions;
2) if there is an overlap, the calculation of winter condensation rates;
3) calculation of summer evaporation rates;
4) assessment of results.

The calculation of the summer evaporation

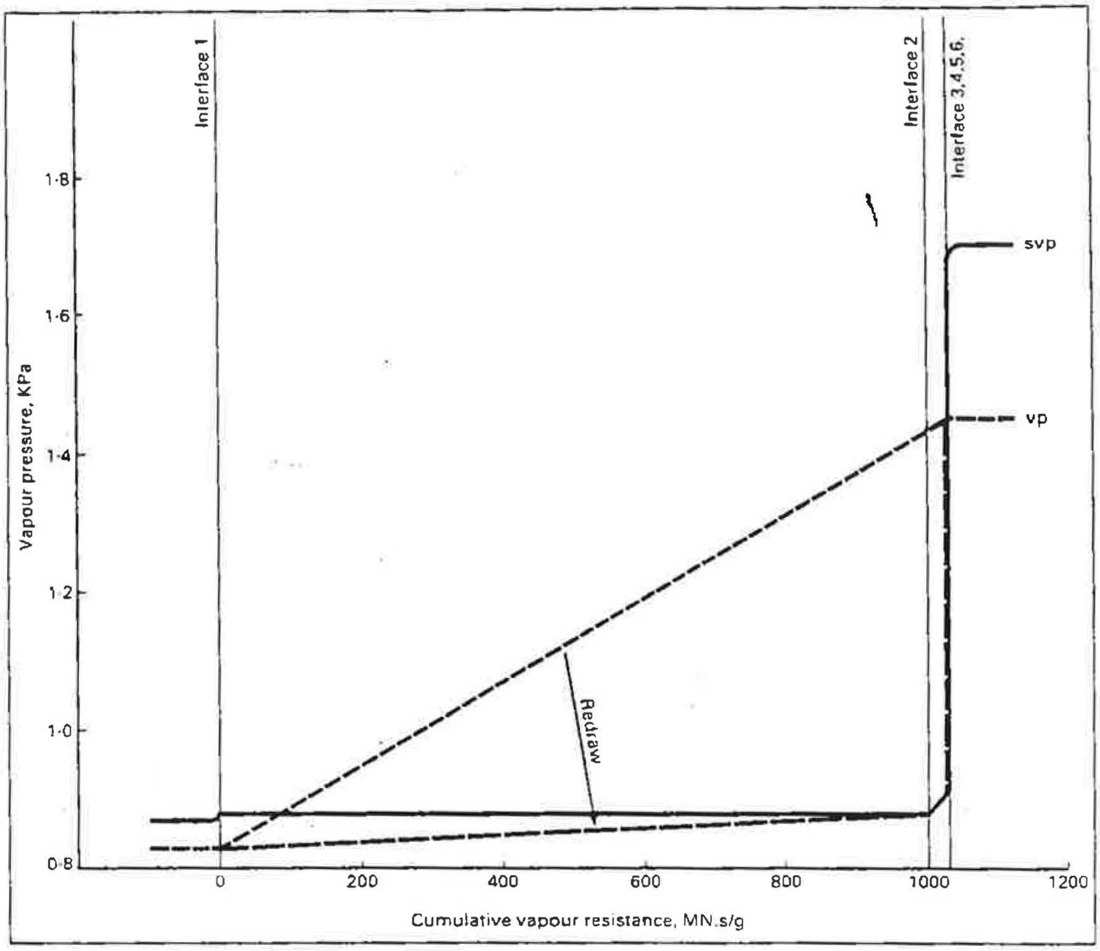


Figure 2
Graphical determination of condensation planes — first stage.

rates and hence the assessment of results are beyond the scope of this paper, which deals only with winter condensation.

1) As already shown in Figure 1, there is an overlap of the svp and vp curves and the Code states that condensation is indicated.

2) The Code then states that "the position at which the maximum extent of condensation would occur should be noted; this is indiicated by the maximum difference in saturated and actual water vapour pressures at one of the interfaces". In this example, this is interface 2 between felt and plywood. The amount of condensate is then calculated for this interface from a formula. Here, this has been transposed to use vapour resistances rather than equivalent air thicknesses, and symbols as per the worksheet, Table 1.

