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## Abstract

A large portion of the UK housing stock was built before the introduction of the 1989's building regulations in which insulated cavity walls became mandatory. It is estimated that 65% of the UK housing stock have uninsulated walls and 49% have single glazed leaky windows making them inefficient in terms of energy performance. There have been great efforts during the recent years to improve the quality and energy performance of such buildings through retrofitting/refurbishment not only to improve the living standards of their occupants but also to achieve UK's carbon emission targets for 2050. Refurbishing such buildings to improve their quality/energy performance may, at the same time, increase the risk of poor indoor air quality (IAQ), condensation, dampness, and mould growth in these buildings. Many refurbished housing stock in the UK are facing similar problems. Damp and mould issues affect between 30-50% of new or refurbished buildings. There is therefore a need for appropriate design strategies not only to improve the quality and thermal performances of such buildings but also to reduce the aforementioned risks through better design, construction detailing, methods, and management processes. This paper reports on the first phase of a joint university/industry Knowledge Transfer project to address the above issues in renovated student accommodations in North West England. Temperature, relative humidity, CO<sub>2</sub>, and meter readings are measured and recorded in three case study buildings. Results revealed a direct relationship between energy consumption, IAQ, and occupants' behaviours in the buildings. CO<sub>2</sub>, Temperature, and RH levels were more acceptable in one of the case study buildings; however, its energy consumption was 7 times higher when compared with a similar building.

**Keywords:** *Refurbishment, damp, mould, indoor air quality, energy efficiency, domestic buildings.*

## Introduction

With around 8.5 million over 60 years old properties, Britain has the oldest housing stock in the developed world (Energy Saving Trust 2007). A large portion of the UK housing stock was built before the introduction of the 1989's building regulations in which insulated cavity walls became mandatory. It is estimated that 65% of the UK housing stock have uninsulated walls and 49% have single glazed leaky windows making them inefficient in terms of energy performance (Building Research Establishment 2005).

Around one third of UK carbon emissions are related to the housing sector (English Heritage 2012 and Department of Energy Climate Change 2013) and considering the current replacement rates, it would take around 1000 years to renew the entire housing stock in the UK (Building Research Establishment 2014a, Energy Saving Trust 2007). More than 70% of the estimated housing stock in England in 2050 has already been constructed (English Heritage 2012). Improving the environmental performances of

existing properties is therefore vital to achieve the UK Government's carbon emission targets aiming to reduce carbon emissions by 34% by 2020 and 80% by 2050 (Building Research Establishment (2014a), Department Energy Climate Change 2009 and Technology Strategy Board 2013).

Recently, considerable efforts have been made to improve the quality and energy performance of the existing buildings by retrofitting/refurbishment through national schemes such as the Green Deal Building Research Establishment (2014b) and Department of Energy and Climate Change (2010). This is not only to achieve the UK's carbon emission targets but also to improve the living standards of the UK population with a focus on vulnerable people helping them to enjoy "warmer" homes (HM Government 2011). There were around 35,000 excess winter deaths in 2008-9 in the UK which could have been avoided through warmer housing. Meanwhile, according to BRE it is estimated that by 2030 the current average annual energy bill of households (£1,124) could rise by 33% which may deteriorate the current issues with regards to the fuel poverty.

There are some direct health benefits associated with improved thermal comfort in dwellings (Department for Communities and Local Government 2007); however, refurbishing old properties (particularly those with existing damp and mould issues) to improve their energy performance may increase the risk of poor indoor air quality by, for example, reducing the ventilation rate and/or trapping the moisture inside the buildings and materials (English Heritage 2012 and Zolfagharifard 2014) resulting in even more damp and mould issues. Many refurbished housing stock in the UK are facing similar problems. Damp and mould issues, according to the Health and Safety Executive, affect between 30-50% of new or refurbished buildings (Zolfagharifard 2014).

Indoor dampness severity also depends on the climatic conditions and varies from country to country. According to the WHO, dampness affects around 10-50% of buildings in Europe, North America, Australia, India and Japan (World Health Organization 2009). According to DCLG (Department for Communities and Local Government 2014), in 2012, out of 22.0 million households in England, around 970,000 homes had some problems with damp. Condensation and mould were the most common issues affecting 3% of the properties followed by penetrating and rising damp affecting 3% and 2% of homes respectively.



**Figure 1: Percentage of houses with damp problems (2012)**  
 Source: Department for Communities and Local Government (2014).

