Air movement & thermal performance

An investigation into the effect of air movement on the thermal performance of domestic pitched roof constructions

BBA Technical Report No 1
Date 8th November 2012

Preface

Resolving the issues involved in turning designed energy performance in buildings into reality is now high on the agenda of Government departments and the construction industry. The BBA, as the UK's leading certification body for both insulation products and installers, has a good overview of the issues involved. It has already contributed to numerous workshops on the topic and has expressed the view that the so called gap between "as designed" and "as built" performance is the result of a complex mix of issues ranging from the insulating values used in design calculations, through component interactions and installation issues to the energy losses caused by the dynamic environment in which buildings exist.

Whilst the possible causes of this energy gap are relatively easy to identify at the qualitative level it is more difficult to quantify the scale of different causes and thus identify where the most cost effective improvements can be made.

In 2010 the BBA, with support from the insulation industry and the NHBC Foundation, embarked on a project to study and quantify the effect of 'wind washing', i.e. the effect of air movement over and into warm roof structures insulated using three types of insulation (mineral fibre, polyisocyanurate foam boards and multi-foil). This report summarises the results of this study and has been overseen by the BBA Technical Advisory Committee.

It is stressed to readers that the intention of the report is not to propose that any particular product or design is better than others but instead to highlight that wind washing as an energy loss mechanism can have a significant effect on the "as built" performance of a structure.

Having identified this as an issue, a sub-committee of the BBA Technical Advisory Committee has also developed initial thoughts on ways of achieving a better correlation between "as designed" and "as built" performance in this specific part of a building and it is hoped that these thoughts will contribute to further discussion.

The BBA would like to thank the participants (listed on the next page) for their contribution.

Greg Cooper
Chief Executive BBA

Key Findings

- As air speed increases, the U-value of the roof constructions tested increases by up to 80%, although such behaviour is not consistent for the constructions tested
- Measured heat loss cannot be accounted for using existing adjustment factors and we believe that the phenomenon of 'wind washing', i.e. when pressure drives wind through or behind thermal insulation, or thermal bypass[1] in general, could be responsible. Overall, the wind washing mechanism indicates that air gaps in a construction could create enough air movement to significantly reduce the effectiveness of thermal insulation
- Further research is required to develop a cost effective and reproducible measurement tool using the applied methodology, but key improvements to the existing apparatus have been identified
- To put our measurements in the context of Building Regulations for a typical semi-detached home, if the roof U-value increases by 50% due to air movement (and provided this is sustained on average throughout the year), this would correspond to a 3.5% increase in the 'Dwelling Emission Rate' (DER) or to 0.8 kg $CO_2 \cdot m^{-2}$ per year. This is significant as in 2016 the anticipated overall energy emissions from a similar home will be in the order of 10 kg $CO_2 \cdot m^{-2}$ per year. As the industry is moving towards reducing carbon emissions, this could be a significant obstacle to achieving the lower and increasingly ambitious targets, particularly as there is evidence to indicate that air movement also influences the thermal performance of a wall[2/11], which would only serve to make the impact on emission rate more severe.

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Introduction

The continued increasing demands to reduce energy usage in new and existing buildings have added urgency to the need for greater understanding and provision of easy to adopt thermal performance solutions. In 2007, the Stamford Brook project[3], among others, started to raise the profile of the performance gap which has caused much interest in the construction industry and has been the subject of debate in Building Regulations, for example the effect of a party (separating) wall included in the part L 2010 guidance.

The performance gap is identified as the difference between the "as designed" and the "as built" thermal performance of buildings, and can be even more than 100%. The cause is a mixture of complex issues but with pre-completion testing for airtightness now well established, attention is focusing on the U-values of various elements of a building's structure.

The current project and its scope

Motivated by this research and its significant implications and findings, the BBA initiated a study to evaluate the effect of air movement (i.e. wind) on the thermal performance of roofs, and in particular three types of warm pitched roof constructions commonly employed in the UK.

The BBA's applied research was performed using a modified Hot Box methodology[4]. The measured air speeds used and their typical effects are shown below.

