CETIEB

D2.1: Matrix of Measures and Impacts Report

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COOPERATION

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1 Preface

The retrofitting of buildings to achieve higher energy efficient standards leads to more airtight external envelopes and this affects the indoor climate. After retrofitting the inhabitants or users are usually not adapted to this new situation. The air exchange rates could be lower than required for health and comfort if a designed ventilation is not installed or the existing system's performance is not optimised. In trying to increase the energy performance of buildings the quality of the indoor environment is often degraded due to the lack of air exchange with the outdoor environment.

People in Europe spend more than 90% of their time indoors in their homes, at work or school and when traveling. In more than 40 % of the enclosed spaces, people suffer from health and comfort related complaints and illness. In 1984 the World Health Organisation reported an "increased frequency in buildings with indoor climate problems". The complexity of the problem and the fact that building related symptom clusters were later described as "Sick Building Syndrome" indicates a need for a greater understanding of the issues involved when retrofitting.

The main objective of the project is to develop innovative solutions for better monitoring of the Indoor Environmental Quality and to investigate active and passive systems for improving it. The focus lies on cost-effective solutions to ensure a wide application of the developed systems. The project is based on three main objectives:

1. Development of monitoring systems (wireless and /or partly wired) to detect insufficient comfort and health parameters. It is envisaged we will develop a modular version for allowing normal building users to make a quick check of the indoor air quality.

2. Development of control systems for indoor environments which will be based on passive elements with cost effective photo catalytic materials and phase change materials (PCM) and active systems which control the air flow rates based on the monitoring data.

3. Modelling of indoor environments for the assessment and validation of monitoring data and to optimise with respect to energy efficiency the control parameters and systems.

2 Summary

This report on the Matrix of Retrofit Measures and their Impacts on IEQ and IAQ explains in general terms the efficacy and impact of a comprehensive retrofit programme for a building. It is applicable in general terms to any of the four types of buildings being studied: office buildings, schools, nursing homes and blocks of apartments. The matrix worksheet for each building type provides a more detailed set of measures and their impacts appropriate to the building type.

To encourage an increase in the scale of retrofitting across Europe to meet EU targets for retrofitting existing buildings there needs to be an implicit emphasis on determining and explaining the most cost effective measures to reduce energy use. Every building is different and should be considered as a 'system' with a comprehensive *Baseline Assessment* as the first step in a holistic retrofit process. Energy use, airtightness and IAQ should all be measured at the beginning and end of a retrofit project to understand and confirm the impact of the retrofit measures.

People use energy, not buildings. The most cost effective retrofit measures are achieved with changes in the behaviour of the people using the building; its occupants and management. At all stages of a retrofit process they should be involved so they increase their knowledge and understanding of how the building should be used for optimal energy efficiency and comfort. A good retro-

fit process will include the relevant stakeholders in assessing the building and identifying the most relevant problems for a cost effective retrofit. At the end of the retrofit works those same people should be involved in the *Soft Landings* procedures to learn how to best use their retrofitted building. This feedback loop of information is critical for us all to learn how to retrofit our buildings for an improved future.

Retrofitting the external envelope for airtightness and increased insulation requires a good understanding of building physics to ensure the retrofit measures do not create problems for the building fabric or its occupants. It is necessary to analyse the movement of energy, air and moisture in and through the building envelope to avoid mistakes in building physics and future problems.

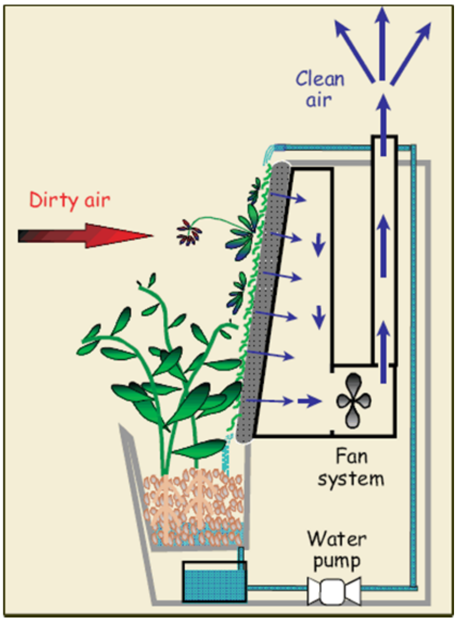
The steps and retrofit measures in a comprehensive and cost effective retrofit programme for any building type are:

1. Baseline Assessment
2. Management Procedures
3. Building Cleaning
4. Airtightness
5. Ventilation
6. Retro-Commissioning of HVAC Systems
7. Exposed Thermal Mass
8. Insulation
9. Thermal Bridging
10. Windows and Glazing
11. Lighting
12. Fans and Pumps
13. Electrical Equipment
14. Renewable Energy
15. Soft Landings Handover Process

If this general retrofit programme is developed in detail for each specific building then value engineering can be undertaken to achieve a cost effective retrofit specification which ensures indoor air quality and indoor environmental quality is enhanced or maintained.

In CETIEB we will be developing and trialling some specific innovative measures which specifically address the issues of indoor air quality (IAQ) and energy efficiency. There are some passive measures and one active measure and the demonstration of these measures in WP6 with monitoring and assessment will contribute to the library of retrofit measures which will improve the environmental conditions in buildings while reducing their energy consumption. These innovative measures are:

1. a Photo catalytic internal insulating plaster with Phase Change Materials (PCM) and a photo-active finish,
2. an Air Biofilter .



Concept diagram of the Air Biofilter

3 Introduction

The retrofitting of buildings requires an overall review of the building operation concept and the health and comfort parameters in the building. A building retrofit impacts on many aspects of a building's performance including the air tightness of the external envelope, the exposure of the thermal mass of the building, the responsiveness of the building to the occupants' needs and the level of control of the indoor environment.

Task 2.1 defines a matrix of energy efficiency measures and their impacts on the quality of the indoor environment. Our focus is on the buildings which represent a substantial proportion of the existing building stock in the EU. These building types are: offices, schools, blocks of apartments and nursing homes. This Matrix will be developed further and included in the Retrofit Guidelines to help in identifying the optimum solution for improving the overall impact of a building retrofit on indoor environmental quality.

The matrix of energy efficient retrofit measures is based on our research and experience as architects and sustainable design consultants who have been involved in the retrofitting and refurbishment of a large number of buildings and building types. We have been involved in two previous EU projects which completed research in this area: EUROPROSPER (2005), which investigated the energy efficient retrofitting and labelling of office buildings, and AVASH (2008), which investigated cost effective retrofit measures for social housing while ensuring indoor air quality was improved. We have drawn on this research and practical experience to develop the Matrix of Measures and Impacts.