For interface A, condensation in g/m². 60 days is obtained from:

$$QA = 5184 \left(\frac{pi - psA}{Rv - RvA} - \frac{psA - pe}{RvA} \right)$$

Interface A in this case is interface 2, so

$$Q2 = 5184 \left(\frac{1.45 - 0.88}{1031.55 - 1000} - \frac{0.88 - 0.83}{1000} \right) = \frac{93 g/m^2}{60 \text{ days}}$$

This is all one is instructed to do before the summer evaporation procedure and an example is then given. In this, two statements are made.

First, condensation is indicated at an interface when the vp is equal to, or apparently greater than, the svp.

Second, when condensation occurs at more than one point (in the roof), the interface of maximum condensation is when the svp — vp difference is a maximum. The example then states that "this criterion is only relevant for the purpose of locating the interface(s) of condensation..." However, it does not indicate what to do with this information and so one is left only with the calculation of the amount of condensation for the interface 2 as above. This presumably represents the total winter condensation calculation.

This figure thus calculated is incorrect and the total result is very different to that from the BS 5250: 1989 method. The vapour pressure drop to the interface has been taken as the difference between internal vp and the svp at the interface, which ignores the fact that under those conditions, the vp at interface 3 and 4 would be above the svp. Calculations must consider the effect of this.

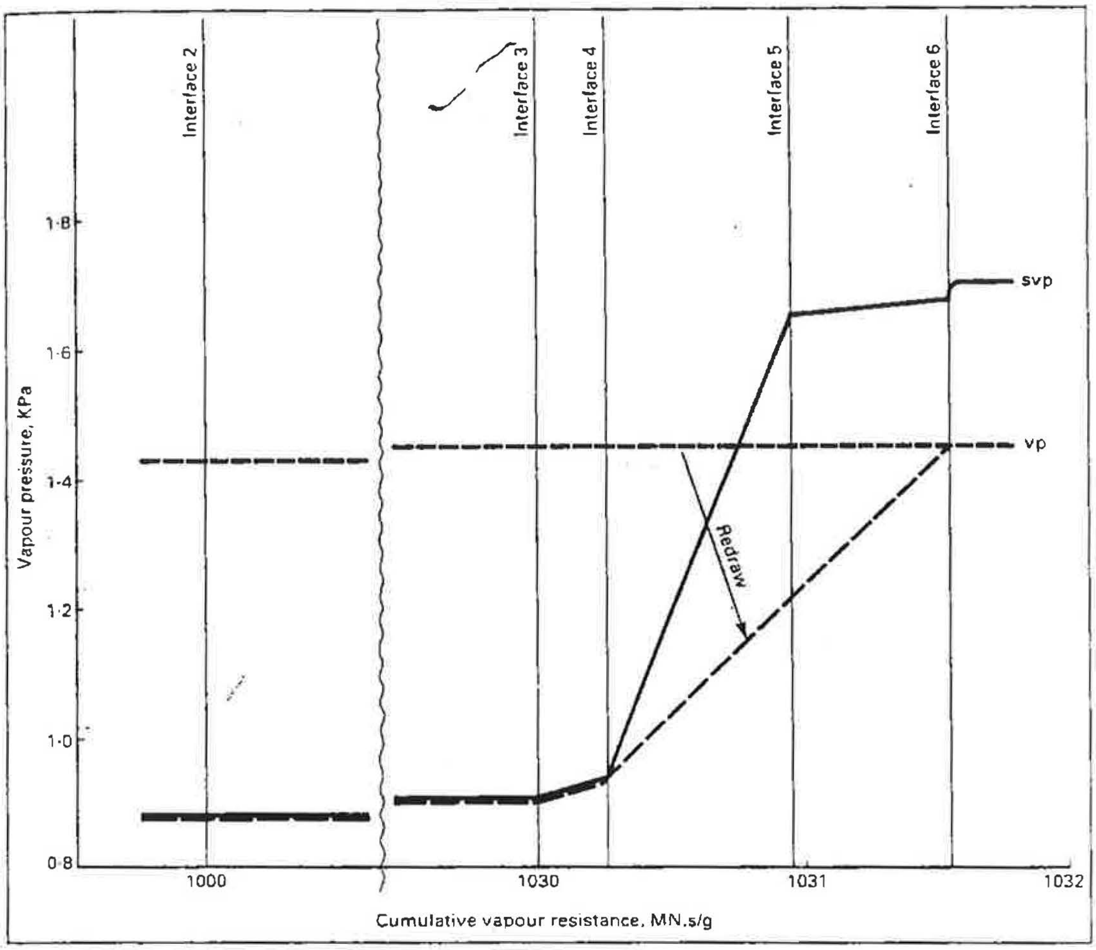


Figure 3
Graphical determination of condensation planes — second stage.