Wind speed ($m \cdot s^{-1}$)	Typical effects
1.5	Smoke drift indicates wind direction
4.5	Leaves and small twigs constantly moving and small, light flags extended
7.5	Small branches beginning to move

These situations are characteristic of a typical day in the UK.

Additional weather data[5] show that the wind speeds below are exceeded for 50% of the time in a variety of terrains, and higher wind speeds above 7.5 $m \cdot s^{-1}$ are frequently observed in coastal areas.

Terrain category	Wind speed ($m \cdot s^{-1}$)
Open, flat country	3.4
Urban	2.0
City	1.6

Data adjusted for domestic roof top heights

It must also be noted that with regards to new dwellings, SAP 2009 currently assumes a fixed value of between 3.7 and 5.4 $m \cdot s^{-1}$ over the year with an average of 4.5 $m \cdot s^{-1}$. However SAP 2012 is expected to introduce wind speeds that vary with geographical location.

Roof Constructions

The BBA tested warm roof constructions, as the open nature of roofs would be the most likely construction element to show the effects of wind washing.

Increasingly, roof voids are being used as living/storage space and this, coupled with rising energy bills, has led to an increase in the need to insulate not only the likely leaking ceiling space in lofts[6], but also the spaces between the rafters, in order to create a habitable space.

This project sets out to study the effect of air movement on warm roof constructions where the most commonly used insulating materials, namely mineral wool, polyisocyanurate foam boards and multifoil, are employed.

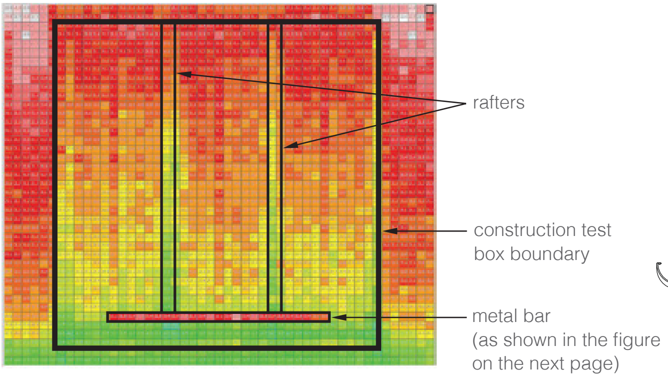
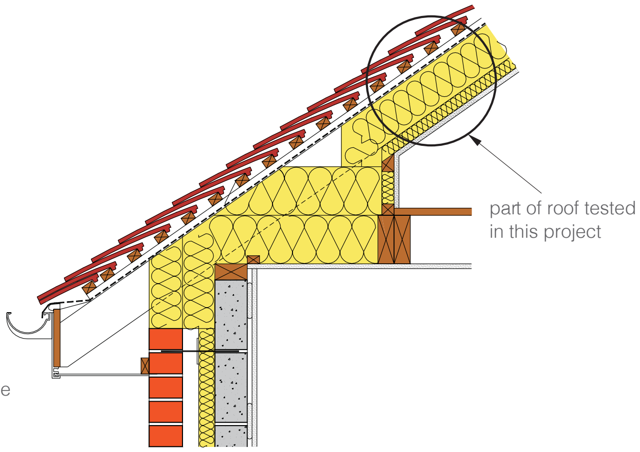


Image of the plasterboard (hot chamber side) taken by thermal scanner inside the Hot Box - temperature shown is approximately 20°C



adapted by the Constructive Details handbook

Test Method

Applied research was performed using a modified Hot Box, an apparatus commonly employed to measure U-values. A section of roof structure was installed between the hot and cold chambers which were then angled at 45° to simulate a pitched roof. Air was blown across the sample at different speeds to replicate the effects of varying wind velocities.

As in any similar type of Hot Box test, with stable temperatures on the hot and cold side, the test sample U-value, in simple terms, is simply the power (Watts) needed to maintain the hot side temperature and the temperature difference (°C) between the hot and cold side, giving a U-value in $W{\cdot}m^{-2}{\cdot}K^{-1}$.

For this project, the tests were run on each test sample with three different air speeds, 1.5, 4.5 and 7.5 $m{\cdot}s^{-1}$. Additionally, for each air speed, the air permeability of the ceiling and the tiles was varied. A series of thermocouples and heat flux transducers were attached to each construction. The calibration runs were performed using a 50 mm solid panel, which is standard practice for this type of experiment.

