Analysis of the risk of condensation in pitched roofs with sprayed polyurethane and mineral wool insulation

Produced for BUFCA

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1. Introduction

The British Urethane Foam Contractors Association (BUFCA) represents contractors who spray polyurethane foam insulation on the underside of the covering (slates or tiles) of pitched roofs. Besides stabilising the roof covering, the polyurethane foam, in combination with mineral wool laid on the ceiling, provides a high level of insulation to the roof. Concerns have been raised that, because the mineral wool is limiting heat from entering the loft, the lower surface of the polyurethane foam may be cold enough to promote condensation.

This report describes the background to the methods used to assess the risk of condensation in pitched roofs, the choice of appropriate boundary conditions and discusses the implications for the chance of problems occurring when sprayed polyurethane insulation is used in conjunction with mineral wool.

2. Assessment of Condensation risks

2.1 Condensation and Regulations

All three sets of Building Regulations in the UK contain similar requirements for the protection of buildings from the effects of condensation. For example the requirements of the 2004 Edition of Approved Document C 2004 includes:

> **C2.** The floors, walls and roof of the building shall adequately protect the building and people who use the building from harmful effects caused by:
> (a) ground moisture;
> (b) precipitation and wind-driven spray;
> (c) interstitial and surface condensation;
> (d) spillage of water from or associated with sanitary fittings or fixed appliances.

The requirement for resistance to interstitial condensation in roofs is expressed in clause 6.10 of the Approved Document:

> **Roofs (resistance to damage from interstitial condensation)**
>
> **6.10** A roof will meet the requirement if it is designed and constructed in accordance with Clause 8.4 of BS 5250:2002[1] and BS EN ISO 13788:2001[2]. Further guidance is given in the BRE Report BR 262[3].

The corresponding regulations in Scotland and Northern Ireland contain essentially the same clauses.

BS5250:2002 contains discussion of the principles of condensation formation and protection and provides detailed guidance for the design of different roof types to minimise problems of condensation. It is recommended that the risks of condensation are assessed using the calculation procedures specified in BS EN ISO 13788:2001.

The BS13788 procedure for interstitial condensation assessment takes monthly mean values of the internal and external climate and calculates whether there is any accumulation of condensate at one or more interfaces within the structure in the winter, and then whether the condensate dries out in summer.

There are three possible outcomes from the calculation:

a) No condensation predicted at any interface in any month
In this case the structure is reported as being free of interstitial condensation.

b) Condensation occurs at one or more interfaces but, for each interface concerned, all the condensate is predicted to evaporate during the summer months.
In this case the maximum amount of condensation that occurred at each interface, and the month during which the maximum occurred are reported. The risk of degradation of building materials and deterioration of thermal performance as a consequence of the calculated maximum amount of moisture shall be considered according to regulatory requirements and other guidance in product standards.

c) Condensation at one or more interfaces does not completely evaporate during the summer months.
In this case the structure has failed the assessment, and the maximum amount of moisture that occurred at each interface together with the amount of moisture remaining after 12 months at each interface is reported.

It is not uncommon for assessments of structures to produce outcome b), i.e. there is some condensation predicted, and it is then necessary to decide whether this is likely to cause problems. This reflects the whole philosophy behind BS 5250:2002 and consequently the Regulations. The whole Code of Practice was drafted with the assumption that condensation cannot be prevented under all circumstances, but its effects can be minimised by good design. A prediction of a small amount of condensate does not necessarily constitute a failure.

2.2 Assessment of interstitial condensation in cold pitched roofs

Assessment of the risk of interstitial condensation in cold pitched roofs, i.e. roofs with insulation on a horizontal ceiling, is particularly difficult and has lead to a considerable amount of controversy in recent years. The problems are caused by the importance of airflows into the loft from the house below and through the loft from the outside. In a typical house, about 20% of the air that enters via the doors and windows leaves via the gaps in the ceiling carrying heat and water vapour with it. About 50% of the heat transfer and 80% of moisture transfer from a house to its loft goes by air movement, with the remainder going by conduction and diffusion respectively.

This has lead to problems because the Scope of the calculation standard BS EN ISO 13788: 2001 specifically excludes any structures in which airflows play a significant role i.e.

