ENERGY RETROFIT OF THE EXISTING HOUSING STOCK IN ENGLAND

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ABSTRACT

The housing stock in the United Kingdom is the oldest in Europe and great part of its energy consumption is due by space and water heating. The high costs of energy are a national matter not only for their economic and environmental implications, but also because they contribute largely to a social problem, known as *fuel poverty*. The cost of heating the housing stock is rather high for different reasons, one of each being the heat loss through the building envelope. The thermal performance of existing buildings can be increased in two ways: by adding insulation to external fabric, and by reducing the unintended air leaks of the envelope. This study focuses on this second method, which can lower heat waste of about 20%.

Typical pre-1970 English buildings are characterised by an evident degree of permeability, emphasised either in the construction techniques or in the materials used. They are also pretty leaky: they have cracks and holes in the fabric, unused open chimneys and fireplaces, gaps around windows and door frames. Unwanted air leakage allows the waste of heat toward the outside and can cause interstitial condensation. As a result, there can be a decrease in the performance of thermal insulation (up to 70%) and fabric damages. Air-proof improvements increase the energy and cost efficiency of a building, raise the level of internal comfort and lower the risk of thermal bypass. They can be very cost-effective and easy to do, but their effects are underestimated. After draught-proofing, less heat will be wasted through the envelope (this can save on average £55 per year) and thus less heat will be required to have a comfortable temperature in the inside (this can save another £60 per year). The Energy Saving Trust (EST) evaluates that if every dwelling in the UK was draught-proofed at its best, £190 million would be saved every year and the unloosen energy would be sufficient to heat nearly 400,000 houses. The benefits from the economic, energy-efficiency, environmental and social point of view would be remarkable and worthy. After reviewing the literature on the topic, this work presents a case study, in which the most common air-leaking points are found in an existing traditional masonry solid wall house. Some easy-to-do and affordable recommendations are suggested to fix those points. Reducing air leaks is a sustainable way to improve thermal performance in dwellings; it is a relatively low-cost solution, with no big impact or negative effects on the environment, and it facilitates further strategies to lowering energy consumption and CO_2 emissions.

KEYWORDS

Airtightness, energy efficiency, building envelope, existing housing stock, eco-retrofit.

INTRODUCTION

The United Kingdom has the oldest housing stock in Europe, counting almost nine million buildings older than 60 years [1]. In March 2012 the UK Department of Energy and Climate Change (DECC) [2] highlighted that the energy utilised for space and hot water heating in households is nearly 80%. DECC reports that the heat demand in the housing sector has

enhanced in the last 40 years, despite the noticeable improvements in the buildings energy efficiency and the more temperate winters; such a growth is due primarily to the raise of either the average internal temperature in homes or the number of dwellings.
The Department for Communities and Local Government (DCLG) [3] informs that the existing housing inventory is somewhat weak from the energy efficiency point of view: more than 40% of dwellings is in band D and more than 30% is in band E. Retrofitting the current buildings to take them to a higher band (hopefully at least to band B) is loosely acknowledged to be a smart goal.
Apart from the economic and environmental aspects of the matter, reducing the amount and costs of heat demand is worthy also to improve the social downside infamously known as *fuel poverty*. In 2009 nearly 20% of households in England were listed as being in fuel poverty and most of them live in private rented dwellings [4]. In other words, four million households cannot afford to heat the place they live in.
As shown in Figure 1, the public sector holds just a small amount of the dwelling stock, which is on average more energy efficient than the private one; this finding is not surprising, as local authorities and housing associations can access more easily to funding and grants, and can get bulk rebate from contractors. Nevertheless, in England approximately 10% of inhabitants in the social housing sector live in fuel poverty [5].