Test Setup

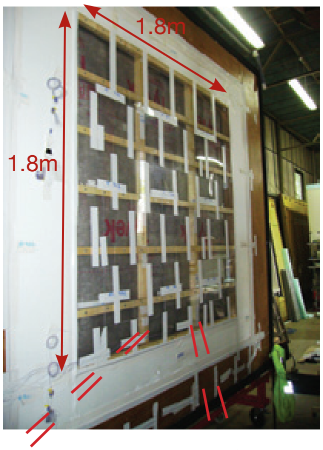
A diagrammatic representation of the test setup is shown on this page.

The three constructions tested comprised:

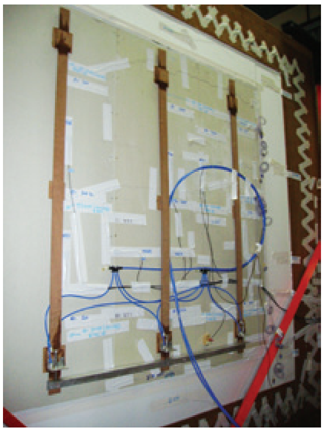
- Construction A - 185 mm of mineral wool insulation between the rafters with a design U-value of 0.21 W·m^{-2}·K^{-1}
- Construction B - 135 mm overall of polyisocyanurate insulation in two layers with a design U-value of 0.16 W·m^{-2}·K^{-1}
- Construction C - two layers of multifoil each 30 mm thick, one below and one above rafters with a design U-value of 0.36 W·m^{-2}·K^{-1}

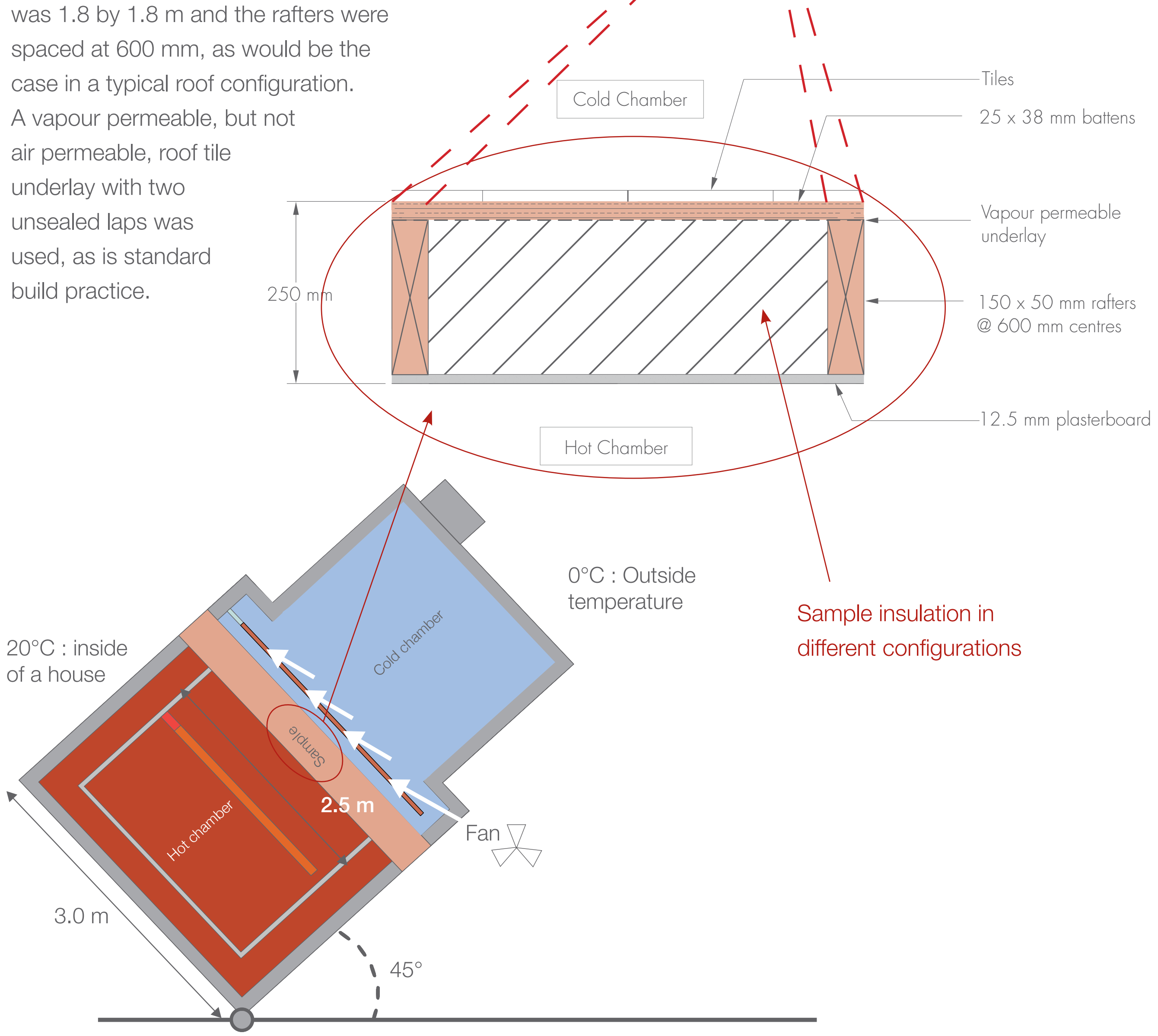
The choice of constructions was focused on representing a wide range of insulation materials in such a configuration. The size of each construction was 1.8 by 1.8 m and the rafters were spaced at 600 mm, as would be the case in a typical roof configuration. A vapour permeable, but not air permeable, roof tile underlay with two unsealed laps was used, as is standard build practice.