> ***1. Scope***
>
> *This standard gives calculation methods for:*

a) The internal surface temperature of a building component or building element below which mould growth is likely, given the internal temperature and relative humidity – the method can also be used to assess the risk of other surface condensation problems.

b) The assessment of the risk of interstitial condensation due to water vapour diffusion. The method used assumes built-in water has dried out and does not take account of a number of important physical phenomena including:
- the dependence of thermal conductivity on moisture content;
- the release and absorption of latent heat;
- the variation of material properties with moisture content;
- capillary suction and liquid moisture transfer within materials;
- air movement through cracks or within air spaces;
- the hygroscopic moisture capacity of materials.

Consequently the method is applicable only to structures where these effects are negligible.

Attempts have been made to develop alternative methods – see BRE IP 4/06[4] and IP 5/06[5] and a BS Code of Practice for airtight ceilings BS 9250[6], has been developed. However there is at present no accepted method for assessing the risk of condensation in cold pitched roofs.

2.3 Roofs with Sprayed Insulation

If a layer of polyurethane insulation has been sprayed onto the underside of the roof covering and into the eaves, it is assumed that this will seal the roof so that there is no air leakage from the outside. In this case, regardless of the condition of the ceiling, there will be no air leakage from the house below into the loft because there is no route for the air to escape. Heat and moisture transfer with therefore take place purely by conduction and diffusion and the risk of condensation can be analysed by the methods of BS EN ISO 13788:2001.

3. Modelling

3.1 Software

Various software packages which carry out the BS EN ISO 13788: 2001 calculations are available. We use ICOND, which is associated with the BRE U-value calculator. Other calculations have been carried out with JPA Designer, a substantial package that enables the calculation of a number of parameters associated with energy use in buildings to be carried out.

Each package requires the input of:

a) Details of each of the material layers making up the structure under investigation

b) Monthly values of the external temperature and relative humidity.

c) The monthly internal temperature and humidity, which is usually calculated from the external data, depending on the use of the building – see below.

The software then calculates the temperature and vapour profiles through the structure each month and the accumulation of any condensate at any interface

3.2 Construction Details

Table 1 shows the properties of the layers of the roof modelled. The columns show:

d the thickness of the layer in mm
λ the thermal conductivity in W/mK
r_v the vapour resistivity in MNs/gm
R_T the thermal resistance in m^2K/W
R_v the vapour resistance in MNs/g

Table 1 – Material properties of the layers of the roof modelled

Layer	Description	d mm	λ W/m·K	r_v MN·s/g·m	R_T layer m²K/W	R_v layer MN·s/g
	Rsi[3]				0.100	
1	Paint[1]					0.20
2	Plaster	2	0.220	60.0	0.009	0.12
3	Plasterboard	12.5	0.170	60.0	0.074	0.75
4	Mineral wool	100	0.040	5.00	2.500	0.50
5	Roof space[2]				0.160	
6	Polyurethane	105	0.026	300	4.038	32
7	Tiles[1]	12	1.5		0.008	2.5
	Rse[3]				0.04	
Total					**6.929**	**36**

Notes:
1. The paint film and tiles are entered as an infinitely thin layer with no thermal resistance, but a fixed vapour resistance
2. The roof space is entered as a standard thermal resistance for an unventilated space, with high emissivity surfaces, and with vertical heat flow taken from Table 2 of BS EN ISO 6946:2007[7].
3. The standard values of internal and external surface thermal resistance quoted in BS EN ISO 6946 are used.

3.3 External climate

While monthly mean temperature data are readily available from many locations in the UK, relative humidity data are much more difficult to obtain.

Table 7.11 of CIBSE Guide A[8] gives monthly mean temperatures and relative humidities for London, Manchester and Edinburgh, which are recommended for use in interstitial condensation calculations.

If the average climates are used, a marginal construction will suffer from condensation problems every other year. When the risk is being assessed it is therefore more appropriate to use a more severe climate that is likely to occur once every 10 years for example. Table 7.12 in CIBSE Guide A shows that this can be achieved by subtracting 1°C from each monthly temperature and adding 4% to each relative humidity.

3.4 Internal climate

The BS EN ISO 13788:2001 calculation procedure includes the internal climate either as a constant temperature and relative humidity, which is appropriate for air conditioned buildings, or by specifying a constant internal temperature and a moisture load which depends on the use of the building. Figure1 shows the climate classes, which are defined in terms of vapour pressure excess (internal – external), which is a function of outside temperature, because houses are assumed to be poorly ventilated in the winter and better ventilated in the summer.