Privately rented properties in the UK are the poorest in terms of energy performance (Building Research Establishment 2005) and damp related issues (Department for Communities and Local Government 2014). According to the Department for Communities and Local Government, some 9% of the private rented properties have problems with damp (Fig. 1) and around 33% do not meet the minimum standards for a decent home (Department for Communities and Local Government 2014).

This paper reports on an ongoing joint university/industry project to address the above issues in renovated student accommodations in North West England. It is aimed to develop strategies to reduce the risks of condensation, dampness and mould growth in renovated properties through better design, construction detailing, methods and management processes.

### IAQ related health issues

Indoor air could be much more polluted than external air (World Health Organization 2006) and as people spend around 60-90% of their time indoor (Slezakova, Morais and Pereira 2012), even minor amounts of contaminants in buildings can significantly increase the occupants' exposure to the pollutants and affect their health (WHO 2009 and Crump, Dengel and Swainson 2009). It is estimated that poor indoor air quality (IAQ) is responsible for around two million disability adjusted life years (DALYs) per year, which is about 3% of the total burden of disease (BoD) due to all diseases in Europe (European Federation of Allergy and Airways Diseases Patients' Associations 2013).

Indoor air contaminants include CO, NO<sub>2</sub>, odours, volatile organic compounds (VOCs), allergens, environmental tobacco smoke (ETS), damp and mould (Energy Saving Trust 2005, 2006a and Jantunen *et al.* 2011) which may result in Sick Building Syndromes (SBS). SBS have been increasing since the 1970s as old, naturally ventilated buildings are gradually being replaced with airtight, energy efficient buildings (Reidlich, Sparer and Cullen 1997). The main symptoms associated with SBS are: headaches; dry or itchy skin, eyes, nose, and throat; lack of concentration; runny or congested nose (Health and Safety Executive 2000, Reidlich, Sparer and Cullen 1997 and Zolfagharifard 2014).

Microbiological pollution in general and filamentous fungi (mould) in particular are of major indoor air pollutants (Energy Saving Trust 2006a, World Health Organization 2009). There is a proved relationship between exposure to dampness and various health issues such as allergies and asthma (Andersen *et al.* 2011, American Society of Heating, Refrigerating and Air Conditioning Engineers 2011, Gravesen *et al.* 1999, World Health Organization 2009, Piecková and Jesenská 1999 and Storey *et al.* 2004). The major reason for the microbial and mould growth is persistent dampness which may also result in survival of viruses and bacterial growth (Andersen *et al.* 2011, Institute of Medicine 2004 and World Health Organization 2009).

Dampness is an indicator of insufficient ventilation which may in turn result in excessive concentration of pollutants and poor IAQ. It is estimated that 11% of the IAQ associated BoDs is due to the building dampness (Jantunen *et al.* 2011). The risks associated with poor indoor environments are more severe for more vulnerable groups, such as children and older people considering their life styles and the amount of time spent at home (European Environment Agency 2011, Garrett *et al.* 1998, Jantunen *et al.* 2011, Slezakova, Morais and Pereira 2012 and World Health Organization 2006).

Health related building regulations and standards are not sufficiently covering the requirements for avoiding/controlling excessive moisture and dampness (World Health Organization 2009). Appropriate building standards should therefore be developed not only to improve the thermal performances of buildings but also to reduce the aforementioned health risks in new and refurbished buildings.

#### **Basic strategies to reduce risks of damp, condensation, and mould growth**

There is no such thing to assume there is one generic solution to all damp and mould problems (English Heritage 2012). Therefore, refurbishment/retrofitting strategies should be on a case by case basis (Energy Saving Trust 2007). There are however some basic recommendations which could be considered to reduce the risk of dampness and mould growth in buildings.

It is generally accepted that moisture is the most critical pollutant in dwellings (Energy Saving Trust 2005, 2006a). Controlling moisture is an effective way to control fungi/mould (Institute of Medicine 2004) which can damage building materials (Pitkaranta *et al.* 2011). One of the major ways to reduce dampness in buildings is increasing the ventilation rate (British Standard Institute 2002b).

Studies suggest that providing enough and effective ventilation to remove excessive moisture is also enough to control other pollutants (Energy Saving Trust 2006a); however, absence of dampness does not necessarily mean acceptable IAQ. While maximum ventilation is required to control dampness, minimum ventilation is required to control CO<sub>2</sub> levels and provide enough Oxygen in dwellings (Energy Saving Trust 2006a). Therefore, CO<sub>2</sub> concentration levels and Relative Humidity (RH%) are good indicators to evaluate the effectiveness of ventilation in residential buildings.