The work completed or underway in the EU projects THERMCO, HITEA, PERFECTION, ENVIE and HOPE has been referred to in this stage of the project via their project websites. Information has been requested from the Co-ordinators of the projects SYSPAQ, and NANOAIR which are recently completed or still in progress. Their work and relevant findings will be included in the subsequent refinement of the Retrofit Guidelines later as the project progresses.

A retrofitting contractor and retrofitting professionals in Ireland have been consulted on the critical issues they have experienced in their retrofitting industry. We have researched the current state of knowledge of retrofitting and its impact on the indoor environment as published in articles, industry journals and the other EU research projects. This report explains the Matrix of Retrofit Measures and Impacts and outlines the current state of knowledge in respect of the particular issues we are investigating in this project.

4 Scope of Work

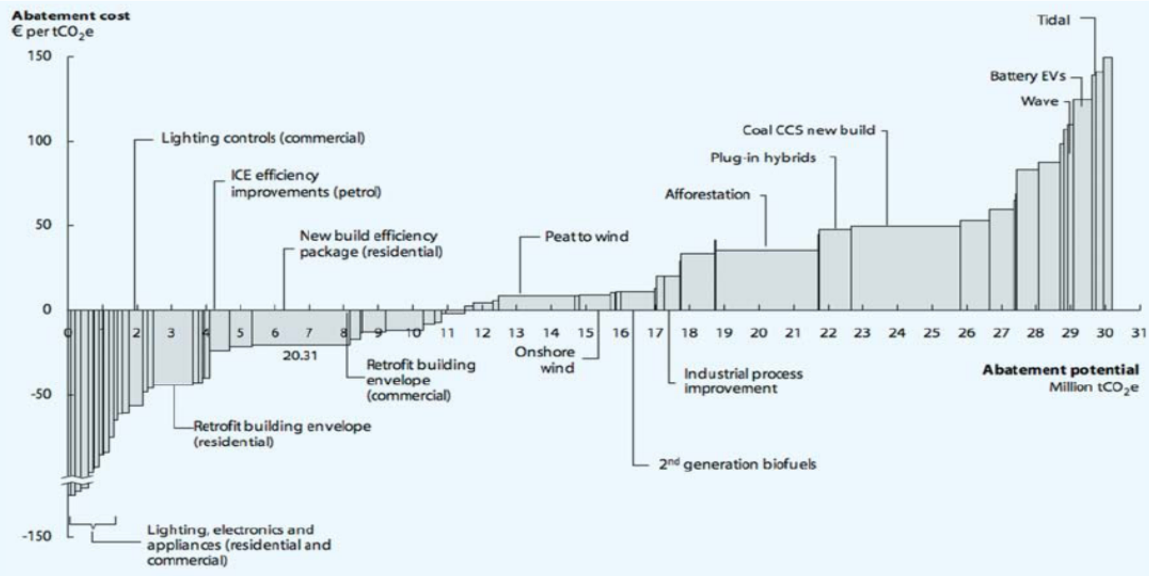
The scope of the work is limited to the four building types the project is focussing on, namely offices, schools, blocks of apartments and nursing homes. There are many possible detailed retrofit measures to reduce energy use but we have attempted to identify the most cost effective measures and to include measures which have been proven to maintain or improve the quality of the indoor environment. The available research in these areas is comprehensive as the number of pollutants is large but we are focussed on identifying and measuring the most common indoor air pollutants[1] which are the key indicators of poor indoor air quality. The low cost air quality sensors to be developed in WP 3 will be designed to monitor and analyse these key indicators in a portable self- contained package.

5 Background

The retrofitting of buildings for increased energy efficiency is recognised by the EU, most governments and the building industry as being one of the most cost effective ways to reduce CO2 emissions globally. The comprehensive study completed by McKinsey in 2009[2] includes a graph of the relative cost effectiveness of CO2 abatement measures which clearly shows building retrofit measures as being some of the most cost efficient. (Graph 1) Buildings in the EU account for between 30% and 40% of total CO2 emissions and the EU's target is to reduce the energy use of existing buildings by 84% by 2050. This will require a massive increase in the number of buildings that are retrofitted with the attendant risk to health of occupants that could be created if the retrofitting does not ensure a high quality indoor environment.

[1] WHO Guidelines for Indoor Air Quality: Selected Pollutants 2010, WHO Copenhagen ISBN 978 92 890 0213 4

[2] 'Pathways to a Low Carbon Economy: Version 2 of the Greenhouse Gas Cost Abatement Curve', 2009 McKinsey and Company www.mckinsey.com/globalghgcostcurve



Graph 1 'Pathways to a Low Carbon Economy' – 2009 McKinsey Report on CO_2 Abatement

The retrofitting of buildings leads to more airtight building envelopes to minimise energy losses. Unless ventilation systems are installed or improved the quality of the indoor environment can be adversely affected. People in Europe spend more than 90% of their time indoors while at home, at work and when travelling. In more than 40 % of these enclosed spaces, people suffer from health and comfort related complaints and illnesses. In 1984 a World Health Organisation Committee reported an "increased frequency of buildings with indoor climate problems". The complexity of the problem and the clusters of building related symptoms were later described as 'Sick Building Syndrome'[3]. Since it was first diagnosed Sick Building Syndrome has received much detailed research to understand the source of the problems and Indoor Air Quality (IAQ) is now recognized as being of critical importance in overcoming the problems of an unhealthy indoor environment.

6 Retrofit Measures and Impacts

The Matrix is organized to reflect the ideal retrofit process for a specific project with the measures organized in time from the initial Baseline Assessment through to completion of the retrofit works and the handover process using the Soft Landings Framework[4]. The particular innovative measures that CETIEB is going to trial on demonstration projects are highlighted separately. These innovations are an internal insulating plaster with phase change materials (PCM) and a photo catalytic finish and an air biofilter using selected plants.

The expected impacts of the measures are described in terms of the indoor environmental quality and energy efficiency. All the measures in a retrofit are expected to improve energy efficiency but their impact might be indirect as people are more tolerant of indoor conditions if they are more generally satisfied with their environment. For this reason the actual energy use will have to be monitored before and after the retrofit, together with the air quality, as part of a holistic analysis that includes the Post Occupancy Evaluation.

[3] "Sick Building Syndrome Fact Sheet". United States Environmental Protection Agency. http://www.epa.gov/iaq/pubs/sbs.html. (Retrieved 2011-11-16)
[4] www.softlandings.org.uk or http://www.bsria.co.uk/services/design/soft-landings/

The impacts are organised under four main headings which we consider the most important for achieving the objectives of the project:

1. Impacts which develop *Knowledge of the Building's Performance*
2. Impacts which *Reduce Energy Use*
3. Impacts *Perceived by People*
4. Impacts *Perceived by Sensors.*

Developing a *knowledge of the building's performance* is an essential first step in assessing and determining the best retrofit measures for the specific building and it provides a benchmark by which any improvements can be measured. A continuous process of understanding how the building is performing is valuable in that it requires an involvement of the users or management of the building and is most likely to result in lower energy costs, preventative maintenance and a more comfortable indoor environment for the occupants. It is a management tool and process.