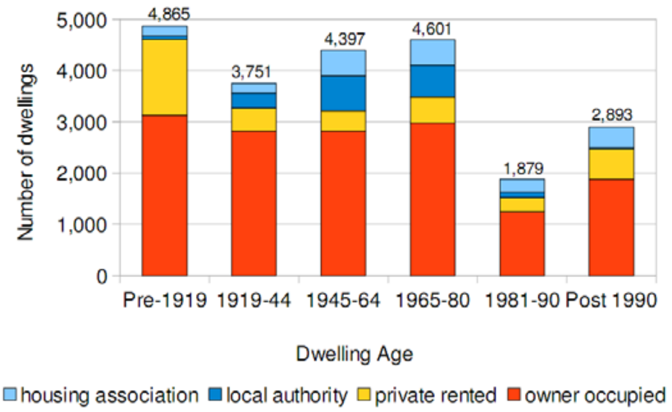

Figure 1. English dwelling stock profile in 2010, in numbers [3].

Most of the heat generated in the UK is wasted through inefficiently insulated envelopes, heats vacant rooms or warms too much lived spaces, causing loss of money and increment of CO_2 emissions. Lowering heat demand is the key to prevent short-term peaks and to encourage the use of energy from low carbon sources; it would also push for low-cost warmth and cut down fuel poverty [2]. The thermal performance of the current dwellings can be improved in two ways: by adding insulation to the envelope, and by reducing the unintended air leaks of the envelope [2, 6]. This study focuses on this second method, which can reduce heat waste of about 20%; moreover, an air-proof envelope can enhance the performance of the insulation and limit the damages to it. A traditional masonry solid wall building is analysed as case study.

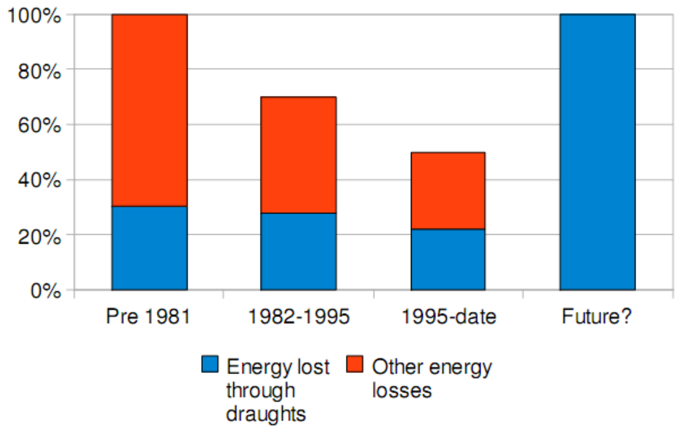

Figure 1. Heat losses [7, 8].

AIMS AND OBJECTIVES OF THE STUDY

This work does not aim at suggesting improvements to bring the existing English housing stock to the highest level of energy performance. A lot of literature is already been published on the topic and it is well known that, without funds from the government, very few owners can afford such an enhancement to their house. The main goal of this study is to suggest recommendations for lowering the heat losses through the building envelope due to air leakage that each owner can do by her/himself in a cost-effective manner. Thus the solutions suggested are affordable and feasible; practical, quick and simple, easy to find in the current market, and easily replicable in different buildings. Pushing for high-energy-performing retrofits is today very costly and it is feasible only if governments intervene with public funds or grants. There are some very efficient examples of retrofits, but they still are not frequent.
The rationale behind the approach proposed in this study is that by promoting feasible and affordable improvements, a larger audience can be involved in the energy-retrofit field. Walking baby-steps toward improving the efficiency of a house is easier and cheaper than performing massive works to insulate it, and more people can afford doing this. Once the existing housing stock reaches its best level of draught-proof, all other improvements (insulation, high performing systems) will be much more effective. The expected results on the long term are the ones suggested by the Energy Saving Trust such as reducing the level of energy needed to heat buildings, and as a result, cutting down energy bills. As explained in The Poverty Site, four million of households in England cannot afford to warm their houses. It is not conceivable that they commit in hugely demanding energy retrofit works. The approach proposed in this study has a surplus value due to the significant social impact it may have; this is another reason why it may be worth pushing for it.
Sealing against draughts is a cost-effective and efficient way to save money and energy in any building, as draught-proof solutions help warm air staying within the building. Householders can save lot money on their bills by simply reducing air leakages. As explained by the EST in the following:

"Full draught-proofing will save you on average £55 per year. Draught-free homes are comfortable at lower temperatures – so you'll be able to turn down your thermostat. This could save you another £60 per year. If every household in the UK used the best possible draught proofing, every year we would save £190 million, and enough energy to heat nearly 400,000 homes." [9]

LITERATURE REVIEW

Traditional Building Construction

Traditional buildings in England have masonry solid thick walls (usually 50-60 cm) made up of stones laid in lime or earth mortar. These walls are inhomogeneous, composed by an external stone leaf, an internal stone leaf and the gap between the two filled with mortar and rubble (a cheap local material); the three layers are glued together by the mortar. The most common internal wall finishes are as follows: plastered on the hard; plaster on laths; dry-lining; or timber lining. All these finishes, apart from the plaster on the hard, are attached to the wall through flat wooden strips (battens) and studs. The distance from the wall to finish could vary from 25 mm (for plaster on laths) to 50 mm for dry-lining and the resulting cavity was usually air-filled [10, 11] (see Figure 3).

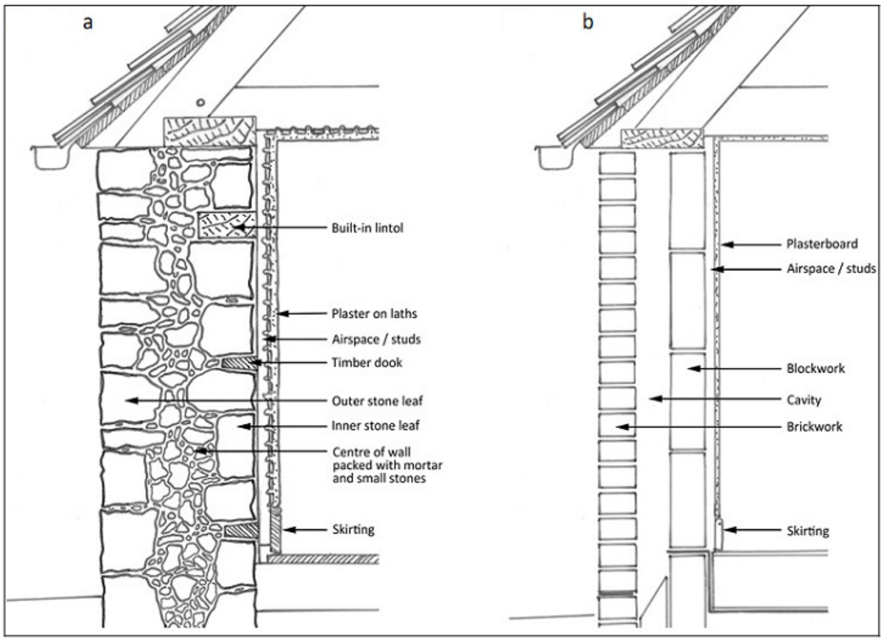

Figure 3. Comparison of (a) traditional solid masonry wall construction and (b) non-traditional cavity wall construction [10].

Air Leakage in Traditional Buildings

Air leakage occurs when air passes through the building envelope through cracks and gaps. The amount of air infiltration depends on the design and quality of the construction. The wind blowing against the construction may also induce air infiltration, as it causes a difference in pressure between the inside of the house and the outside: on the windward wall air gets into the house through gaps (infiltration), while in the leeward face air gets out (exfiltration) [12].
Despite their permeability, pre-1900 houses are frequently more airtight than some modern buildings; this might be due to the fact that the skilled labour who built traditional constructions was more precise than the modern one [13, 14, 15].