Installed sample with surround panel – cold chamber side



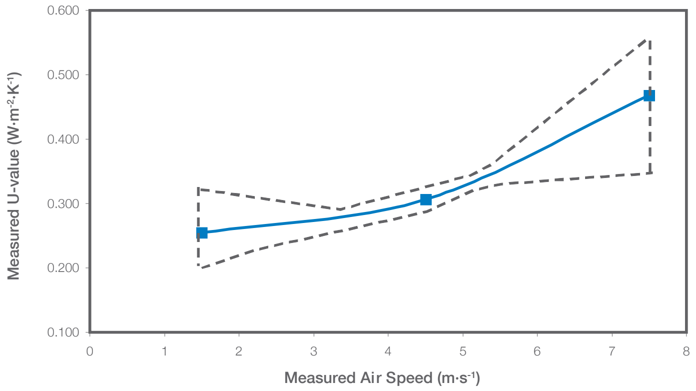
View of the plasterboard - hot chamber side





Test Results and Conclusions

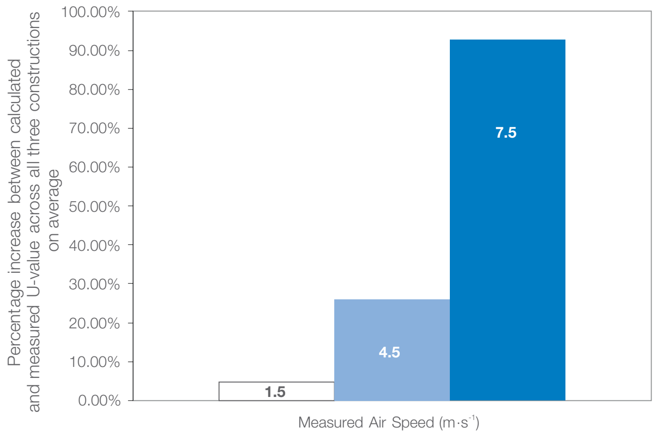
The line in the graph below shows an average of all the measured data points, incorporating all the three constructions and all test results. The area enclosed by the dotted line represents the zone of collected data, averaged across all available permutations.