According to BS 5250 (British Standard Institute 2002), two major ways of controlling dampness, surface condensations, and mould growth are:

- a) increasing ventilation and/or reducing generated moisture to reduce vapour pressure; and
- b) increasing internal temperature and/or insulation to achieve higher surface temperature (British Standard Institute 2002b).

In other words, decreasing ventilation rate will increase the risk of condensation and mould growth unless it is counterbalanced by reducing generated moisture or by increasing insulation and/or internal temperature. Mould is very likely in buildings where a steady surface RH of 80% and above is probable (British Standard Institute 2002a, 2002b and Chartered Institution of Building Services Engineers 2006).

The general aim should be to improve energy performance of the building (Energy Saving Trust 2006b, 2007) while keeping the RH% below 70% (Energy Saving Trust 2005). Other studies indicate that a lower RH (60%) would be enough for mould to develop (Crook and Burton 2010). To achieve effective ventilation strategies, local extraction will be required for rapid removal of moisture at the point of production to avoid spread of moisture to other parts of the building. Openable windows will also help for rapid purge ventilation of moisture (Energy Saving Trust 2005).

Improving thermal performance of the building by increasing the thermal insulation is another approach which should be considered in addition to the ventilation strategies. Retrofitting strategies may include, internal/external wall insulation; roof/loft insulation, floor insulation, draft stripping, insulated doors, replacing old windows with high energy performance windows. However, the adopted specification greatly depends on the construction form/type and the main purpose of the improvement (Energy Saving Trust 2006b, 2007).

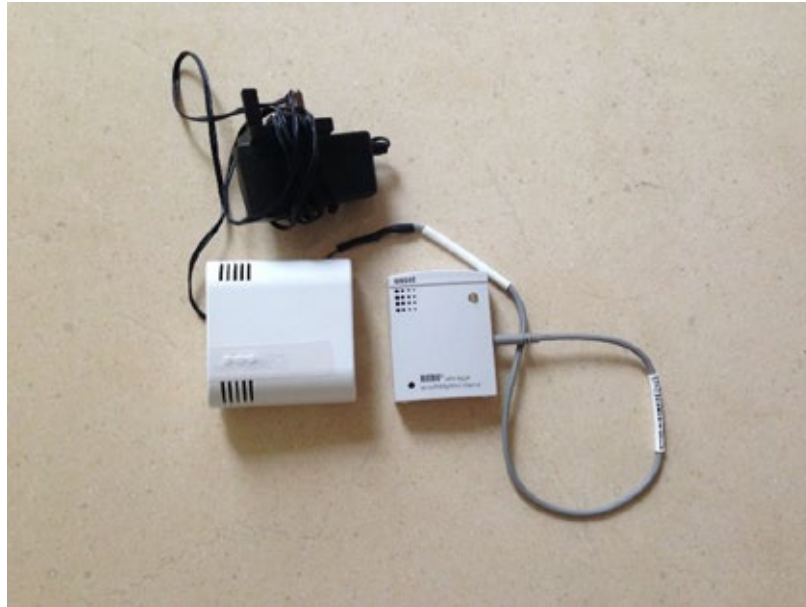
#### Project's **Research Methodology (Phase 1)**

Three typical student accommodations properties managed by Mistoria Group within the North West of England were selected after several visits and discussions on 11 properties. A building survey was then completed for the selected properties to record building layout, orientation, construction method, building materials, and signs and extent of mould and dampness. A checklist was developed to facilitate this survey. This information will be used for the computer models.

Data loggers and sensors were installed in the selected buildings to measure and records four indicators of temperature, RH%, light, and CO<sub>2</sub> for a period of six months to identify the percentage of time when these are above acceptable levels recommended by CIBSE (Chartered Institution of Building Services Engineering) and WHO. This is done to identify the extent of any existing IAQ related issues in the case study buildings.

For the purpose of physical measurements five HOBO U12/12 data loggers and two CO<sub>2</sub> sensors with traffic light indicators were installed in each property to record RH%, Temperature, and CO<sub>2</sub> concentrations on 15 minutes intervals (Fig. 2). The traffic lights were covered to avoid disturbing the occupants particularly in the bedrooms. According to the manufacturers' data sheets, CO<sub>2</sub> sensors can measure a range of 400-4000ppm with an accuracy of +/- 5%. Data loggers also can measure temperature and RH ranges of -20°C to +70°C; and 5% to 95% RH respectively. As suggested by BSRIA (Building Services Research and Information Association 1998), sensors and data loggers were installed at a height of 1-1.5m above the floor level.