Impacts which *reduce energy use* are the main focus of EU policy and most national retrofit programmes. However it is acknowledged that retrofitting needs also to consider the indoor environment so not all measures directly influence or reduce energy use and increased ventilation to improve indoor air quality will usually use more energy. It is therefore important to distinguish the measures which reduce energy use.

The impacts *perceived by people* are listed separately as these affect the satisfaction of people in a building and there is a complex subjective relationship between these impacts and a wide tolerance of acceptable standards. The PMV (Predicted Mean Vote) metric used in Post Occupancy Evaluation is affected by these impacts so it is important to identify and understand them . Many of these impacts can be measured by sensors but it is people's perceptions and levels of satisfaction which are important, not the measurable quantity of the impact.

The impacts *perceived by sensors* are listed separately as these are not able to be detected by humans at the low levels which can cause a health hazard or risk. These impacts are measures of contaminants which we have identified in Task 2.2 as being the most common and most hazardous to human well-being and health. These contaminants can be measured now but often only with expensive laboratory grade equipment and skills which the retrofitting industry does not have. One of the major objectives of the project is developing low cost sensors for the retrofit industry to measure some of these contaminants.

7 Retrofit Programme

The following general 16 stage programme for a building retrofit describes the measures which achieve reductions in energy use, their impacts and sets out the order in which the measures should be implemented. The measures and the expected impacts are explained in general terms. The Matrix is organized with a specific matrix worksheets for each of the four building types. The impacts of the measures are assigned relative values using a 1-5 scale and a range of 5 shades of blue in the cells of the matrix. The headings of Measures and Impacts are 'frozen panes' in Excel so that you can scroll down and across the whole matrix easily.

GRADING SYSTEM	
No impact	
Low impact	1
	2
Medium Impact	3
	4
High Impact	5

1.0 Baseline Assessment

People are the most intelligent 'sensors' in a building and the detailed knowledge and day to day experience of a building's indoor environment by its occupants should be the primary source of information for identifying problems and issues of any indoor environment. If occupants and the management of a building are engaged at the beginning of a retrofit program to identify the problems and baseline situation a more effective retrofit with higher occupant satisfaction is likely to result. Establishing this Baseline performance of a building is the first step in a retrofitting programme and we have included it in our matrix as the first retrofit measure.

The Baseline Assessment should include:

1. the previous 12 months of energy bills, or BMS monitored energy use, for the building
2. an airtightness test.
3. an indoor air quality survey using the CETIEB 'sensors toolkit'
4. a radon monitoring test of 3 months with a radon monitor should be undertaken to determine if radon is a problem in the building.[5]
5. a visual inspection of the building to determine its condition
6. a Post Occupancy Evaluation with the occupants and building management.

Impact

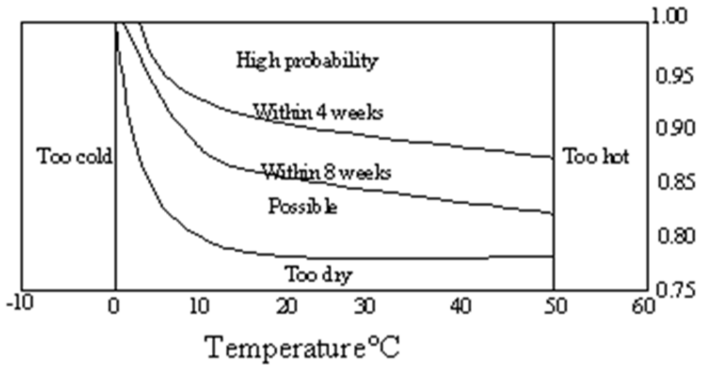
The Baseline Assessment information will help determine which specific retrofit measures are going to be most cost effective for the particular building as well as defining the baseline performance metrics for a comparison post retrofit.

A significant impact of this first stage will be developing an understanding of the performance of the existing building, its problems and the opportunities to retrofit the building to reduce energy use, improve the indoor environment and add value. This should involve the users or occupants of the building as they have detailed experience of the building through all the seasons of the year and they can quickly and cost effectively provide valuable information about the building to the retrofit designers.

The visual inspection should focus on determining if there is a persistent problem or history of dampness in the building and to identify its source. Dampness can be caused by a leaking building envelope, leaking water pipes, thermal bridging leading to condensation and inadvertent cooling of parts of the building by equipment. Dampness leads to mould or other microbial growth and this is one of the most common and hazardous contaminants affecting indoor air quality.

[5] Radiological Protection Institute of Ireland http://www.rpii.ie/Measurement-Services/Radon-Measurement/Services/Apply-For-Measurement-Online.aspx

Microbial growth may result in greater numbers of spores, mycotoxins, cell fragments, allergens, endotoxins, β-glucans and volatile organic compounds in indoor air. The causative agents of adverse health effects have not been identified conclusively, but an excess level of any of these agents in the indoor environment is a potential health hazard. The best solution is to remove the source of the problem and permanently stop dampness from occurring within the building.[6]



Graph showing temperature and moisture conditions which support mould growth[7]

2.0 Management Procedures

'No cost' changes in the management of a building can usually achieve between 5% and 20% energy savings due to the conventional default to 'on' of most building systems. The facilities management and energy auditing industry has demonstrated this through many case studies and experience with many building types. Occupant behaviour has a significant impact on energy use and with feedback, information, awareness campaigns and incentives it is possible to reduce energy use significantly. These management and occupant behaviour changes should be high priority retrofit measures in any retrofit programme or project because they are the most cost effective.

The Baseline Assessment should identify those areas of the building where simple management and behaviour changes will reduce energy use or improve the indoor environment. These changes apply to all building types. Examples of the types of 'no cost' management changes possible include:

- Making someone, or everyone, responsible (ideally a 'champion') for turning off lights, appliances and equipment at the end of the day or when not in use.
- Changing the update schedule on computers so that they don't have to be left on all night when software update routines are commonly programmed.
- Implementing a programme to purchase only low energy computers or laptops and electrical equipment
- Changing the cleaning products used by cleaners and maintenance staff to ones with a lower chemical content and environmental impact.
- Starting an awareness programme focused on indoor air quality and energy efficiency with the occupants. The programme should include incentives to support long term behaviour change.

