An Independent Analysis of the Impact of Installing Internal Solid Wall Insulation in Existing Dwellings

A WHITE PAPER
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This study analyses the actual and predicted performance of two existing solid–walled dwellings before and after the installation of Kingspan Kooltherm® K18 Insulated Plasterboard.

The findings show that Kingspan Kooltherm® K18 Insulated Plasterboard can have a positive impact on the overall thermal performance of solid walls, leading to a sizable reduction in primary space heating energy use, associated CO₂ emissions and costs.

The installation of Kingspan Kooltherm® K18 Insulated Plasterboard can improve building air–tightness by up to 57% and wall U–values by up to 89%, whilst facilitating annual savings in fuel for primary space heating of up to 45%.

Background

Carbon dioxide emissions reduction has become an increasing focus for the world’s major governments. As a result, policy and legislation continue to target those human activities, which consume vast amounts of energy and contribute most to carbon dioxide emissions.

The UK’s housing stock is amongst the least energy efficient in Europe¹ and is responsible for nearly 27% of overall energy consumption in the UK.² Approximately 36% of the 24.5 million dwellings in the UK are non-cavity wall constructions.³ Also notable is that in an uninsulated home, 66% of heat loss is through uninsulated solid walls.⁴ Therefore insulating walls to make them more energy efficient has substantial potential to deliver significant and cost–effective reductions in space heating energy use.

With the aim of quantifying the energy savings that result from insulating solid walls in existing dwellings, the Energy Saving Trust (EST) undertook the largest in–situ solid wall insulation (SWI) trial in England.

Between 2009 and 2013 a comprehensive dataset of detailed building performance from 36 dwellings was gathered by the EST, before and after the installation of differing SWI systems.

As part of the trial, Kingspan Insulation funded the supply and installation of Kingspan Kooltherm® K18 Insulated Plasterboard for two stone–built, pre–1900s dwellings located in Lancashire. One is a mid–terrace located in the market town of Burnley. The other is an end–terrace located in the seaside town of Morecambe.

The performance of each dwelling was monitored, measured and recorded over a period of 17 months for the Burnley property, and 34 months for the Morecambe property.

The resultant data was subsequently analysed by the EST to determine the impact of Kingspan Kooltherm® K18 Insulated Plasterboard on: wall U–values; air–tightness; primary space heating energy use, associated CO₂ emissions; heating patterns; indoor environmental conditions; and occupant behaviour.

¹ http://www.ukgbc.org/content/retrofit-homes (10:02 9 June 2016)
² Department of Energy & Climate Change (DECC), Energy Consumption in the UK 2015 Chapter 1, Overall Factsheet URN: 15D/373 (30 July 2015)
Site Assessment, System Selection & Installation

Initial building surveys were carried out to assess the suitability of each property for installation of SWi and to determine, in consultation with the owners, which Kingspan Insulation solution would be most appropriate for the refurbishment of the walls i.e. internal wall insulation (IWI) or external wall insulation (EWI). In both cases, Kingspan Kooltherm® K18 Insulated Plasterboard was deemed to be the best option.

Mansell Projects were appointed as the dry-lining contractor for both projects. They defined the programmes of works following a pre-installation survey. To ensure that the required standard of workmanship was achieved, the installation was completed by experienced operatives. In both cases, the homeowners preferred to remain in their properties throughout the duration of the works. Whilst this allowed them to oversee the project and be involved in decisions about both the finish and aesthetics of the works, precautionary measures were taken to minimise the impact of any disruption.

Kingspan Insulation made regular site visits to provide troubleshooting support and to verify that the required standard of installation and detailing was being achieved.

Figure 1: Kingspan Kooltherm® K18 Insulated Plasterboard was installed in both properties.

Data Collection & Analysis

BSRIA (The Building Services Research & Information Association) was appointed to monitor and record:

- indoor and outdoor ambient temperatures;
- internal and external wall surface temperatures;
- indoor humidity; and
- gas and electricity consumption.

BSRIA was also required to:

- gather site survey data;
- carry out a series of thermal imaging surveys, both indoors and outdoors; and
- take U-value and air-permeability measurements.