**Figure 2: Hobo U12 data logger and CO<sub>2</sub> sensor**

Gas and Electricity meter readings were also recorded to evaluate the energy consumptions of the case study buildings (CSBs). The collected data were used to evaluate the current situation of the CSBs as well as the ways forward to prevent/control dampness, condensation, and mould growth in the properties while optimising their energy performance.

### **Case Study Buildings**

The case study buildings are typical 4-5 bed two-storey mid-terrace, end-terrace, and semi-detached houses occupied by students and are located in Salford/Manchester. All properties have one bathroom/shower on the first floor, with the kitchen and living rooms located on the ground floor. Bedrooms are positioned on both ground and first floor levels. Out of three shortlisted properties one was removed from the study due to the irregular occupancy patterns which affected the reliability of the results. Physical measurements were therefore carried out for two buildings only. Both buildings have masonry walls with energy performance certificate (EPC) rating of C and are located in residential areas surrounded by similar two-storey buildings (Fig. 3).



**Figure 3: Locations of the Case Study Buildings**

In both buildings heating and hot water are provided by gas-fired central heating systems controlled by radiator valves. None of the CSBs have mechanical cooling systems and ventilation is provided through openable doors and windows in addition to local extract fans in the kitchens and bathrooms. CSB1 also benefits from the hit and miss vents which help to enhance the natural ventilation. Table 1 summarises the specifications of both case study buildings.

**Table 1: Characteristics of CSBs**

	CSB1	CSB2
Location	Salford/Manchester	Salford/Manchester
Area (m <sup>2</sup> )	123	96
Building Type	Semi detached	Mid-terrace
Construction type	Masonry	Masonry
Glazing type	Double glazed PVC windows	Double glazed PVC windows
Energy Performance Certificate (EPC) Rating	C (73)	C (72)
Number of storeys	2	2
Number of occupants	5	4
Number of Bathrooms	1	1
Heating System	Central heating and local radiator	Central heating and local radiator
Cooling system	No cooling system	No cooling system
Ventilation System	Natural ventilation (windows, doors and hit & miss vents) + local extract fans	Natural ventilation (windows, doors) + local extract fans

### Results of the studies (Phase 1)

Physical measurements were conducted in order to study the performance of the CSBs. Collected data from the living rooms and one of two similar bedrooms are reported below.

As shown in Figures 4 and 5, IAQ and thermal comfort have been considerably better in CSB1 compared to CSB2. The relative humidity in CSB1 almost always remained in acceptable ranges of 40-60%, recommended by CIBSE (Chartered Institution of Building Services Engineers 2006), while in CSB2 the RH exceeded 60% several times revealing a high risk of condensation, damp, and mould growth in this building.

Results also revealed that the RH and outside temperature ( $T_o$ , based on Weather Underground data, Salford, Manchester) (Weather Underground 2014) followed the same pattern in CSB1 (especially in the bedroom). This is most probably because of high ventilation rates due to frequent opening of the windows/vents and/or high air permeability rate of the building. Reduced internal RH in CSB1 is caused by the mixture of internal warm air (with high water content) with external cold air and very low water content despite the high external RH (Hashemi and Gaze 2014). Although CO<sub>2</sub> concentration levels in CSB1 were considerably lower than CSB2, CO<sub>2</sub> levels were still higher than the maximum recommended level of 1200 ppm suggested by BS EN 15251 for existing buildings (British Standard Institute 2007).



Moreover, according to the physical measurements, the bedrooms' average daily temperatures were 19.1°C and 16.2°C in CSB1 and CSB2 respectively. This is while, according to WHO (World Health Organization 2003), an indoor air temperature of 18°C is recommended for bedrooms and, according to Hong, Oreszczyn and Ridley (2006), average bedroom temperature in England is 18.5 °C. Average living rooms' temperature in CSB1 and CSB2 were also 19.7 °C and 16.7 °C respectively. It should be noted that the average temperature in CSB1 is also higher than the average living room temperature of 19.1°C in England (Hong *et al.* 2006).