Impact

[6] WHO Guidelines for Indoor Air Quality: Dampness and Mould; 2009 Edited by: Elisabeth Heseltine and Jerome Rosen. WHO Copenhagen ISBN 978 92 890 4168 3

[7] www.kefa.com

This measure has the potential to reduce the use of energy, improve indoor air quality and increase awareness of an individual's and management's impact on their own indoor environment. This inclusive process can increase the satisfaction the occupants feel about the building and this can improve productivity by reducing absenteeism. This management measure can be developed as part of the *Soft Landings* procedures[8] outlined in Measure 16.

3.0 Building Cleaning Products

The common proprietary products used to clean the interior of buildings contain volatile chemicals which can pollute the indoor air. Common ingredients include: ammonia, dimethyl glycol, sodium hydroxide, sodium hypochlorite, 2-butoxyethanol, anionic and non-ionic surfactants, butane and propane propellants for sprays, and various synthetic perfumes and solvents.[9] Almost all of these substances are from the petro-chemical industry and most are not bio-degradable when released into the environment via the waste water system. The hazard warnings on these products indicate that they are hazardous to health if used incorrectly. For some products this includes the warning that using them in combination with certain other products, often unnamed, can cause chemical reactions that can produce hazardous gasses like chlorine.

A 2006 study by the Air Resources Board of the California Environmental Protection Agency[10] investigated the effects of cleaning products with ethylene-based glycol ethers, which are classified as toxic air contaminants; terpenes, which react rapidly with ozone to form formaldehyde, any amount of which is considered unhealthy[11] and 2-butoxyethanol, which is highly reactive. These three substances were found in several of the cleaning products tested in a domestic scenario and all produced significant volumes of pollutants. The concentrations depend on use, room size and ventilation rate and they concluded that ordinary use could lead to exposure levels of similar magnitude to guideline values. Scenario model results suggest that exposure levels could exceed guideline values under exceptional yet plausible conditions, such as cleaning a large surface area in a small, poorly ventilated room.

> The US Environmental Protection Agency (EPA) describes formaldehyde as causing '…watery eyes, burning sensations in the eyes and throat, nausea, and difficulty in breathing in some humans exposed at elevated levels (above 0.1 parts per million). High concentrations may trigger attacks in people with asthma. There is evidence that some people can develop a sensitivity to formaldehyde. It has also been shown to cause cancer in animals and may cause cancer in humans. Health effects include eye, nose, and throat irritation; wheezing and coughing; fatigue; skin rash; severe allergic reactions.'

These types of products are used by cleaning contractors to clean commercial premises on a daily basis. Floors, walls, glass partitions, desks, furniture, toilets, sinks, kitchens, lunchroom dining tables, phones and computer screens are often sprayed and wiped with various products regularly and the impact on the indoor air quality can be significant. (*) All these surfaces then give off the VOC's and chemicals to the indoor environment and are circulated by the ventilation system, particularly if it is a mechanical ventilation system.

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[8] www.softlandings.org.co.uk

[9] WHO Guidelines for Indoor Air Quality: Selected Pollutants 2010, WHO Copenhagen, ISBN 978 92 890 0213 4

[10] "Indoor Air Chemistry: Cleaning Agents, Ozone and Toxic Air Contaminants" April 2006, W Nazoroff, University of California Berkeley

[11] USA Environmental Protection Agency website at www.epa.gov/iaq/formalde.html

There are alternative cleaning products made with almost no chemicals and which are designed as healthier, safer products. Vinegar, bicarbonate of soda and lemon juice are traditional cleaning substances which work very well and have none of the negative effects of the proprietary chemical products. Used with 'elbow grease' there are few types of dirt that these materials will not clean just as effectively as the chemical products. There are commercial 'eco-products' on the market which use these traditional cleaning substances in combination with tea tree oil, table salt, essential oils from natural sources, vegetable glycerine, eucalyptus leaves, and bio-based surfactants to create the eco-cleaning products. They typically do not contain synthetic colourings, synthetic perfumes or fragrances, enzymes, optical brighteners and bleach and they minimize their use of chemicals.

We have not found any specific research or testing that confirms the benefits of these eco-cleaning products on indoor air quality but there is specific guidance from organizations like the US Environmental Protection Agency[12] recommending the purchase and use of low chemical and low environmental impact cleaning products. The Air Resources Board of California has published a Fact Sheet[13] on cleaning products based on their research and they have set mandatory minimum standards for cleaning products which limit the amount of certain chemicals in products sold in California.

Impact

A change to the cleaning products used in the building should improve the indoor air quality by reducing the VOC's and reactive chemicals which can create air pollutants. This is a no cost measure with significant immediate benefits.

Often the cleaning of buildings is subcontracted out with no or little direct contact or feedback with the cleaning company or staff. The cleaning company, and the product manufacturers, want to leave a 'scent' to prove cleaning work has been done and to mask other odours. Unfortunately the scent is most likely pine oil which is highly reactive and causes the formation of other contaminants.

It is necessary to engage with the cleaning company to source alternative products and cleaning methods and to ensure they do not revert to old habits over time.

4.0 Airtightness

The most cost effective physical measure to reduce energy use in a building is the airtightness of the building envelope. Infiltration and energy losses due to leaks in the building envelope can account for up to 30% of energy losses in temperate and northern climates. The Matrix lists a range of detailed retrofit measures which can improve the airtightness of a building and most of them are very cost effective. Each building should ideally undergo a blower door test as part of the Baseline Assessment to establish the degree of airtightness and to identify the leaks in the envelope which need to be sealed.

The optimal target airtightness varies for the type of building, its use and the local climate. In temperate and northern climates the more airtight the building the more heating energy use is reduced. Apartments, nursing homes and schools will benefit from a very airtight envelope so the target airtightness should be as 'low as possible' and at least less then 3 ACH (air changes per hour). At this minimum level of airtightness a designed ventilation system will be necessary to maintain adequate ventilation rates and indoor air quality. Passive, hybrid and mechanical ventilation systems all work much more effectively in an airtight building and the industry recommends a minimum airtightness of 3 ACH for their systems to be effective. The recommendations for this minimum airtightness of 3 ACH has been confirmed in discussions with several companies who manufacture, supply and install ventilation systems for dwellings, nursing homes and schools.

[12] http://www.epa.gov/epp/pubs/cleaning.htm

[13] http://www.arb.ca.gov/research/indoor/cleaning_products_fact_sheet-10-2008.pdf .

Office buildings are more complex and from computer simulation studies undertaken by DWEcoCo over a number of years using the IES suite of building simulation software we have learned that the optimal degree of airtightness depends on the type of ventilation and cooling system. We therefore recommend airtightness levels of between 3.5 ACH for naturally ventilated office buildings and 7.5 ACH for mechanically cooled office buildings, depending on the climate zone.