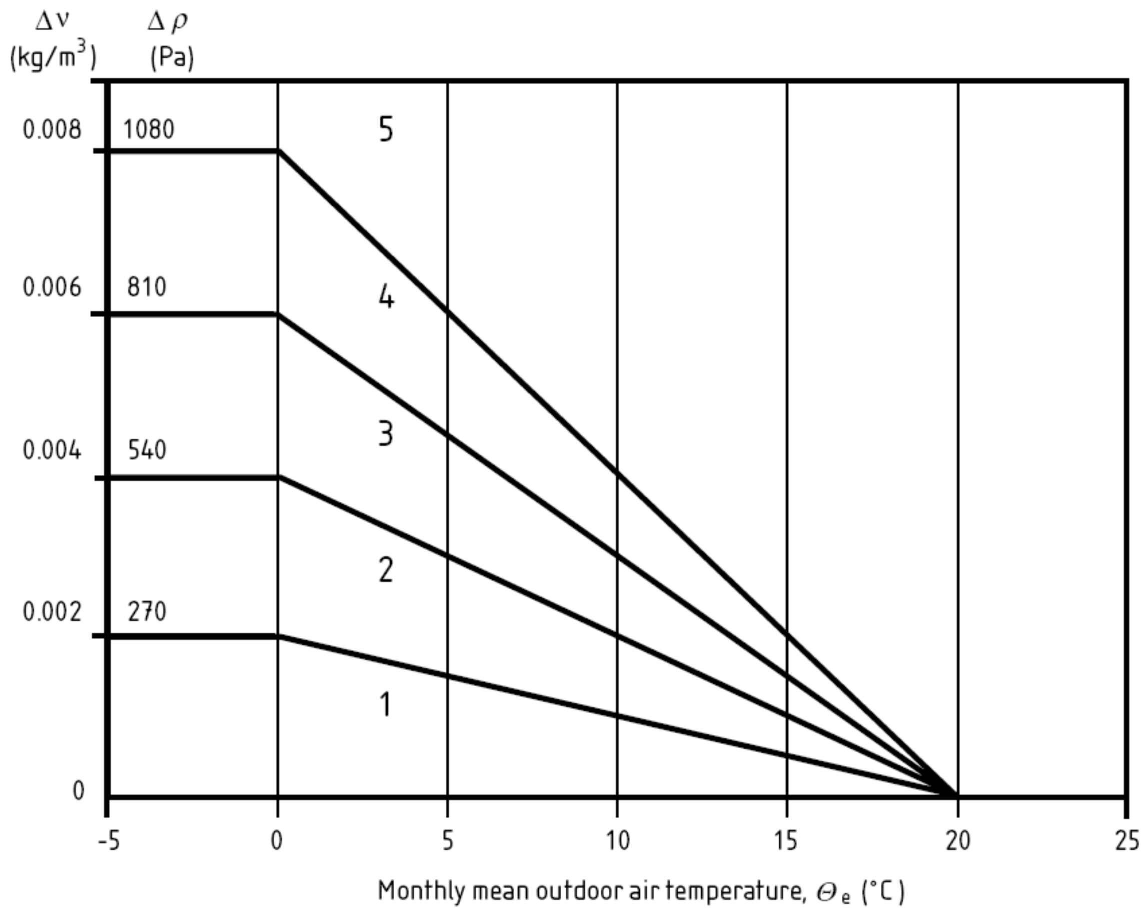

Figure1 BS EN ISO 13788 humidity classes

Table 2 shows the defintions of the humidity classes in different building types.

Table 2 Definitions of humidity classes

Humidity class	Building type	Relative humidity at internal temperature		
		15 °C	20 °C	25 °C
1	Storage areas	<50	<35	<25
2	Offices, shops	50 – 65	35 – 50	25 – 35
3	Dwellings with low occupancy	65 – 80	50 – 60	35 – 45
4	Dwellings with high occupancy, sports halls, kitchens, canteens; buildings heated with unflued gas heaters	80 – 95	60 – 70	45 – 55
5	Special buildings, e.g. laundry, brewery, swimming pool	>95	>70	>55

BS EN ISO 13788:2001 contains two statements about the appropriate internal conditions to take:

1. In Appendix A, which is informative, it states:
   For the calculations, it is recommended that the upper limit value for each class is used unless the designer can demonstrate that conditions are less severe.

2. In Section 4.24, it states:
   Take values of Δp and Δv according to the expected use of the building and multiply them by 1,10 to provide a safety margin.

This means that the building under investigation is firstly assumed to be at the top of the range of the likely moisture loads for that occupancy; then a further 10% extra load is is added.