The example chosen here also clearly shows that the maximum condensation does not necessarily correspond to the maximum svp — vp overlap. All three "indicated" positions are subject to condensation, but this is not a general rule either; for example, a timber framed construction with no vcl[6] often has four interfaces corresponding to the overlap zone, but calculation of flow rates by BS 5250: 1989 can show only one actually at risk.

■ CIBSE A10

There are two procedures set out in A10, one using a straight calculation and the other using a graphical solution. Both start by determining the svp and vp at each interface effectively as in BS 5250: 1975. It is then stated that "if the calculated vapour pressure exceeds the saturated vapour pressure at a particular surface, condensation will occur at that surface". This is not necessarily true as stated above.

1) *Straight calculation* The instruction is given that if condensation is indicated then "the calculation must be repeated using the value of the saturated vapour pressure". For the flat roof example this is correct, but not for the timber framed construction referred to above.

Howevever, no information is given on how to calculate for more than one affected interface (except in the graphical method, see later). The Guide example has only one interface at risk.

Couple this with the statement that excess moisture condenses out at a particular surface where the calculated vp exceeds the svp by the greatest amount and one might be misled into a calculation using the formula for one interface. This would be even more likely if one was familiar with BS 6229. For the cold deck flat roof this calculation is then identical to the BS 6229 procedure, giving 93g/m². 60 days between felt and plywood.

One might also be misled with the A10 example because there are some incorrect numbers in the calculation and the vp curve in the diagram has not been redrawn in the correct position following the changing of vp to svp at the condensation interface.

There is in addition a paragraph referring to negative rates of condensation, which only makes sense if one knows

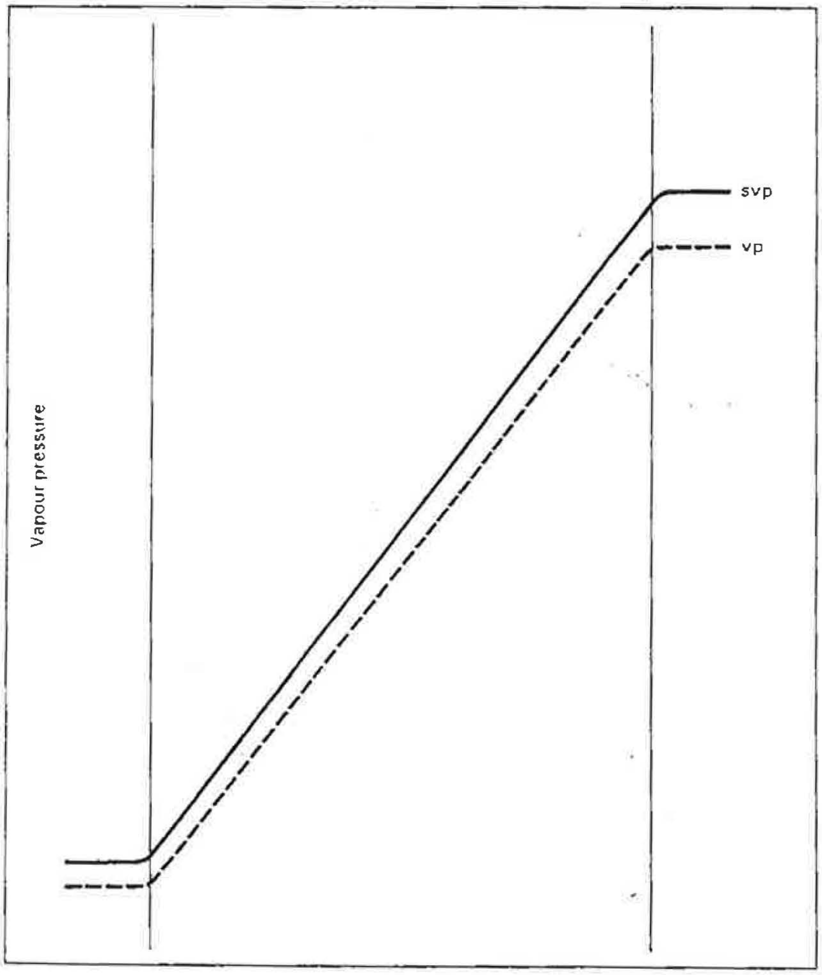
Table 2: Comparison of predictions from various sources for unventilated cold deck — flat roof with no vcl.