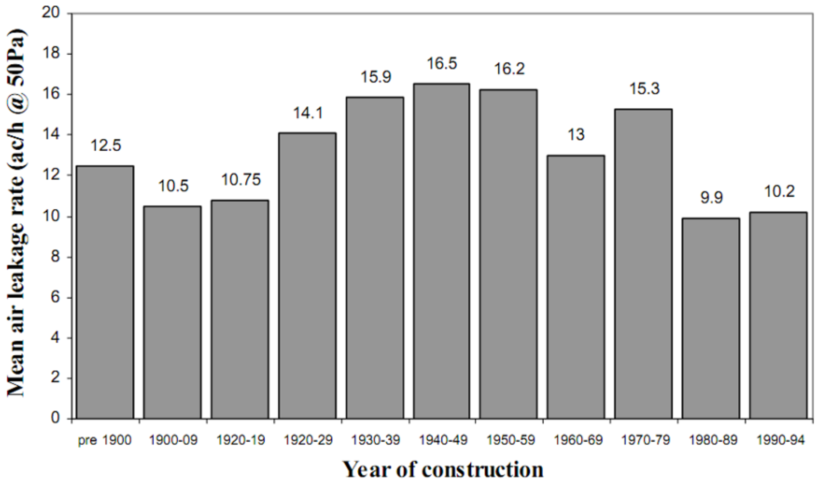

Figure 4. Relationship between dwelling age and air leakage [13].

Antretter et al. [15] highlight also that houses built after 1980 are tighter than previously built ones. Such a difference is explained by the use of upgraded and new materials, and improved construction and design techniques. The evolution of building codes has also played a key role in promoting the enhancement of airtightness. The same research found that bigger houses tend to have more air leakage and that seasonal changes have no effects on building air leakage.
Sedlak et al. [16] found that 1950s houses are more airtight than modern and refurbished ones, and this probably depends on the construction method (solid walls with wet plastering).

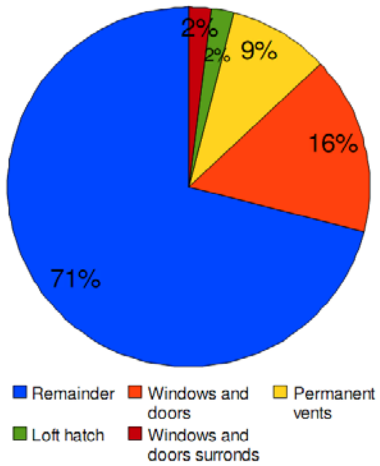

Figure 5. Air leakage paths [17].

As the above figure highlights (see Figure 5), the bigger slice (71%) is composed by the remainder, namely [17]:

• *Plasterboard dry lining on dabs or battens;*
• *Cracks, gaps and joints in the structure;*
• *Joist penetrations of external walls;*
• *Timber floors (under skirting and between boards);*
• *Junctions between internal stud walls and with floors and ceilings;*
• *Electrical components such as sockets, switches and light fittings;*
• *Service entries and ducts;*

• *Areas of unplastered wall between intermediate floors, behind baths etc.*

The Holistic Approach

Adopting a holistic approach in energy retrofitting a traditional building is crucial. Before making any changes to improve energy efficiency, it is fundamental to understand how traditional buildings were designed to work; how tick walls perform in term of thermal mass; how moisture moves within the structure; and what is the actual thermal performance of the house. Several completed retrofits are based on modern methods of insulation and internal climate control which has been deleterious for buildings [6, 10, 11, 18].

As explained previously, traditional constructions are made of soft and pervious materials, and therefore the building envelope is permeable to moisture and water vapour. Traditional buildings behave in a quite different way from modern ones, and this must be taken into consideration when working on energy retrofit.