In warmer climates and air conditioned buildings the 'free cooling' from a degree of leakiness can be useful in reducing the cooling demand. A detailed analysis of a specific building in its climate is required to balance the effects of airtightness on the heating and cooling loads to find the optimal degree of airtightness.

Retrofit airtightness detail at window / wall junction.

Retrofitting an airtightness membrane and insulation to a timber floor.

Impact

The impact of increased airtightness will be a reduced demand for energy and an increased requirement for a suitably designed ventilation system. The optimal degree of airtightness for a building depends on its type and the climate. Airtightness will also improve comfort levels in buildings by stopping draughts which can create internal air velocities that are beyond the comfort range of most people. Increased airtightness will also prevent sound waves and therefore noise pollution from entering the building. To ensure this benefit is maintained the ventilation system should also be designed to minimize outside noise from entering the building.

Airtightness is now understood to be one of the most cost effective means to reduce energy use in buildings. Retrofitting building usually involved adding more layers and newer components which are inherently more airtight. The impact of increased airtightness can be felt immediately in terms of indoor air quality but the impact can be very negative and require fast remedial action if it has not been anticipated. It is therefore essential that a designed ventilation system is considered as an essential part of any retrofit programme.

5.0 Ventilation

A building that is retrofitted to be more airtight automatically needs its ventilation to be carefully reconsidered as part of the retrofit process. An airtight building has less air leaking in and out of the building and this reduces the air change or ventilation rate to the point where the indoor air quality can be negatively affected. Many buildings do not have designed ventilation systems and rely on a natural ventilation strategy using permanent vents, trickle vents and openable windows deployed according to common practice in the industry, minimum standards and 'rules of thumb'. While these may have been adequate when the buildings were originally built, changes in the way we use buildings has increased the ventilation 'load' over time.

Impact

Installing a designed and energy efficient ventilation system which effectively removes indoor air pollutants and provides fresh air in to maintain a high standard of indoor air quality is going to improve the health of the occupants and users and increase their satisfaction with the building. If it includes a heat recovery system then it can also reduce energy use. The ventilation system can help to reduce noise pollution from entering the building if it is designed with this impact in mind.

5.1 Natural Ventilation

Apartments, nursing homes and many schools rely on a basic natural ventilation strategy for ventilation. They rely on the occupants to open windows as necessary for 'fresh air' and this often doesn't happen in cold or inclement weather. Permanent vents rarely provide sufficient background ventilation in apartments and some buildings as they rely on pressure differentials and double sided dwelling designs with cross ventilation. Many permanent vents are blocked up by the occupants as they cause cold air drafts and discomfort in the winter.

Natural ventilation has been successfully used in new office buildings as part of an integrated sustainable design which usually involves exposed concrete soffits for thermal mass with passive stacks and narrow floor plates. There are few existing office buildings where a retrofit might be able to successfully use natural ventilation. The problematic issues are noise from open windows, cold drafts and inadequate control.

The options for a designed natural ventilation systems will depend on the building but generally a passive stack system (PSV) or a demand controlled extract system (DCV) in a hybrid PSV system are the only two options. These provide a designed solution and with the intake and extract vents suitably located urban noise pollution can be minimized.

There are specialist systems designed for schools which bring the air in through a radiator casing so that the fresh air is heated up before entering the classroom. This overcomes one of the main problems in schools where complaints of cold draughts lead to restricted ventilation and high CO_2 levels.

Impact

Natural ventilation systems need to be designed to be effective and it requires careful design and possibly simulation studies to ensure it will work in an existing building.

PSV and DCV systems do not have supply air ducts and therefore there are no filters that need maintenance or supply ducts to be cleaned. They are generally less expensive to install and use less electricity than HRV systems, or no electricity in the case of PSV systems.

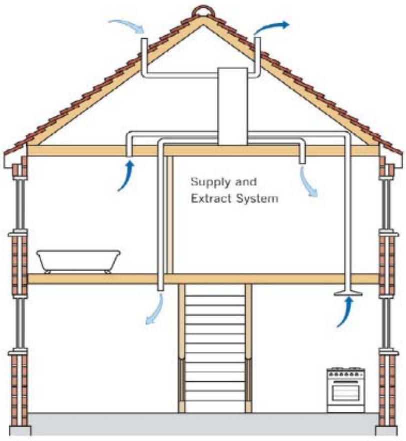
5.2 Mechanical Ventilation

Most larger office buildings built since 1950 have mechanical ventilation systems which will have been refurbished or adapted depending on the age of the building. These systems are usually not commissioned, maintained or managed properly. If the filters are not cleaned or changed often enough the ductwork collects dust and dirt and in humid conditions they can become a breeding ground for mould and bacteria. The dust and spores can be circulated around the building with the occupants suffering sinusitis, coughs, colds and headaches. This is the 'Sick Building Syndrome'*. The solution in this instance is to assess the HVAC system to see if it needs to be refurbished replaced or retro-commissioned.

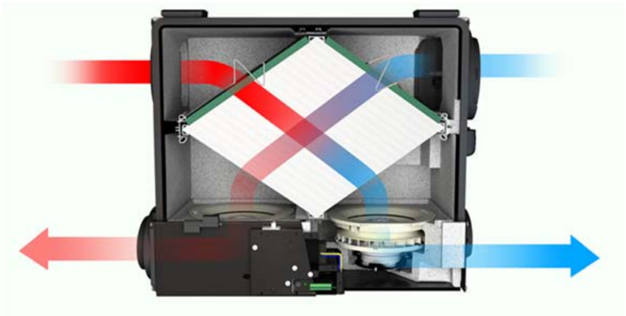
A heat recovery ventilation system (HRV) with supply and extract ducts will work well for apartments, nursing homes and schools. There are variants and hybrids of these systems depending on the method of bringing air into the building and they can all be retrofitted. The impact will be a designed minimum background ventilation rate which will improve IAQ and allow openable windows to be used for 'flushing' ventilation. HRV is more energy efficient than DCV and PSV systems, though the difference is not that significant.

Impact
A refurbished, replaced or retro-commissioned HVAC system will deliver increased energy efficiency and increased indoor air quality. Appropriate filters can prevent some common contaminants from entering the building and in many building

HRV systems need to be considered carefully as their filters and supply ducts need cleaning and regular maintenance to maintain indoor air quality. Experience in Sweden and Canada with such systems in housing over the past 30 years has demonstrated the negative potential of these systems, particularly in housing where people do not remember to do the necessary maintenance.