Interface	Figures are g/m² for a 60 day period			
	New BS 5250	BS 6229	CIBSE	CIBSE-graphical
Roofing felt/ plywood	5	93	93	93
Plywood/ airspace	617	—	—	1806
Airspace/ mineral wool	1412	—	—	2033
Mineral wool/ plasterboard	—	—	—	—

how to do calculations on a multi-interface zone where vp's have been put equal to svp's, for example the timber framed case again.

If negative rates are found, one is told to recalculate vapour flows using "equilibrium values" of vapour pressure, but what this means is not explained. In fact, a correctly calculated negative condensation rate means that condensation will not occur at that interface which then contradicts the stated rule about condensation at all surfaces within the overlap zone.

Figure 4
svp and vp curves from BS 5250 : 1989.



2) *Graphical method* This commences by plotting a graph of the svp at each interface of the construction against the (cumulative) vapour resistance of the elements. A line is then drawn to connect the internal and external vp points with straight lines such that no overlap occurs of the svp line: condensation is therefore predicated at each interface where the lines touch, exactly as in BS 5250: 1989.

One is then instructed to determine the rates of condensation at each point so affected by taking the difference in rates of moisture transfer "from inside to the point of condensation" and "from the point of condensation to the outside"

In the example quoted in A10 this is correct since there is only one condensation plane predicted; in the flat roof example with three planes affected, wrong rates are predicted, Table 2.

The reason is the same as for the BS 6229 procedure: when taking the vp differences, the vp has effectively been left above the svp in part of the construction and so the calculation is incorrect.

■ POINTS ABOUT BS 5250: 1989

1) *Curved svp lines* In all the discussions so far, it has been assumed that svp lines are straight throughout each element of a construction. Although the temperature drop through each element is linear, svp lines should in fact be curved. This is only of any consequence

if the corresponding vp line is near to the svp line.

Figure 4 shows such a situation where the svp line is straight and clearly no condensation is indicated. The calculation procedure can be used here by subdividing any element thought to be at risk into a number of equal parts, and considering the interfaces so created. Figure 5 shows the svp curve corrected (but exaggerated) in this way and clearly a risk condition exists within the material.

If this situation is encountered, the whole construction should be recalculated. Suspect elements should be subdivided, because the change of vp within the element will affect vp's elsewhere.

However, such high humidities should rarely be encountered in practice and if they are, the construction is probably unacceptable anyway. The exception is the outer brickwork of a construction which often has high humidities either side of the brick. The amount of condensate expected on or within the brick is small compared to wetting by rain and is therefore inconsequential.

2) *High/low resistance interfaces* It is perhaps logical to expect condensation to occur when moisture has diffused through a material of low resistance and then meets a surface of a high resistance material. This is usually the case, but not necessarily so. In the flat roof example, it was shown that condensation is expected on the outer surface of the insulation next to the air layer which is of lower resistance.

3) *Effect of high relative humidity* In assessing the suitability of a construction, the amount of condensate should not be the only factor considered. Absorbent materials which are predicted to be in a high humidity may degrade without any condensation occurring; humidity can be calculated from the vp and svp values read from the vp-resistance graph.

4) *Vented or ventilated cavities* The procedure can be used to give some indications of the effect of venting any cavity and is best explained by reference to the extreme conditions.

If there is a high level of ventilation sufficient to keep the air in the cavity at the same temperature and moisture content at that of the outside air (termed fully ventilated), then usually risk is removed from the cavity but at the expense of increased risk in the inner parts of the construction.