The data collated for each property was subsequently reviewed by the EST in order to ensure that it was as robust and as accurate as possible.

The performance of each dwelling was calculated, both before and after the installation of insulation, using the 2005 edition of the Standard Assessment Procedure (SAP). The input data included the pre- and post-installation wall U-value and air-permeability measurements.

The resulting pre- and post-installation primary space heating gas consumption estimates were compared with actual primary space heating gas consumption to identify any discrepancies.

The actual total gas consumption was normalised for heating degree days (HDD), which was calculated using either the recorded outdoor ambient temperatures or HDD records for the geographical area. Primary space heating gas consumption was derived by modelling hot water energy demand in SAP and deducting it from the total normalised gas consumption.

Indoor humidity, wall surface temperature and ambient temperature measurements were used in dew point calculations to identify any changes in the risk of condensation occurring on the walls.

Thermal images were used to visually map surface temperature, before and after the refurbishment works, to assist in identifying gross thermal bridging, air-leakage paths, dampness and the effects of the insulation.

Air-permeability measurements were used to determine whether the addition of insulation had had an effect on building air-tightness.

Heating patterns during the heating season were determined by examining gas use, timed heating programmes, thermostat levels and indoor ambient temperatures.
Case Study Detail - Burnley

Description
The Burnley property is a pre–1900 stone–built, solid–walled, mid–terrace with a total building floor area of 138 m² and double glazed windows throughout, one of which being a front bay window with plaster cornice detailing. It comprises two main floors and a cellar beneath the front part of the house with one wall exposed to the outdoors. A pre–1979 gas boiler provided primary space and water heating. The property was occupied by a retired couple in their mid–sixties.

Insulation Works
The area in which the dwelling is located was part of an ongoing renewal project involving property face–lifts. As a consequence, restrictions were placed on any alterations to the exterior including EWI. Thus, IWI was the only option.

Kingspan Kooltherm® K18 Insulated Plasterboard was mechanically fixed to 25 x 50 mm pre–treated timber battens faced with 100 mm wide damp proof course (DPC) strips, on the external walls. A 92.5 mm thickness of Kingspan Kooltherm® K18 Insulated Plasterboard was selected based upon the space requirements of the property owners. Particular care was required around the bay window in the lounge, where the existing plaster cornice detailing was removed and subsequently replaced to accommodate the insulation. The roof, ceiling and floors were not insulated as part of the project.

Figure 2: The selected property in Burnley

Figure 3: Kingspan Kooltherm® K18 Insulated Plasterboard was mechanically fixed

Figure 4: Sealant was applied between the bottom of the insulated plasterboard and the floor
Observations & Key Findings

Figure 5 shows the interior front door prior to the installation of IWI. The average external wall area temperature is 0.9 degrees cooler than the ambient temperature. There is clear ingress of cold air around the doorway, and particular cold spots on the wall above the door.

Following the installation of IWI to this wall (Figure 6) the average wall temperature is almost identical to the internal ambient temperature. We can further see the effect of the insulation by observing the clear difference between the wall and door areas in this second image. Whilst there is still cold air permeating the property under, to the sides, and at the window of the external door, the thermal performance of the wall has improved and this is more noticeable.

Figure 7 shows the lounge interior wall at the front of the property prior to the installation of IWI. The measured area on the walls surface is 1.3 degrees cooler than the ambient temperature showing the heat loss occurring through the walls. In places this difference appears greater. For example there are particular cold spots in the alcove above the central window that appear to be as much as 3 degrees cooler. This could potentially lead to condensation in this area.
Following the installation of IWI (Figure 8) the average wall area is much closer to the ambient temperature. The significant heat loss in the area above the window has also been addressed. However there remains a cooler patch in the ceiling where the top of bay window remains un-insulated.

An indication of good installation practice and the positive effect of the insulation is that heat loss through linear thermal bridging at junctions appears to have decreased on the whole. Junctions, left uninsulated by poor installation and detailing can increase the risk of surface condensation. The single instance of condensation risk identified inside the dwelling during the winter heating season was eliminated following the renovation.