HRV diagram for a house


HRV heat recovery unit

6.0 Retro-Commissioning (RCx)

The successful operation of a building's ventilation system is very important in achieving a high standard of IAQ. 'Retro-commissioning' (RCx)[14] is the application of the commissioning process to the HVAC services and controls in an existing building. Retro-commissioning is a cost-effective retrofit

[14] *California Commissioning Guide: Existing Buildings*, 2006, California Commissioning Collaborative, http://www.cacx.org

measure which addresses the importance of the HVAC systems in a building in creating and maintaining the IAQ while optimizing the energy efficiency of the systems.

Retro-commissioning is a process that seeks to improve how building HVAC equipment and systems function. Often heating and cooling systems will be working at the same time which leads to excessive energy use. Depending on the age of the building, retro-commissioning can often resolve problems that occurred during design or construction, or address problems that have developed during the building's life. Retro-commissioning improves a building's operations and maintenance (O&M) procedures to enhance overall building performance.

All building commissioning processes share the same objectives: to produce a building that meets the needs of its owner and occupants, operates as efficiently as possible, provides a safe, comfortable environment and is operated and maintained by properly trained staff, facilities manager or a service contractor.

The retro-commissioning assessment will also identify opportunities for increasing the energy efficiency of the heating and cooling systems which might include installing more efficient boilers and cooling equipment, installing heat recovery equipment onto existing systems and identifying opportunities for 'free cooling'.

The multi-national Healthy Buildings Company (www.healthybuildings.com) uses sensors in the ventilation ductwork to monitor the conditions in existing ductwork as the first step in their baseline assessment process of an HVAC system. If there are high levels of pollutants in the ducts then the HVAC system is likely to have problems which can be tracked to the source. Recommendations are then made for maintenance or refurbishment during the retro-commissioning process.

Impact

Retro-commissioning a building's HVAC systems as a retrofit measure can have a significant impact on IAQ, IEQ and energy efficiency as most HVAC systems do not operate optimally and suffer from lack of maintenance. The retro-commissioning assessment will identify opportunities for replacing existing plant with more efficient equipment and controls which can reduce energy use significantly.

7.0 Exposed Thermal Mass

Exposing the thermal mass of a building allows heat to be absorbed by the thermal mass which releases it slowly when internal temperatures are lowered. Thermal mass can balance minimise temperature changes as its 'thermal flywheel' effect stores energy while internal conditions change. In an office building internal heat gains during the day can be absorbed and the heat dissipated during the night when the heating is off or turned down low. In summer 'night time cooling ventilation' can remove the heat absorbed during the day and significantly reduce the cooling load and energy use. It can also reduce the peak daytime temperatures and improve comfort levels.

In houses, schools and nursing homes thermal mass will have a similar effect but is most useful to store heat, increase the surface temperature of the building and minimise temperature swings.

Exposed thermal mass of concrete structure in an office building

Impact

Exposing the thermal mass inside a building is usually a measure which will reduce energy use and increase thermal comfort. However it can cause acoustic problems which will need to be solved with the probable addition of other sound absorbing materials during the retro-fit.

8.0 Insulation

Insulating a building seems the most obvious thing to do when retrofitting a building to increase energy efficiency. However a successful and effective retrofit project will have identified priorities for the most cost effective measures and insulating the external envelope is sometimes not the most cost effective measure. It is more cost effective to insulate the roof or attic space before the walls and floors. Insulating existing floors is practically restricted by the floor construction and concrete ground or basement floors are particularly difficult to insulate. In general terms for apartments, nursing homes and schools insulation will be a cost effective measure.

It is crucial to consider the movement of moisture and the moisture balance of the external envelope at the same time as the movement of energy. Particularly in masonry construction the addition of insulation in the wall during a retrofit will change the behaviour of moisture in the wall. Existing masonry walls will have absorbed moisture both from rain externally and from the humidity and water vapour pressure from within the building and it will have achieved a balance over time. For example when external insulation is added to the wall during a retrofit moisture the insulation should be of vapour permeable, or ‘breathable’, materials to allow the wall to dry out over time. The waterproof render on the external insulation will prevent rain from being absorbed by the masonry but it must allow it to ‘breath’ or the moisture content of the wall could build up over time. The retrofit measure for insulating walls should be analysed to avoid these risks.

The industry standard method for analysing the behaviour of moisture and energy flows through a wall over time is by a simulation using the WUFI[15] software developed by the Fraunhofer IBP Institute of Building Physics.

Impact

Insulation slows the flow of energy through the external envelope of the building reducing energy use. It will increase the surface temperature of internal surfaces and if installed correctly and is sealed to the adjacent building elements it can increase the airtightness of the building. However it also affects the movement of moisture through the envelope construction and this needs to be carefully considered.

8.1 Roof Insulation

Insulating a roof is usually the most cost effective insulation measure to reduce energy use. Pitched roofs where the waterproof material is 'cold' with insulation on a horizontal ceiling is the easiest to retrofit with additional insulation. A flat roof can have additional insulation added on top of the waterproof membrane to create a 'warm' roof with minimal additional work.

A careful assessment of the location and continuity of the roof insulation with the wall insulation is important to avoid thermal bridges. An assessment of the airtightness / vapour control layer in the roof construction is also important to avoid interstitial dew points occurring with the attendant risks of condensation within the construction.

Impact

Reduce heat loss and heat gain through the roof construction while potentially improving the airtightness of the building. This will improve thermal comfort and potentially the effectiveness of the thermal mass of the roof if it of 'heavyweight' construction.

8.2 External Wall Insulation

External insulation is the best solution for insulating an external wall for a number of reasons. The insulation keeps the structure and services of the building warm and allows the thermal mass of the existing external envelope to store a useful amount of energy which balances the daily flow of energy through the building. It keeps the heat in, and out, thus saving heating and cooling energy use and costs.

External insulation can solve most thermal bridging problems and there is little disruption to occupants while it is being installed.

The external walls of office buildings are often not suitable for external insulation and usually have a large ratio of glass to solid wall. Therefore it will not usually be a high priority to insulate the solid part of the external walls in an office building, depending on the form of construction.