4. Results

Using the ICOND software and taking the external climates for the three cities,from CIBSE Guide A, corrected for a more severe winter, and the internal climate on the boundary between classess 4 and 5 gives:

- No condensation is predicted at any interface with the London and Manchester climates, even in a once in ten years severe winter.
- No condensation is predicted at any interface with the average Edinburgh climate. In a once in ten years severe winter, a maximum accumulation of 40.8 g/m^2 of condensate is predicted on the underside of the polyurethane foam in January. This partially evaporates in Februray and completely evaporates in March – see the ICOND output in Appendix A.

5. Discussion

These calculations demonstrate that taking the most severe internal climate likely to be found in housing, no condensation is predicted in London or Manchester, even in a once in ten years severe winter. No condensation is predicted in an average winter in Edinburgh, however a peak of 40.8 g/m^2 is predicted to occur once in ten years; this evaporates rapidly in the spring. This amount of condensate would be a fine film of drops that is unlikely to cause problems by dripping onto the ceiling and will not affect the moisture content of the roof timbers. The structure can be considered to be passing the criteria set in BS EN ISO 13788:2001 and therefore, via BS5250:2002, to be complying with the three sets of Regulations in the UK.

There are therefore no grounds to reject this method of insulating roofs on the grounds of condensation risk and it provides a satisfactory method of achieving the target insulation value of 0.16W/m^{2}K without the need to install mineral fibre insulation above the level of the 100mm ceiling joists. This allows the roof space to have a solid ‘floor’ to be used for storage.

Although the risk of problems due to condensation is negligible, they would be reduced still further by ventilating the loft space between the mineral wool and polyurethane foam.

However this would reduce the thermal performance of the roof very substantially as it would largely eliminate the thermal benefits from the spayed polyurethane foam.

References

1. BS 5250:2002 Code of practice for the control of condensation in buildings
2. BS EN ISO 13788:2001 Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation. Calculation methods
3. BRE Report BR 262 Thermal insulation: avoiding risks, 2002
4. BRE IP 4/06 Airtightness of ceilings :Energy loss and condensation risk
5. BRE IP 5/06 Modelling condensation and airflow in pitched roofs
6. BS 9250: 2007 British Standard Code of practice for design of the airtightness of ceilings in pitched roofs.
7. BS EN ISO 6946:2007, Building components and building elements – Thermal resistance and thermal transmittance Calculation method
8. CIBSE Guide A, Environmental design, CIBSE 2006.

APPENDIX : ICOND output

Calculation of interstitial condensation
by ICond Calculator version 1.21a
Printed on 17 Jul 2009 at 15:30

Filename: C:\Documents and Settings\chs\My Documents\Advisory\BUFCA\BUFCA ROOF_3.hg3
(File saved: 15 Jul 2009 14:59)

Element type: Roof
Calculation Method: BS EN ISO 13788

BUFCA ROOF

Construction Details

Layer	d	λ	rv	R layer	Rv layer	Description
	mm	W/m·K	MN·s/g·m	m²K/W	MN·s/g	
				0.100		Rsi
1			Rv-value		0.20	Emulsion Paint
2	2	0.220	60.0	0.009	0.12	Plaster
3	12.5	0.170	60.0	0.074	0.75	Plasterboard
4	100	0.040	5.00	2.500	0.50	Mineral wool quilt
5		R-value		0.160		Roof space

6	105	0.026	300	4.038	32	Polyurethane
7	12	1.500	Rv-value	0.008	2.5	tiles
				0.040		Rse
	232 mm			6.929	36	

Boundary conditions Edinburgh (CIBSE_Edinburgh.hgt)
Return period 10 years (T -1°C, RH +4%)
Internal Humidity: BS 5250 Class 4

Results
Interstitial condensation present from January to February
Interface 5-6: Maximum accumulation = 40.8 g/m² in January

Condensation/evaporation rate and moisture accumulation for interface 5-6

Month	Internal T °C	Internal RH %	External T °C	External RH %	Rate g/m²/month	Accumulation g/m²
October	20.0	66	8.2	86	0	0
November	20.0	66	4.8	87	0	0
December	20.0	66	3.3	88	0	0
January	20.0	66	2.5	87	40.84	40.84
February	20.0	65	2.7	85	-12.37	28.47
March	20.0	64	4.3	82	-165.83	0
April	20.0	62	6.0	79	0	0
May	20.0	62	8.9	79	0	0
June	20.0	64	11.8	79	0	0
July	20.0	67	13.7	80	0	0
August	20.0	68	13.4	82	0	0
September	20.0	67	11.1	84	0	0