It can be seen from Table 1 that following the installation of Kingspan Kooltherm® K18 Insulated Plasterboard:

- the measured U-value of the wall decreased by 89%;
- the normalised actual gas consumption for primary space heating decreased by 45%, thus corresponding CO₂ emissions and costs also decreased;
- air-leakage decreased by 57%;
- the mean average indoor ambient temperature rose by 0.8 degrees;
- the Energy (SAP) and Environmental Impact (EI) Ratings moved up a band; and
- the Dwellings Emission Rate (DER) decreased by 32%.

This clearly demonstrates that Kingspan Kooltherm® K18 Insulated Plasterboard had a positive impact on the energy and environmental performance of the dwelling, possibly increasing its attractiveness to potential tenants or buyers to whom such performance factors are key considerations.

### Analysis

The dramatic 45% saving in normalised actual gas consumption for primary space heating was more than twice the predicted saving modelled using SAP. This inconsistency may largely be accounted for by the combined changes in occupant heating behaviour and indoor environmental conditions, which cannot be modelled reliably using SAP.

Monthly gas use data taken during the heating seasons revealed a marked change in heating pattern following the insulation upgrade, with both the intensity and duration of gas consumption for space heating events decreasing, particularly in the daytime. A defined bimodal heating pattern emerged post-installation.

The use of the thermostat to maintain desired temperature levels resulted in the constant low level of gas use observed in the post-insulation period. This, combined with the 0.8°C increase in mean average indoor ambient temperature indicates a small level of comfort take whereby the previous lack of insulation may have inhibited the ability of the occupants to achieve their preferred temperatures.

### Table 1: Performance measures for the Burnley property before & after IWI

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Before IWI</th>
<th>After IWI</th>
<th>Change Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall U-value (W/m²·K) as Measured</td>
<td>1.588</td>
<td>0.18</td>
<td>89%</td>
</tr>
<tr>
<td>Air Permeability (m³/m²·hr@50 Pa) as Measured</td>
<td>7.88</td>
<td>3.42</td>
<td>57%</td>
</tr>
<tr>
<td>Mean Average Indoor Ambient Temperature (°C)</td>
<td>22.6</td>
<td>23.4</td>
<td>–</td>
</tr>
<tr>
<td>Normalised Actual Gas Consumption for Primary Space Heating (kW·h/yr)</td>
<td>20504</td>
<td>11348</td>
<td>45%</td>
</tr>
<tr>
<td>SAP Predicted Gas Consumption for Primary Space Heating (kW·h/yr)</td>
<td>18879</td>
<td>15303</td>
<td>19%</td>
</tr>
<tr>
<td>SAP Rating</td>
<td>50 E</td>
<td>66 D</td>
<td>32%</td>
</tr>
<tr>
<td>EI Rating</td>
<td>44 E</td>
<td>61 D</td>
<td>39%</td>
</tr>
<tr>
<td>DER (kgCO₂/m²/yr)</td>
<td>57.97</td>
<td>38.31</td>
<td>34%</td>
</tr>
</tbody>
</table>
Case Study Detail – Morecambe

Description

The Morecambe dwelling is a pre–1900, stone-built, solid-walled, end-terrace with a total building floor area of 140 m² and double glazed windows throughout. It comprises two main floors, a small converted loft room and a cellar beneath the lounge. The cellar walls are not exposed to the outdoors. The ground level outside the property rises above that inside, from the front to the rear, and is potentially a risk area for damp, although none was evident on the internal wall surface. A gas condensing boiler provides primary space and water heating, whilst a solid fuel stove in the open-plan ground floor living space provides auxiliary space heating. The dwelling is occupied by a young family of four.

Insulation Works

Internal wall insulation (WI) was preferred over external wall insulation (EWI), since the latter would result in the rustic stone façade being concealed and provide a slower response heating within the house. Furthermore, planning permission for works to the exterior of the dwelling may have been difficult to gain as the property is located in a conservation area.