Traditional masonry wall	**Modern masonry wall**
Massive construction, thick walls	Relatively slender construction
Porous, highly permeable construction	Porous materials but low permeability finishes
Large volume of absorbent materials (porous stone and mortar)	Limited ability to absorb moisture
Moisture can penetrate into and evaporate easily from the wall. This helps stabilise moisture levels in rooms	Moisture within the wall not easily evaporated
Modern levels of insulation may not be achievable	Insulation materials may be adversely affected by moisture
Construction can absorb small thermal and moisture movements	Well insulated construction Prone to cracking due to hard, brittle materials Cracks in external finishes permit water penetration into construction
Air movement required behind dry lining to prevent raised moisture content of timbers	Ventilation of cavities not required
Damp-proof course not normally installed	Damp-proof course essential
No vapour checks or barriers	Vapour checks integrated into construction

Table 1. Comparison of traditional masonry wall and modern masonry wall constructions [11].

As Urquhart suggests, new additions should never be stronger or denser than the existing elements, as they could deteriorate the original structure, which he also encourages the use of material of natural origin. Furthermore, adding too different materials to a traditional solid wall could affect its moisture equilibrium and risk to damage the timber elements in touch with the wall.

The traditional construction techniques exploit the higher thermal mass of thick walls to regulate the temperature and comfort within the building, cooling it in the summer and warming it in the winter. Despite the potential energy efficiency of traditional building envelopes, they often over-leak heat, mainly through cracks and holes in the fabric, unused open chimneys and fireplaces, gaps around windows and door frames [6, 10, 11, 18].

Traditional masonry constructions usually do not have damp-proof courses or damp-proof membrane under the ground floors. They use the mass of the walls and the movement of the air to balance the moisture transfer coming from the ground; porous walls exploit capillarity forces to drag moisture in their inside and let it evaporate on their external surface. It is therefore important to keep the porosity of the walls, in order to allow air to pass and draw moisture. The experience has shown that inserting modern moisture barriers may not be an effective solution, and it may be better to add perimeter drainage to regulate the effects of raising damp [11].

CASE STUDY: J&M'S HOUSE IN NETHER EDGE, SHEFFIELD, UK

Nether Edge is a Conservation Area located few miles south west of Sheffield, South Yorkshire, UK. The area is a leafy suburb, characterised by fine Victorian and Edwardian buildings. J&M's house is a 19th century Victorian semi-detached house located in this neighbourhood.

Air Leakage Points

The main air leakage points in J&M's house have been identified [19]. Like in thermal insulation, in correcting airtightness it is crucial to have continuity. All gaps and cracks in the structure allow air to get into and out the building, so they all should be sealed at the same time. The table below lists the most common problems and the suggested improvements (see Table 2).

Most common problems	**Suggested improvements**
Gaps in cellar's walls and ceilings	• All gaps, holes and breaks in the walls of the cellar need to be repaired with materials similar to the existing ones. • Top hat elements or collars may be used to seal around services pipes. • Small cracks around pipes can also be sealed with silicon fillers, while larger gaps can be filled with expanding polyurethane foam.
Gaps in and around suspended timber floors	• All damages and gaps in the timber floor should be repaired. •The junction between suspended timber floors and the skirting should be sealed with a flexible sealant. • Joints in timber floor should be sealed with suitable glue and any angular edge joints in the decking to the joists should be fully supported and fixed. • If there is an air barrier, all penetration through it should be filled up with a flexible sealant. • Gaps around service pipes passing through suspended timber floors should be adequately sealed.
Gaps around windows and doors	Draught-proofing timber windows limit air leakage and improve the internal comfort. • It is not a good practice to use foaming gap-filling adhesives, as they tend to contract and break the seal. Internally silicone is an appropriate sealant, while for the exterior it is better to use moisture-resistant strips of EPS between the window frame and the reveals. • Window closing devices need to be checked to secure a tight closure. • The wall-to-frame junctions need to be air-proof and can be sealed, especially at sills. • It is better to avoid draught-stripping existing windows and external doors in kitchens and bathrooms unless there is an extract fan [14]. Sealing outside doors is very cost-effective as it is cheap but can save a lot of heat. • Four main elements have to be considered: 1. the keyhole has to be covered by a metal disk that falls down when the key is not in; 2. the letterbox should have a flap or a brush; 3. the gap at the bottom should be closed with a brush or hinged flap draught excluder; 4. gaps around the edges should be filled up with fit foam, brush or wiper strips like the ones used for windows. The doors in the inside have to be draught-proofing, especially if they connect unheated to heated spaces. • Gaps around these doors should be sealed with a draught excluder that can be made by used plastic bags or pieces of spare material [9].