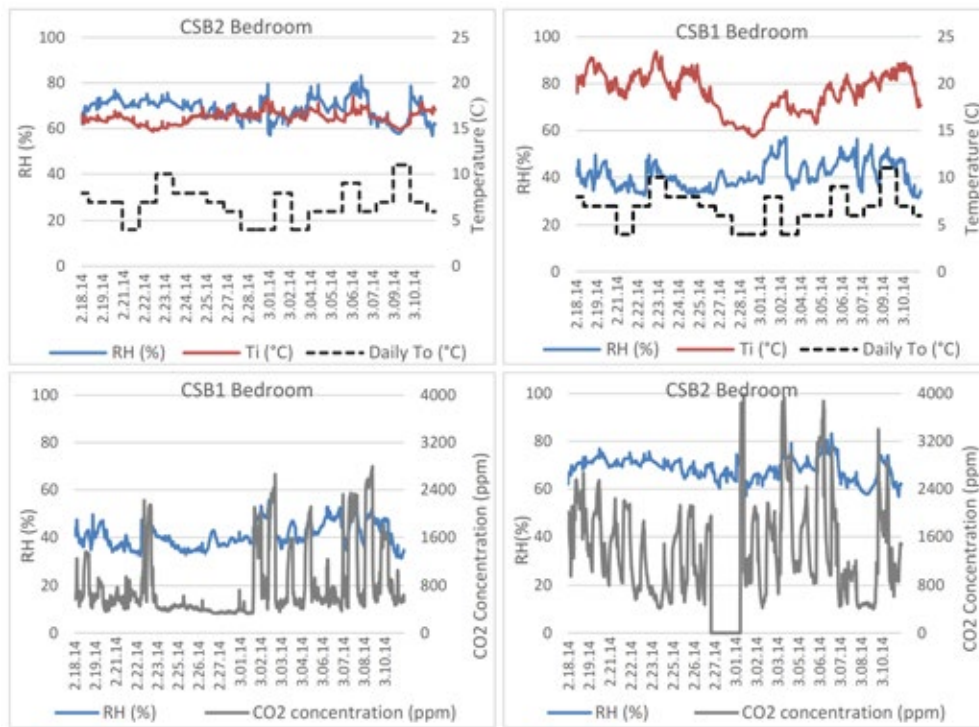


Figure 4: Temperatures and IAQ in two similar bedrooms

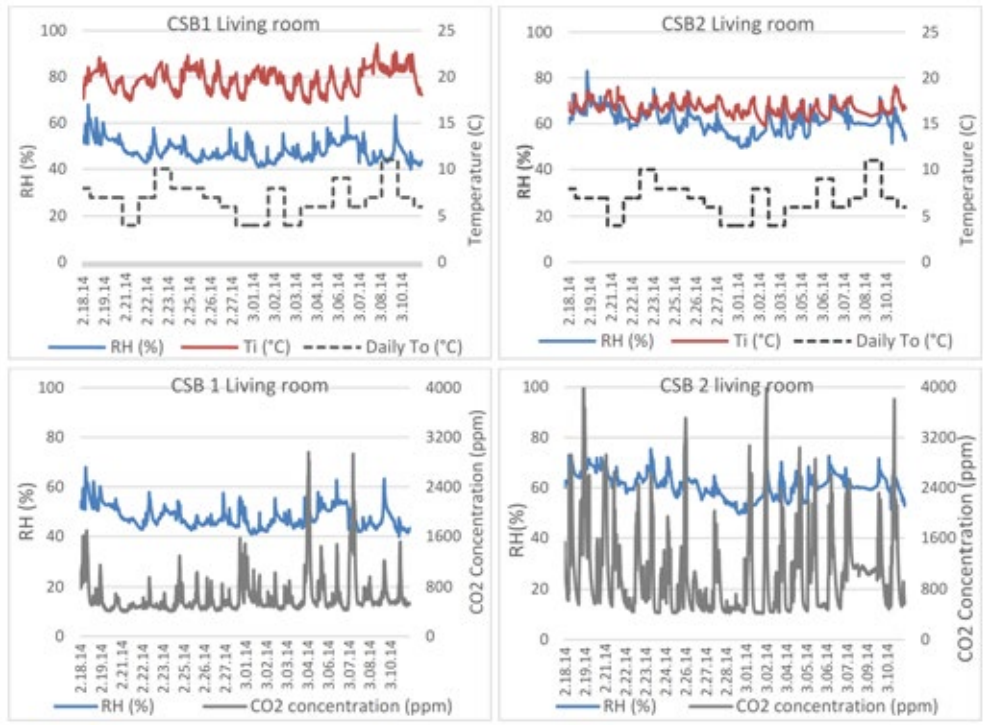
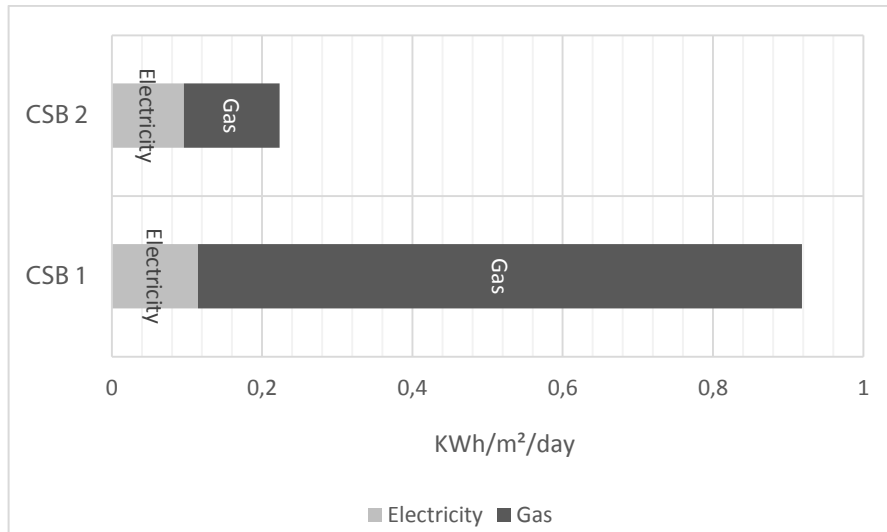