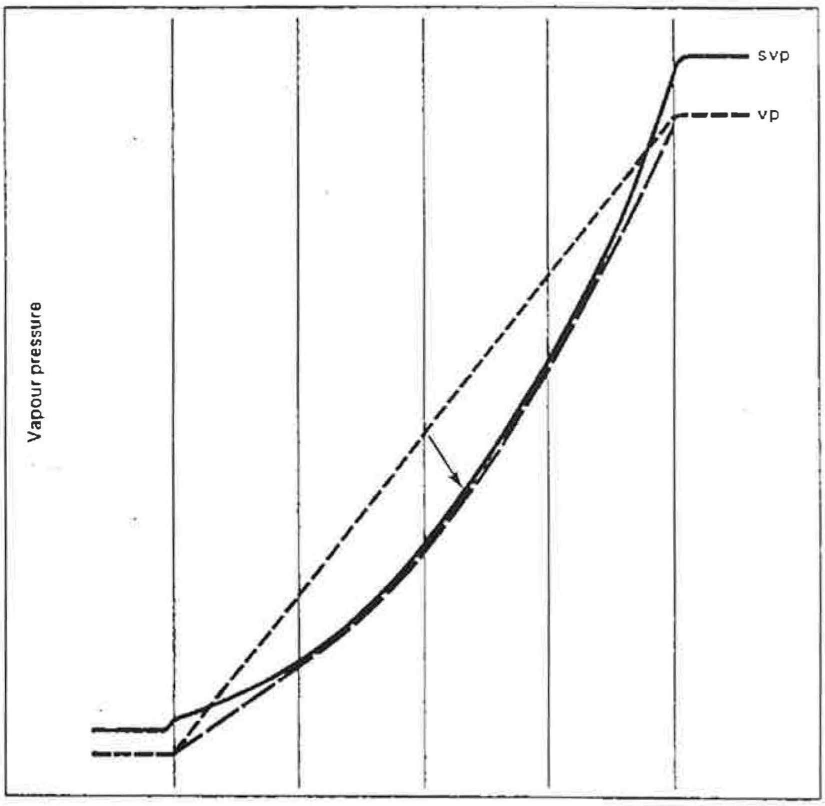


Figure 5
Effect of splitting element into four equal parts on svp and vp (svp curve is exaggerated).

In the calculation procedure, this is simulated by setting the vapour and thermal resistances of the cavity and all materials to the outside of it at zero, leaving the external surface resistance which is effectively moved to the inner face of the cavity.

If there is a level of ventilation sufficient to keep the moisture content in the cavity equal to that of the outside air but not high enough to destroy the insulating effect of the cavity air (and hence of materials to the outside of the cavity), then condensation risk is generally reduced throughout the construction. This is thought to be the mechanism by which open perpends in brickwork reduce risk. This is termed vented and is simulated by setting the vapour resistances (only) of the cavity and materials to the outside to zero.

In practice, one can expect a situation somewhere between non-vented and fully ventilated or vented and the procedure can be used to determine the effects and sensitivity of the construction to such effects.

REFERENCES

1. BS 5250: 1989. British Standard Code of Practice: the Control of Condensation in Buildings (publication expected June 1989).

2. BS 6229: 1982. British Standard Code of Practice: Flat roofs with Continuously Supported Coverings.

3. CIBSE Guide A10. The Chartered Institution of Building Services Engineers Guide, Section A10: Moisture Transfer and Condensation.

4. BS 5250: 1975. Code of Basic Data for the Design of Buildings: the Control of Condensation in Dwellings.

5. Interstitial Condensation. *Building Technical File,* Number 8, January 1985. K A Johnson.

6. Improving the Thermal Performance of Timber Framed Walls. *Building Technical File,* Number 21, April 1988. K A Johnson.

5) *Calculation accuracy and negative rates* The method of calculation is precise and this could create a false sense of accuracy in the condensation prediction. When interpreting the results it must be remembered that the vapour property values vary considerably depending on the source of the information and the test methods which use very different conditions from those found in practice.

Calculations are for constant average conditions which are proposed in the new Code and are thought to represent what will happen over a winter period. In practice, conditions vary from day to day and even day to night, so condensation may be expected for short periods even if not predicted by the procedure.

Another problem which occurs is associated when decimal place corrections are made to numbers within the calculation. It is suggested that corrections are made as per the example in the new Code. Corrections at other times can produce great differences in the final condensation rate numbers due to the taking of differences between similar large numbers in the calculations.

In the procedure it is possible to make a mistake in determining if the vp line touches the svp line at a particular interface. If it is taken as touching, when it does not, then a negative condensation rate will be produced for that interface. It is then necessary to recalculate completely, omitting the interface in question.

■ CONCLUSIONS

BS 5250: 1989 provides a calculation procedure for determining condensation planes and quantities. In absolute terms it is probably at best only a rough guide, but it is particularly useful in predicting the effect of a change or the sensitivity of a construction to a change. The procedures in BS 6229 and the CIBSE Guide produce incorrect results in some circumstances.