Gaps at the ceiling-to-wall joint at the eaves	• The ceiling junction has to be continuous. If it is not, an airtightness membrane or tape should be installed; as alternative, a flexible sealant should be applied between ceiling board and wall. • The ceiling should be repaired first (if necessary), and then all gaps between ceiling and the masonry wall should be sealed with flexible or adhesive sealant.
Open chimneys	• It is appropriate to close fireplaces and chimneys, and this can be done in two ways: by adding a vent in the fireplace or a chimney balloon (an inflatable cushion that blocks the chimney); and by capping the chimney-pot with a hood (it is recommended to have this work done by a professional) [9, 14].
General air leakage through walls	• Collars should be applied around the pipes, in order to better airtight them; otherwise a weather-resistant sealant should be applied. • All gaps and cracks in the wall should be repaired by using materials similar to the existing ones.
Bathroom and kitchen wall vent or extract fan	• Gaps around the extractor fans and cooker hoods have to be properly sealed. • If in the wall there are old fan outlets, these should be filled with material similar to the existing wall and sealed either in the inside or the outside [9].
Gaps around bathroom and kitchen waste pipes	• Gaps around pipes should be sealed with top hat elements or collars. •All services passing through the wall (water, drainage, gas pipes, boiler flues and electrical cables) that have some gaps around the pipes should be sealed with an appropriate sealant. • Sealants around boiler flues have to be heat resistant [14].
Gaps around loft hatches	• The loft hatch has to be sealed with an air-proof tape. • Having the hatch thermally insulated, as well as the rest of the ceiling, is a plus [14].
Gaps around service pipes	• Gaps around service pipes, cables and ducts should be blocked with top hat elements or collars and be sealed with an appropriate sealant. • Sealant around hot pipes has to be heat resistant.
Ceiling roses and recessed ceiling lights	• Holes around light fittings and pull cords in the ceiling should be appropriately sealed and, if possible, an airtight box over the light fitting in the ceiling void should be installed. • When changing the light fittings, it is good practice to choose airtight ones [14].

Table 2. List of most common problems and suggested improvements [19]

CONCLUSION

Old houses have modified over time to adjust to the changing needs of the owners and to the environment. However, the variations they had not always benefit the energy performance of the building, as shown by the case study.

J&M's house has very special features that make it very characteristic and appealing: beautiful chimneys almost in every room, high ceilings, large windows, spacious cellar. The downside of these features is that they ask for a lot of energy in order to keep rooms warm and comfortable and that they favour the waste of heat.

The house perfectly adapted to the changing needs of the owners: as bedrooms were rented to different people, new bathrooms were added and the new pipes were installed on the outside walls. While making the house more liveable, these improvements required to pass the pipes through the external walls, leaving gaps around them where heat is lost. Also the age of the house does not help much in term energy performance, as the settlements of the ground over time caused cracks to the ceiling-to-wall joints and to the floor-to-wall joints.