Figure 5: Temperatures and IAQ in living rooms

Meter readings showed slightly higher electricity consumption in CSB1 which could be explained by higher number of occupants (Tab. 1). However, according to recorded energy consumption, gas usage in CSB1 was around 7 times higher than in CSB2 (Fig. 6). Although CSB1 provided better IAQ and thermal comfort, energy consumption was considerably higher and remedial actions are required to solve this issue.

Occupants' behaviours and construction details appear to be the main reason for such huge differences in energy performance, IAQ, and RH% of the CSBs. According to the recordings and the observations, CSB1's occupants frequently opened the windows whereas occupants of CSB2 kept the windows closed which meant high and low energy consumptions associated with rather acceptable and poor IAQ respectively. Construction details (e.g. Hit & Miss vents) on the other hand, provided more ventilation in CSB1 while ventilation seemed to be unsatisfactory in CSB2.



**Figure 6: Average daily energy consumptions in the case study buildings**

According to the findings, bedrooms may pose more critical conditions in terms of IAQ and RH levels. Better IAQ and RH levels in the living rooms in both buildings seem to be related to the life style of students and larger sizes of the living rooms. Therefore, it could be argued that design strategies should concentrate more on providing acceptable IAQ and RH as well as thermal comfort in the bedrooms.

### Conclusions

This study intends to develop refurbishment strategies to prevent/control dampness, condensation, and mould growth while improving the energy performance of buildings. According to the results of Phase 1 of the studies on the case study buildings, CSB1 had better CO<sub>2</sub> and RH% levels with acceptable internal temperatures and very high energy consumptions. CSB2, however, had a very poor IAQ in terms of CO<sub>2</sub> and RH% levels with rather low internal temperatures falling below the average UK standards. This was despite the fact that both CSBs are similar in terms of construction details, EPC ratings and number of occupants.

The challenge of this research is therefore to refurbish the case study buildings to improve their energy performance without sacrificing IAQ. Although it is generally believed that improving IAQ is associated with increased energy consumption, studies show that both IAQ and energy efficiency could be improved (American Society of Heating, Refrigerating and Air Conditioning Engineers 2011) if efficient refurbishment strategies are considered. Yet, although there are some existing recommendations to improve the energy performance and IAQ of buildings, it should be borne in mind that “no one size fits all” (English Heritage 2012) and to achieve the best results, each building should be treated separately considering its unique conditions including building behaviours; construction details; orientation; location; and occupancy patterns, types and behaviours.

This paper reported on the Phase 1 of the KT research project. The following are the next stages of the study:

- a) air pressure tests will be carried out to identify the air permeability rates of the case study buildings to evaluate the possible effects of air infiltrations on the

- IAQ and energy performances of the buildings. One test will be carried out for each case study buildings;
- b) questionnaire surveys will be carried out to study/record the occupants' lifestyles and occupancy patterns in more detail;
  - c) CAD models of the selected CSBs will be developed using all data from the physical measurements;
  - d) dynamic thermal simulations will be conducted to evaluate the effects of various construction details and ventilation rates on IAQ, dampness, condensation, and mould growth as well as on the energy performance of the buildings; and
  - e) triangulation of results achieved from aforementioned stages will be correlated to establish recommendations to prevent/control dampness, condensation and mould growth in the properties while optimising their energy performance.

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### References

ANDERSEN, B., FRISVAD, J.C., SØNDERGAARD, I., RASMUSSEN, I.S., and LARSEN L.S., 2011, 'Associations Between Fungal Species and Water-Damaged Building Materials', *Applied and Environmental Microbiology*, 77(12), pp. 4180-4188.