To that end, Kingspan Kooltherm® K18 Insulated Plasterboard was mechanically fixed onto 25 x 50 mm pre-treated timber battens faced with 100 mm wide damp proof course (DPC) strips, on the external walls. A 92.5 mm thickness of Kingspan Kooltherm® K18 Insulated Plasterboard was selected based upon the space requirements of the property owners. The cellar walls were not insulated as part of the project, nor were the roof, ceilings and floors.
Observations & Key Findings

Figure 12: Thermal Image of External Gable Wall before IWI (Outdoor Ambient Air Temperature = 7.3°C & Wall Surface Temperature Defined in Area = 9.4°C)

Figure 13: Thermal Image of External Gable Wall after IWI (Outdoor Ambient Air Temperature = 0.0°C & Wall Surface temperature Defined in Area = 0.8°C)

Figure 14: Thermal Image of Internal Gable Wall in Loft before IWI (Indoor Ambient Air Temperature = 19.0°C & Wall Surface temperature Defined in Area = 14.5°C)

Figure 15: Thermal Image of Internal Gable Wall in Loft before IWI (Indoor Ambient Air Temperature = 19.0°C & Wall Surface temperature Defined in Area = 16.7°C)

Figure 16: Thermal Image of Internal Gable Wall in Loft after IWI (Outdoor Ambient Air Temperature = 18.5°C & Wall Surface temperature Defined in Area = 18.5°C)

Figure 12 shows the gable wall of the property prior to the insulation works. There is substantial heat loss. The average temperature of the measured area is 2.1 degrees warmer than the ambient temperature.

Following the installation of IWI (Figure 13) the thermal image shows a substantially different temperature pattern. The average temperature of the measured area is 0.8 degrees warmer than the ambient temperature indicating an improvement in some areas of the wall. However, the most striking aspect is the sloped vertical band of warmth rising the height of the wall. This heat loss is where the chimney runs from the dual fuel ground floor room heating fireplace. Since the property has received IWI to this wall, and the chimney is set back within the external wall, it essentially remains uninsulated following the works – causing this pattern.
Prior to the works (Figures 14 & 15) there is heat loss, both on the main wall areas as well as more intensely at the wall / wall and gable / roof junction. The main wall area is 2.3 degrees cooler than the ambient temperature, and this difference is greater in the junctions. For example in Figure 14 the wall corner is around 4–6 degrees cooler than ambient. Substantial heat is being lost through these points of linear thermal bridging.

Figure 16 shows the same wall area following the works. The wall is identical in temperature to the ambient, highlighting the positive effect of the insulation. There are no major points of linear thermal bridging or inconsistencies in wall temperature. An indication of good installation practice and the positive effect of the insulation is that heat loss through linear thermal bridging at junctions appears to have decreased on the whole. Junctions, left uninsulated by poor installation and detailing can increase the risk of surface condensation.

It can be seen from Table 2 that following the installation of Kingspan Kooltherm® K18 Insulated Plasterboard:

- the U–value of the wall decreased by 83%;
- the normalised annual gas consumption for primary space heating decreased by 20%, thus corresponding CO₂ emissions and costs also decreased;
- air–leakage decreased by 1%;
- the mean average indoor ambient temperature dropped by 1 degree;
- the Energy Efficiency (SAP) and Environmental Impact (EI) Ratings moved up a band; and
- the Dwellings Emission Rate (DER) decreased by 32%.

Although there was an improvement in the air–tightness of the Morecambe property, it was negligible at 1% signifying that the primary routes for uncontrolled air–leakage were through the roof and floors, which had not been insulated as part of the project.

The above clearly demonstrates that Kingspan Kooltherm® K18 Insulated Plasterboard had a positive impact on the energy and environmental performance of the dwelling, possibly increasing its attractiveness to potential tenants or buyers to whom such performance factors are key considerations.

Analysis

The survey report indicates that, contrary to the standardised assumptions contained in SAP (that 10% of overall space heating is generated from secondary sources), the solid fuel stove in the open-plan ground floor living space was contributing more heat than assumed and was, in actual fact, the primary heat source for the ground floor living space. As a consequence, this may account for the disparity between the actual 20% reduction in normalised annual gas consumption and the SAP–predicted 44% reduction.