From our measurements we conclude overall that:

- the U value of the roof constructions tested increases up to 80%, although such behaviour is not consistent
- as tested, conventional lightweight breathable roof tile underlays with unsealed (dry) overlaps may not form an effective air barrier
- some evidence is available from pressure measurements that turbulent air flow could be present in all constructions
- further research, with the use of more sensitive techniques, is required to quantify the effect of air permeability of the plasterboard and tiles
- a series of improvements has been identified which should, with relatively modest funding, lead to the development of a cost effective and reproducible measurement tool for other types of constructions and materials.

Another way of viewing our data is by comparing the difference between the design and measured U-value, as an expression of the performance gap, shown in the figure above right.



The wind speeds used in this test can frequently be experienced during a typical UK winter, at the times when energy demands are the highest. Therefore any potential heat loss due wind washing, must be given serious consideration.

Heat Loss Mechanisms

Existing European and British standards[7/8/9] have introduced a number of adjustment factors to account for gaps in insulation and the effect of wind on the external surface resistance of a construction.

For the constructions tested, the corrections mentioned above don't apply. However, if we were to apply them, to the extreme, the anticipated increase in the U-value would be in the region of up to 25 %. This is not sufficient to explain the measured heat loss and we believe that other mechanisms are responsible such as the thermal bypass.

Studies of the thermal bypass heat loss mechanism[10/11/12] report a wide range of factors influencing the performance gap and they conclude that it is highly dependent not only on construction type but also on build quality.

There are two ways in which the thermal bypass can manifest itself. The first is wind washing, where cold air can infiltrate and circulate within (or across) the construction due to gaps, air voids or ventilation, and the second is due to the movement of air within or through the insulation itself, or uninsulated cavities.

In the roof constructions tested, as the wind speed increases, gaps between the timber and/or the insulation itself could allow cold air to enter and warm air to escape. Such types of behaviour are shown in the schematics on the next page.

Common air flow patterns within insulated and un-insulated cavities:

(a) air leakage through gaps

(b) infiltration of internal air by natural convection

(c) diffuse air leakage

(d) infiltration of external air by natural or forced (wind) convection

(e) wind washing at a corner/edge

(f) ventilation or venting

(g) air rotation by natural convection within insulation

(h) air rotation by natural convection in an un-insulated cavity

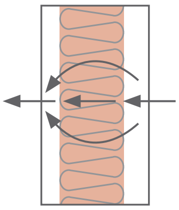
(i) air rotation by natural convection around insulation

(j) air rotation by natural convection through insulation

(k) infiltration of external air by natural or forced (wind) convection through insulation

(l) mixed pattern

(m) air rotation by natural convection between two regions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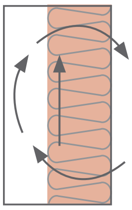
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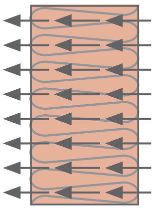
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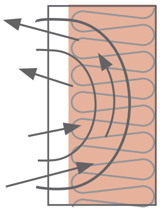
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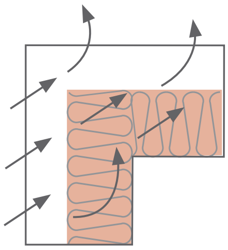
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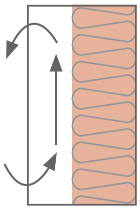
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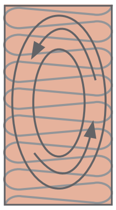
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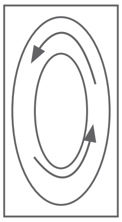
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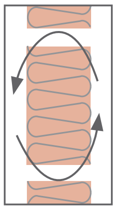
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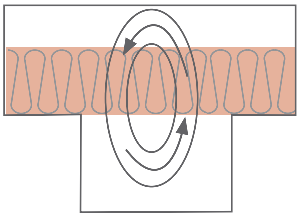
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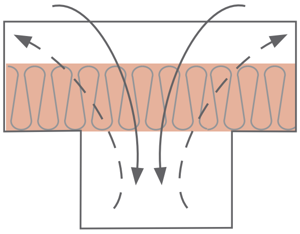
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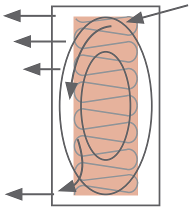
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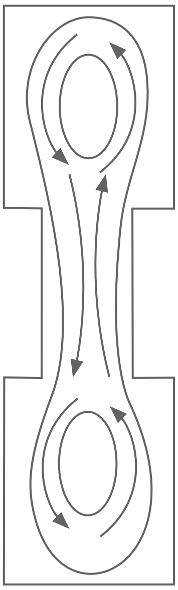
(m)

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Formulating Solutions

We believe that these results add important information to the performace gap debate, and in the light of this work the BBA, with input from its Technical Advisory Committee, has identified a list of possible solutions:

Do nothing!