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR CONDITIONING ENGINEERS, 2011, Position Document on Indoor air quality, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta.

BUILDING RESEARCH ESTABLISHMENT, 2005, 'Energy Use in Homes: A Series of Reports on Domestic Energy Use in England,' Energy Summary Report, Building Research Establishment, Watford.

BUILDING RESEARCH ESTABLISHMENT, 2014b, Green Deal Guide: The Green Deal Explained, Building Research Establishment, Watford. <[http://www.bre.co.uk/filelibrary/accreditation/GreenDeal/KN\\_-\\_Green\\_Deal\\_Explained\\_Brochure\\_v5.pdf](http://www.bre.co.uk/filelibrary/accreditation/GreenDeal/KN_-_Green_Deal_Explained_Brochure_v5.pdf)> retrieved on February 14, 2014.

BUILDING RESEARCH ESTABLISHMENT, 2014a, Project: Towards Zero (T-ZERO) emission refurbishment options in UK housing. Building Research Establishment, Watford. <<http://www.bre.co.uk/page.jsp?id=825>> retrieved on February 14, 2014.

BRITISH STANDARD INSTITUTE, 2002a, BE EN ISO 13788, Hydrothermal Performance of Building Components and Building Elements: Internal surface temperature to avoid critical surface humidity and interstitial condensation, Calculation methods, British Standard Institute, London.

BRITISH STANDARD INSTITUTE 2002b, BS 5250, Code of Practice for Control of Condensation in Buildings, British Standard Institute, London.

BRITISH STANDARD INSTITUTE, 2007, BS EN 15251, Indoor Environmental Input Parameters For Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting And Acoustics, British Standard Institute, London.

BUILDING SERVICES RESEARCH AND INFORMATION ASSOCIATION, 1998, Building Control and Indoor Environmental Quality: A Best Practice Guide, Technical Note TN 9/98, Building Services Research and Information Association, Berks.

CHARTERED INSTITUTION OF BUILDING SERVICES ENGINEERS, 2006, CIBSE Guide A: Environmental design, Chartered Institution of Building Services Engineers, London.

CROOK, B. and BURTON N.C., 2010, 'Indoor Moulds, Sick Building Syndrome and Building Related Illness,' Fungal Biology Reviews, 24(3/4), pp. 106-113.

CRUMP, D., DENGEL, A. and SWAINSON, M., 2009, 'Indoor Air Quality in Highly Energy Efficient Homes: A Review', NHBC Foundation Report, Building Research Establishment, Watford.

DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT, 2007, Final Regulatory Impact, Assessment Building a Greener Future, Department for Communities and Local Government, London.

DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT, 2014, English Housing Survey, Headline Report 2012-2013, Department for Communities and Local Government, London.

DEPARTMENT OF ENERGY & CLIMATE CHANGE, 2009, Climate Act Impact 2008 Assessment. Department of Energy & Climate Change, London.

DEPARTMENT OF ENERGY & CLIMATE CHANGE, 2010, The Green Deal: A Summary of the Government's Proposals, Department of Energy and Climate Change, London.

DEPARTMENT OF ENERGY & CLIMATE CHANGE, 2013, Energy consumption in the UK, Department for Energy and Climate Change.

EUROPEAN ENVIRONMENT AGENCY, 2011, Air quality in Europe, EEA Technical report No 12, European Environment Agency, Copenhagen.

EUROPEAN FEDERATION OF ALLERGY AND AIRWAYS DISEASES PATIENTS' ASSOCIATIONS, 2013, Indoor Air Quality and its Effects on Health: a Presentation of the Guidelines for Health-Based Ventilation in Europe, European Federation of Allergy and Airways Diseases Patients' Associations, Brussels.

ENGLISH HERITAGE, 2012, Energy Efficiency and Historic Buildings, Application of Part L of the Building Regulations to Historic and Traditionally Constructed Buildings, English Heritage, Birmingham.

ENERGY SAVING TRUST, 2006a, Energy Efficient Ventilation in Dwellings: A Guide For Specifiers: GPG268, Energy Saving Trust, London.

ENERGY SAVING TRUST, 2005, Improving Airtightness in Dwellings, Energy Saving Trust, London.

ENERGY SAVING TRUST, 2006b, Domestic Energy Primer: An Introduction to Energy Efficiency in Existing Homes, Energy Saving Trust, London.



ENERGY SAVING TRUST, 2007, Energy-Efficient Refurbishment of Existing Housing, Energy Saving Trust, London.