Since solid fuel use was not monitored throughout the duration of the study, the contribution of its reduction to the space heating energy saving was not quantified. Thus, it can only be assumed that the overall yearly space heating energy savings, resulting from the installation of Kingspan Kooltherm® K18 Insulated Plasterboard, may indeed have been considerably greater than 20%.

This assumption is corroborated by the post–installation indoor ambient temperature data. Closer inspection of the temperature data reveals that whilst the temperature of each of the two bedrooms upstairs remained broadly similar to that prior to the installation, the temperature of the ground floor living space, in which the stove was located, dropped. This may be explained by a reduced reliance on heat generated from solid fuel, which has resulted in the room being cooler overall, yet tolerable without the need to use the stove. It is likely that the improved thermal performance reduced the requirement for heat generated from solid fuel, as the occupants were able to maintain a comfortable temperature without the additional heating.

The change in temperature was also consistent with a change in heating pattern. Data, illustrating the heating pattern over a month during the heating season, revealed that gas–fired morning and daytime space heating events were almost entirely absent in the post–insulation period. Heating events in the pre–insulation period, on the other hand, were common throughout the day. This constant use of gas required to maintain comfortable temperatures, despite the stove being the main heat source, reflects the extent of the heat loss through the uninsulated building fabric.

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<th>Before IWI</th>
<th>After IWI</th>
<th>Change Ratio</th>
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</thead>
<tbody>
<tr>
<td>Wall U–value (W/m²·K) as Measured</td>
<td>1.300</td>
<td>0.215</td>
<td>83%</td>
</tr>
<tr>
<td>Air Permeability (m³/m²/hr@50 Pa) as Measured</td>
<td>16.56</td>
<td>16.44</td>
<td>1%</td>
</tr>
<tr>
<td>Mean Average Indoor Ambient Temperature (°C)</td>
<td>18.1</td>
<td>17.1</td>
<td>–</td>
</tr>
<tr>
<td>Normalised Actual Gas Consumption for Primary Space Heating (kWh/yr)</td>
<td>10428</td>
<td>8316</td>
<td>20%</td>
</tr>
<tr>
<td>SAP Predicted Gas Consumption for Primary Space Heating (kWh/yr)</td>
<td>15792</td>
<td>8810</td>
<td>44%</td>
</tr>
<tr>
<td>SAP Rating</td>
<td>67 D</td>
<td>77 C</td>
<td>15%</td>
</tr>
<tr>
<td>EI Rating</td>
<td>64 D</td>
<td>76 C</td>
<td>19%</td>
</tr>
<tr>
<td>DER (kgCO₂/m²/yr)</td>
<td>35.38</td>
<td>24.13</td>
<td>32%</td>
</tr>
</tbody>
</table>

Table 2: Performance measures for the Morecambe dwelling before & after IWI
Conclusion

The installation of internal wall insulation on the two properties has demonstrated that the use of *Kingspan Kooltherm*® K18 Insulated Plasterboard can improve building air-tightness by up to 57% and wall U-values by up to 89%, whilst facilitating annual savings in fuel for primary space heating of up to 45%.

*Kingspan Kooltherm*® K18 Insulated Plasterboard has proven to have had a positive impact upon the overall thermal performance of solid walls, leading to a sizable reduction in primary space heating energy use, associated CO₂ emissions and costs, whilst enabling an improved level of thermal comfort to be enjoyed through greater energy efficiency. This inevitably has a consequential effect upon indoor environmental conditions, thus living standards and general well-being. It has also possibly increased the attractiveness of the properties to potential tenants or buyers to whom such performance factors are key considerations.

In addition, it is important to note that the quality of installation, due to training and quality standards, is as important as the performance and physical properties of the insulant. Quality of installation is crucial in ensuring compliance with regulations, delivering required thermal performance levels, ensuring adequate air-tightness and minimising the risk of condensation.
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The Kingspan Insulation Technical Service Department can also give general application advice and advice on design detailing and fixing etc... Site surveys are also undertaken as appropriate.

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