- this would be a cheap, simple and easy route forward. However, most industry stakeholders and government legislators now recognise the urgent need to address the performance gap, of which further evidence has been provided by this project.

Develop more guidance on workmanship

– this would promote a better understanding of how to optimise the performance of roof structures. However guidance alone is unlikely to make a significant difference, unless incentives are provided to take it on board across the industry.

Robust thermal design techniques

– this could form a complete solution for detailing to include thermal performance and condensation risk but accompanied with guidance to encourage robust design and high workmanship levels. This could be an all-encompassing solution which would take time and effort from the industry to implement, but it is not without precedent, for example in the form of Robust Details for Part E – Sound.

Include correction factors in standards for U-value calculations

– this solution could lead to the calculation of more accurate U-values. It could however be too soon to introduce such a solution for roofs as there are many parameters which are still unclear, such as the effect on different types of construction. More research is required to increase accuracy but this could be an expensive and lengthy process.

Adjust U-values with geographical location

– The U-value within the SAP calculation could be multiplied by a factor related to the average wind speed of the region of the country within which the dwelling is situated, in much the same way that other factors in SAP are related to an average geographical value e.g. solar radiation, external temperature. However, there are other factors which will affect the wind speed experienced on a particular site, possibly making the average regional wind speed too coarse a measure to use. Similarly, there are other site specific factors which may have a bearing on the impact of local air speed within a structure. For example, this experimental work did not explore the effects of different pitches or the orientation of roofs and the constantly changing wind direction. It is considered that there is insufficient data at present to formulate a simple relationship between wind speed and U-value.

Include confidence factors in SAP

– a familiar concept used, for example, in SAP 2009 for heat loss across cavity party walls and for thermal bridging calculations. Similarly, 'in use factors' are being built into the Green Deal to counter uncertainty surrounding energy cost savings from retrofit measures, such as cavity wall and roof insulation. The principle here is to build in a penalty where a problem is believed to exist, but in a way that gives developers and manufacturers sufficient incentive to gather evidence that their solution does not need the application of a confidence factor.

However, due to the limited nature of research to date on thermal bypass-type mechanisms, this could prove to be a subjective and controversial process and is unlikely to be popular with industry.

Employ different types of construction

– acknowledge the benefits of offsite construction or other types such as green roofs[13], with easier to derive U-values, solutions for airtightness and increased safety. This solution would, however, challenge the traditional way of building and could meet with resistance and apprehension from the industry.

In developing solutions to deal with the phenomena observed as part of this project, it is important that any new test methods and methodology must be open and transparent and results and analysis should be subject to peer review.

In the course of this project the BBA has exchanged knowledge with the CSTB in France which has dealt with similar issues and observed broadly similar behaviours. It is recommended that further research in this area is required, to focus on identifying the most significant contributing parameters for heat loss not only in roofs but also in other building elements, such as walls.

British Board of Agrément

The British Board of Agrément (BBA) is the UK's major authority offering approval and inspection services to manufacturers and installers supplying the construction industry. Originally set up in 1966 by Government, but now an independent non-profit distributing organisation, the BBA's certification and inspection services are recognised by building control, local authorities, industry insurers and key trade associations in the construction industry.

The BBA is increasingly engaging in testing and research beyond Agrément Certification. The work covered by this report is an example of these activities, but there are others such as the use of full fill cavity wall insulation in masonry walls at very severe exposures and the assessment of walls with partial fill insulation where cavity wall insulation is subsequently added. Thermal simulation tools are widely used in further research, with all activities taking place on the same site and under BBA control.

What do we do?