GARRETT, M.H., RAYMENT, P.R., HOOPER, M.A., ABRAMSON, M.J., and HOOPER, B.M., 1998, 'Indoor Airborne Fungal Spores, House Dampness and Associations With Environmental Factors and Respiratory Health in Children', *Clinical and Experimental Allergy*, 28(4), pp.459-67.

GRAVESEN, S., NIELSEN, P.A., IVERSEN, R., and NIELSEN, K.F., 1999, 'Microfungal Contamination of Damp Buildings: Examples of Risk Constructions and Risk Materials', *Environmental Health Perspectives*, 107(Supplement 3), pp. 505-508.

HASHEMI, A., and GAGE, S., 2014, 'Technical Issues That Affect the Use of Retrofit Panel Thermal Shutters in Commercial Buildings', *Building Services Engineering Research and Technology*, 35(1), pp. 6-22.

HM GOVERNMENT, 2011, *Healthy Lives, Healthy People: Update and way forward*.

HONG, S.H., ORESZCZYN, T., and RIDLEY, I., 2006, 'The Impact of Energy Efficient Refurbishment on the Space Heating Fuel Consumption in English Dwellings', *Energy and Buildings*, 38(10), pp.1171-1181.

HEALTH AND SAFETY EXECUTIVE, 2000, *How to Deal With Sick Building Syndrome (SBS)*, HSE Books, London.

INSTITUTE OF MEDICINE, 2004, *Damp Indoor Spaces and Health*, National Academies Press, Washington DC.

JANTUNEN, M., FERNANDES E.O., CARRER, P. and KEPHALOPOULOS, S., 2011, *Promoting Actions For Healthy Indoor Air (IAIAQ)*, European Commission Directorate General for Health and Consumers, Luxembourg.

PIECKOVÁ, E., and JESENSKÁ, Z. 1999, 'Microscopic Fungi in Dwellings and Their Health Implications in Humans', *Annals Agricultural Environmental Medicine*, 6, pp. 1-11.

PITKARANTA, M., MEKLIN, T., HYVARINEN, A., NEVALAINEN, A., PAULIN, L., AUVINEN, P., LIGNELL, U., and RINTALA, H., 2011, *Molecular Profiling of Fungal Communities in Moisture Damaged Buildings Before and After Remediation: A Comparison of Culture-Dependent and Culture-Independent Methods*, *BMC Microbiology*, 11, 235.

REIDLICH, C.A., SPARER, J., and CULLEN, M.J., 1997, 'Sick -Building Syndrome', *The Lancet*, 349, pp.1013-1016.

SLEZAKOVA, K., MORAIS, S., and PEREIRA, M. do C., 2012, 'Indoor Air Pollutants: Relevant Aspects and Health Impacts', OOSTHUIZEN, J. (Ed.), *Environmental Health: Emerging Issues and Practice*, In Tech.

STOREY, E., DANGMAN, K.H., SCHENCK, P., DEBERNARDO, R.L., YANG, C.S., BRACKER, A., and HODGSON, M.J., 2004, *Guidance for Clinicians on the Recognition and Management of Health Effects Related to Mold Exposure and Moisture Indoors*, University of Connecticut Health Center, Farmington.

TECHNOLOGY STRATEGY BOARD, 2013, Retrofit Revealed, The Retrofit for the Future Projects: Data Analysis Report, Technology Strategy Board, Swindon.

WEATHER UNDERGROUND, 2014, History for Manchester, United Kingdom <[http://classic.wunderground.com/history/airport/EGCC/2014/2/22/CustomHistory.html?dayend=11&monthend=3&yearend=2014&req\\_city=NA&req\\_state=NA&req\\_statename=NA](http://classic.wunderground.com/history/airport/EGCC/2014/2/22/CustomHistory.html?dayend=11&monthend=3&yearend=2014&req_city=NA&req_state=NA&req_statename=NA)> retrieved on March 10, 2014.

WORLD HEALTH ORGANIZATION, 2003, Extreme Weather Events: Health Effects and Public Health Measures fact World Health Organization, Copenhagen.

WORLD HEALTH ORGANIZATION, 2009, WHO Guidelines For Indoor Air Quality: Dampness and Mould, World Health Organization Regional Office for Europe, Copenhagen.

ZOLFAGHARIFARD, E., 2014, Are Energy Efficient Homes Making Us ILL? Toxic Mould Caused By Poor Air Circulation Could Trigger 'Sick Building Syndrome, Mail [online] 18/02/2014. <<http://www.dailymail.co.uk/sciencetech/article-2562146/Are-energy-efficient-homes-making-ILL-Toxic-mould-caused-poor-air-circulation-trigger-sick-building-syndrome.html>> retrieved on February 18, 2014.