The issues found in J&M's house are common in pre-1900 English buildings, but they can be easily fixed with simple and cost-effective improvements. The benefits householders can have from such enhancements are often underestimated, but they may be worth the work and the cost of doing them. Raising the airtightness of old buildings limits the amount of heat wasted through the envelope, with the resulting less heat required to have a comfortable temperature in the rooms. Home owners can save up to more than £100 per year on their energy bills (mainly heating). Furthermore, bringing the draught proof of the dwelling to its best will lift

considerably the effectiveness of the insulation, of the high performance systems, and of all other enhancements done to improve the energy performance of the house.
The literature suggests that up to 20% of energy can be saved by bringing the air-proofing of existing buildings to their best. Such an amount is significant and commonly undervalued in the energy retrofit processes. Energy performance software usually focuses on U-values and do not consider the raise in thermal performance due to the improved airtightness. For practical purposes this is tricky.
Let's suppose the thermal performance of a building is actually improved by 20% only by limiting its air leakage. No software will corroborate a shift to a higher energy efficiency rating band; but in the reality, this could happen, above all for buildings laying at the highest limit of a band (a dwelling in band E, rating 53 or 54, could raise to band D).

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REFERENCES

[1] Energy Saving Trust. (2010b). *Sustainable Refurbishment*. London.
[2] Department of Energy and Climate Change. (2012). *The Future of Heating: A Strategic Framework for Low Carbon Heat in the UK*. London.
[3] Department for Communities and Local Government. (February 2012). *English Housing Survey. Headline Report 2010-11*. London. ISBN: 978-1-4098-3314.
[4] The Poverty Site. (2012). *Fuel Poverty. Key Points*. (Accessed on April 2012): http://www.poverty.org.uk/.
[5] Energy Saving Trust. (2010a). *Reducing Emissions from Social Housing*. London.
[6] Jenkins, M. (2011). *Improving Energy Efficiency in Traditional Buildings*. Historic Scotland, Longmore House, Salisbury Place, Edinburgh.
[7] Jennings, P. (2001) *Airtightness in Buildings. (Parts 1 & 2)*. Building for a Future, Winter 00/01, Spring 01.
[8] Morgan, C. (2006). *Design and Detailing for Airtightness*. SEDA Design Guide for Scotland No. 2. SEDA.
[9] Energy Saving Trust. (Accessed April 2012): http://www.energysavingtrust.org.uk/.
[10] Baker, P. (2011). *Historic Scotland Technical Paper 10*. Historic Scotland.
[11] Urquhart, D. (2007). *Conversion of Traditional Buildings. Application of the Scottish Building Standards. Part 1. Principles and Practice*. Historic Scotland, Edinburgh.
[12] Jaggs, M. and Scivyer, C. (2009). *A Practical Guide to Building Airtight Dwellings*. Published by IHS BRE Press on behalf of the NHBC Foundation.
[13] Johnston, D., Wingfield, J., Miles-Shenton, D. and Bell, M. (2004). *Airtightness of UK Dwellings: Some Recent Measurements*. Paper presented at COBRA 2004 conference.

[14] GreenSpec (Accessed April 2012): http://www.greenspec.co.uk/.
[15] Antretter, F., Karagiozis, A.N., TenWolde, A. and Holm, A. "Effects of Air Leakage of Residential Buildings in Mixed and Cold Climates." in *Thermal Performance of the Exterior Envelopes of Buildings X*, Proceedings of ASHRAE THERM X, Clearwater, FL, Dec. 2007.
[16] Sedlak, P. and Sheward, N. (2008). *Advanced Ventilation Approaches for Social Housing (AVASH) - Irish Sampling & Survey Report*. DWEcoCo and Cluid Housing Association.
[17] Trainenergy (Accessed April 2012): http://www.trainenergy-iee.eu/.
[18] Pickles, D., Brocklebank, I. and Wood, C. (2011). Energy Efficiency and Historic Buildings. English Heritage. SEDA.
[19] Barbisan, R. (2012). *Energy Retrofit of the Existing Housing Stock in England.* Master Thesis (Master Klimahaus). Faculty of Science and Technology, Free University of Bolzano, Italy.