The BBA provides reassurance to the industry that the products, systems and procedures are 'fit for purpose', as they have undergone a rigorous and thorough assessment process. It is continuously investing in its people and test equipment to further extend its capabilities, and provide a better service to its customers.

Product Approval and Certification

- Agrément Certificates: The BBA's premium award, recognised by key stakeholders in the construction industry as a robust, impartial and rigorous assessment of a product's 'fitness for purpose'.
- HAPAS Certificates: A nationally recognised approval for new products and systems developed especially for highway use.
- Microgeneration Certification Scheme (MCS): A third party scheme developed by Government to independently assess manufacturers and installers of small-scale renewable technologies to documented standards. The BBA is a notified body under this scheme, offering MCS certification for products covered by it.
- Environmental Profile Certification: A statement of characterised data and eco-points per functional unit of a building element assessed using the BRE methodology. Additional information such as recycled content and reference to responsible sourcing can also be included.
- Certificates of Competency: This scheme has been devised in association with TIMSA (Thermal Insulation Manufacturers and Suppliers Association) and is used for assessing and monitoring U-Value and condensation risk calculation competency. Competent Persons are awarded with a unique identification number which they can use to identify their calculations.

Installer and Inspection Services

The BBA has over 40 years experience in providing independent and unbiased information on products and their installation. Our inspection teams cover various activities, ranging from monitoring of BBA Approved Installers and installers operating under client managed schemes, to surveillance visits carried out on behalf of the Government endorsed Competent Person and TrustMark schemes. Our inspection teams cover the whole of the UK including the Isle of Man, the Channel Islands and Northern Ireland as well as Eire, and also operate in the USA and China.

Test Services

The BBA's Test department has supported the Agrément Certificate process by providing test facilities for manufacturers wishing to gain Agrément approval. Its experience extends to over 200 different product areas across the entire spectrum of building products, backed by a wide range of UKAS accreditations. The department is increasingly involved in bespoke activities, undertaking tests against European Standards and new product development, by using state of the art thermal and durability testing equipment.

Management Systems

The BBA provides registration to BS EN ISO 9001 and BS EN ISO 14001 either in support of an Agrément Certificate application or as a stand alone approval for companies wishing to demonstrate that they have robust practices and procedures in place.

Recent Developments

- CE Marking: With the Construction Products Regulation (CPR) coming into force in July 2013, the BBA has been involved in the preparation of a Guidance Note on CPR, to be published by the Construction Products Association, which explains the implications of this legislation to the industry.
- Green Deal: This is a government backed initiative and the BBA has been accredited by UKAS to assess installers via the requirements of the Green Deal Installer Installation Standard (PAS 2030). In collaboration with the BRE it works to give reassurance to providers that installations will be carried out in accordance with the Green Deal standards.
- Constructive Details Limited: The BBA has also joined forces with Robust Details Limited to create Constructive Details Limited (CDL), with a view to delivering a thermal bridging details scheme. The first handbook, created for the Aircrete Products Association, is now available free to view and download from the Constructive Details website.

Glossary of terms

Thermal bypass: Heat transfer that bypasses the conductive or conductive-radiative heat transfer between two regions. It is generally used to describe any form of air movement that is due to some type of unregulated heat transfer. Phenomena such as air infiltration and wind washing would fall under this category[1].

U-value: Also known as thermal transmittance, this is a measure of the heat loss in building elements such as walls, roofs, floors and windows. The higher the U-value, the worse the insulating capacity of the element, i.e. the more heat is escaping from a property.

Warm roof construction: Insulation is placed at the rafters, usually as part of the provision of storage or living space.

SAP: The Standard Assessment Procedure is a methodology used for assessing and comparing the energy and environmental performance of new dwellings.

Thermal bridging: This describes the additional heat loss, over and above a U-value calculation, in the junction between different elements. The term psi-value is a measure of this heat loss.

Green roofs: Otherwise known as a living roof, it is the roof of a building partially or entirely covered with vegetation and a growing medium.

The schematics on page 8 have been reproduced from an article that was first published in Green Building Magazine, Summer 2009 (Volume 19 No. 1) and are copyright of and reproduced with permission from Green Building Press.

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Further information

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