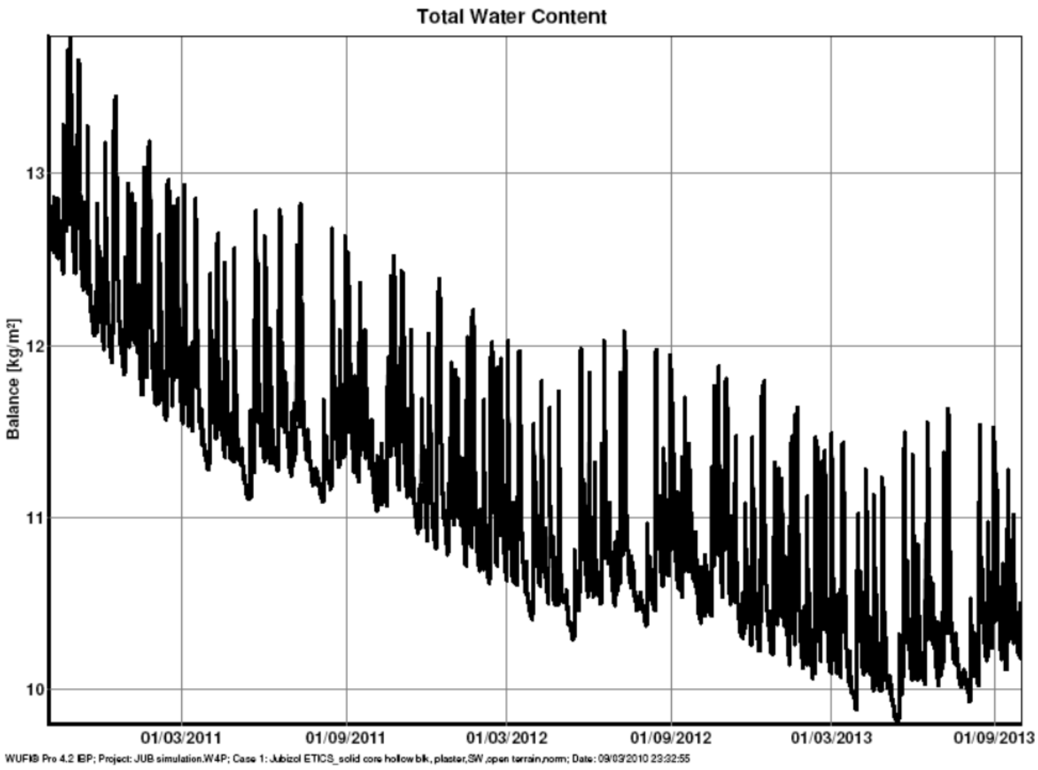
Impact

External wall insulation will reduce the energy required for heating and cooling and increase the surface temperature of the internal face of the walls thus improving thermal comfort. If installed correctly the waterproof render can increase the airtightness of the external envelope and if it is a mineral wool insulation product it can reduce the transmission of sound into the building.

All rockwool external insulation materials are fire proof and 'breathable' (moisture permeable) and are recommended for external wall insulation. All rigid board insulation is made from petrochemicals and is flammable and when used externally will melt if exposed to the heat of a fire.

[15] http://www.wufi.de/index_e.html

External wall insulation being retrofitted



Example of a graph from a WUFI software analysis showing total water content in a retrofitted masonry wall declining over 3 years due to correct installation of external insulation.

8.3 Cavity Fill Insulation

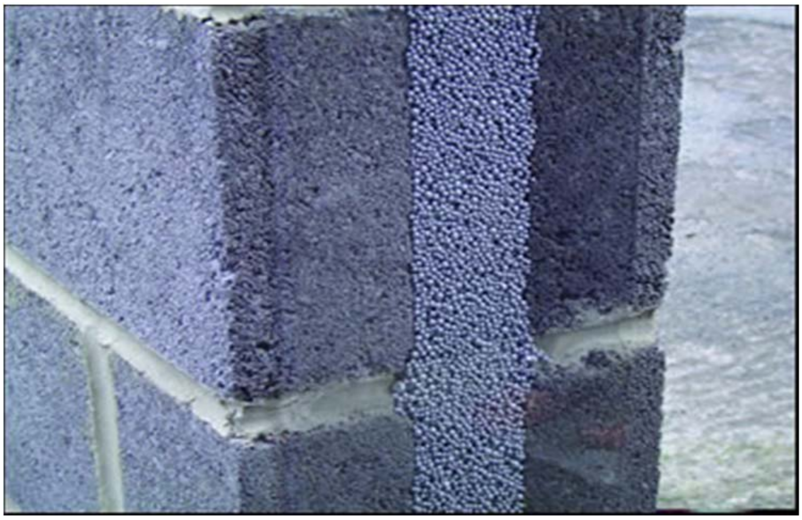
Inject all masonry cavity walls with injected cavity fill insulation. To achieve a lower U-value and heat losses install external insulation after the cavity has been fully filled with injected insulation. Full fill cavity insulation can be a polystyrene bead system or a rockwool product. The wind driven rain index for the site and Agreement Certificate for the product must be checked to ensure the product is suitable for the location.

Impact

Reduce the heat loss and U-value of the wall and stop thermal looping in the cavity by completely filling the cavity with full fill cavity insulation.

The cavity fill insulation prevents convection currents of air from transferring heat across the cavity in a process known as 'thermal looping' and this can have a more significant impact on reducing heat losses.

Filling a cavity with injected insulation does not usually reduce the U-value by a significant amount and is often not enough to meet retrofit programme objectives. If the site is not suitable for full fill cavity insulation then external insulation must be installed after the cavity is injected to protect it from wind driven rain.



Injected cavity fill wall insulation

Injecting a cavity wall with full fill insulation

External insulation (8.2) may also be required to meet the U-value targets. It is important to note that external insulation applied to a cavity wall will not perform well as there is still a ventilated void of cold air on the wrong side of the external insulation. It is therefore an essential first step to inject a cavity wall with insulation before external insulation is installed.

8.4 Internal Wall Insulation

Install insulation to the inside face of the external walls only if insulation cannot be installed externally or in the cavity. The insulation system should have an airtight vapour barrier installed on the warm side of the insulation to prevent moist air from reaching the existing internal face of the wall.

Internal wall insulation being retrofitted correctly with airtightness membrane sealed on the warm side of the insulation to prevent moisture movement to the cold part of the wall.

Impact

Reduce heat losses but at the expense of the loss of the advantages of the thermal mass of the external walls. More critically there is an increased risk of condensation on the now colder internal face of the external wall which can not be seen. Under certain conditions this can lead to mould growth and a drastic and quick deterioration in indoor air quality and illness from the spread of spores within the building. This impact can be so negative that internal wall insulation should be very carefully considered before it is recommended or installed.

8.5 Floor Insulation

Insulating the lowest floor of a building will reduce heat losses and increase thermal comfort. Depending on the construction of the existing floor and the extent of the retrofit a radon barrier can be installed during the retrofit to prevent radon from entering the building. A monitoring period of 3 months with a radon monitor should be undertaken as part of the Baseline Assessment to determine if radon is a problem in the specific building.[16] The cost of two monitors and the analysis costs less than €60.00 in Ireland and there are experts to provide advice and recommendations for dealing with problem buildings.

Impact

[16] Radiological Protection Institute of Ireland
http://www.rpii.ie/Measurement-Services/Radon-Measurement/Services/Apply-For-Measurement-Online.aspx

Reduce heat losses, thermal bridging and increase surface temperatures and thermal comfort.
There is the potential to reduce or prevent radon from entering the building by installing suitable radon barriers, sumps and ventilation systems at the same time as the floor is insulated. The radon barrier can act as a damp proof membrane which might not have been installed when older buildings were first constructed and this can also reduce damp and moisture from entering the building.

9.0 Thermal Bridging

Install insulation correctly with the objective of reducing thermal bridging in the existing building at critical locations such as window frames, cills and reveals, balconies, canopies and roof to wall junctions. Ensure retrofitted insulation is a continuous layer around the whole of the external envelope. Thermal bridging or 'cold bridging' has a significant impact on overall heat loss as the general level of insulation in the external envelope increases. Linear thermal bridging analysis is required by the Passivhaus Institute and recently by the Irish and UK Building Regulations to demonstrate compliance with minimum standards.

Impact

Reduce heat loss, increase the internal surface temperatures and minimise the risks of internal condensation which can lead to mould growth which can negatively affect indoor air quality and be a serious health risk.

10.0 Windows and Glazing

Install either new high performance windows or a retrofit glazing system and make the windows frames airtight to the adjacent construction by sealing with tapes and mastic from a proprietary airtightness sealing system.

Windows and glazing systems are very expensive and usually one of the least cost–effective retrofit measures so a careful analysis of the condition and performance of the windows should be undertaken before deciding to replace them. An example of a cost effective alternative for office buildings with curtain wall cladding systems is Serious Materials Ltd.'s 'iWindows Retrofit System' [17] which simply adds a new layer of high performance glass internally to the curtain wall system.

There are very sophisticated glazing systems available with two, three or more layers[18] and a variety of thin coatings to improve the performance of the glazing. These should be very carefully selected to suit the building and climate to optimize the performance for both heating, cooling and lighting requirements. The three most important specification metrics to consider are the U-Value (thermal insulating performance) and the G-Value (solar reflecting performance) and the light transmittance value. The U-value reduces heat losses and the G-value reduces solar gains. However increases in U-value and G-values usually reduce the light transmittance of the glazing and can increase the amount of electricity used for lighting. A balance must be found with these three factors which takes both energy efficiency and human comfort into account.

Impact

Replacing windows and glazing with higher performance products can significantly reduce the heat loss, cooling load, solar gains and affect the internal illuminance quality. The indoor environmental quality will be improved by increasing thermal comfort, increasing airtightness, reducing thermal bridging, reducing glare and improving the acoustics performance of the glazing system. The light transmittance must also be considered.

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[17] http://www.seriouswindows.com/commercial/products/retrofit-glass-system.html
[last accessed 2012_01_26]

[18] 'Suspended Film Glazing' by Southwall Technologies at http://www.southwall.com

11.0 Lighting

Install energy efficient lighting in the building by replacing luminaries with the latest high efficiency type suitable for the rooms and spaces. In complex and larger buildings like offices install all the retrofit measures listed below and in the Matrix and implement the management changes referred to in Measure 15.0.

A complete lighting system retrofit for an office building would include the following:

1. Install / replace with highest efficiency luminaire type (T5 or latest generation of LED)
2. High Frequency Ballasts
3. Presence detection PIR
4. Lux controls
5. Time controls
6. Commission lighting controls regularly
7. Seasonal adjustment of lighting timing programmes
8. Security and cleaning co-ordination of lighting

Impact

Reduce the energy used by lighting in the building. In an office building lighting typically accounts for about 30% of energy use and significant reductions can usually be achieved. In apartments, nursing homes and schools the energy used for lighting can be reduced by a replacement programme that installs high efficiency luminaries with simple and easy to use controls. Increasingly wireless systems are being used to maximize control, energy efficiency and minimize the cost of retrofitting.

12.0 Fans and Pumps

All electric motors for fans and pumps can be replaced with high efficiency ECM (brushless DC electronically commutated motors) motors fitted with solid state variable speed drives (VSD's) to minimise energy use. The VSD's need to be properly commissioned and integrated with the BMS system to achieve optimal performance.

Impact

Reduce energy use in the electric motors of all appliances, the HVAC and pumped water systems of the building. The VSD will vary the motor speed to meet demand so the motors will not be generating as much sound for most of the time. The reduction of fan speeds in ventilation systems can reduce the noise they produce.

13.0 Electrical Equipment

Install a system for automatically switching off electrical equipment and appliances with a 'champion', presence detection, a timing programmer or a wireless automation and control system to prevent the common practice of leaving equipment on, or in 'sleep mode', all the time. Implement a policy to only buy the most energy efficient equipment on the market. Instal a voltage optimization system for the building to make the most efficient use of the local grid's voltage variability.

Impact

Reduce the energy used by electrical equipment and appliances in the building and optimise the use of grid electricity.

14.0 Renewable Energy

Install renewable energy systems appropriate to the building, its location and local environment. Renewable energy systems can often be most cost effectively added to a building during a retrofit process as the installation costs can be integrated with other works. For example a solar collector system integrated into a roof can replace an area of roofing tiles or membrane that would otherwise have to be installed. Similarly if a boiler is being replaced its size, and cost, can be reduced if a renewable heat technology is also being installed. This reduces the cost of the renewable energy system, future proofs the building and reduces its CO2 emissions.

Impact

A suitable renewable energy system will reduce the use of fossil fuel energy in the building and its CO2 emissions. Reducing CO2 and associated emissions improves outdoor air quality generally and therefore indoor air quality indirectly.

15.0 CETIEB Retrofit Measures

In WP 5.0: Passive Systems a layered system of approx. 20-25 mm thickness will be developed to improve indoor air quality and the thermal performance of external walls as 2 layers of that system will be functional layers:

1) the first layer placed on the wall aims to improve the adhesion of the second mortar layer

2) the second layer is a mortar containing phase change material (PCM) for better adjustment of heat absorption capacity and expanded perlite for better insulating properties, helping thus to keep the indoor temperature more constant and reduce heat loss

3) the third finishing layer is a photo catalytic paint containing TiO_2 coated expanded perlite: this layer needs UV –light (sunlight) for evolving its catalytic property that helps in improving indoor air quality by VOC and NO_x reduction.

An innovative air biofilter which uses selected plants in a recycling ventilation system to condition indoor air will be built and tested. These innovative retrofitting measures are being developed to improve the performance of retrofitting and address the critical issue of indoor air quality.

15.1 Insulating Plaster with Phase Change Materials

The proposed development is the incorporation of PCM materials in a lightweight cement-limestone plaster / mortar with expanded perlite, intended for indoor application. Expanded perlite will inhibit the transfer of heat from inside to outside and vice versa and therefore the variation between maximum and minimum indoor temperature will be decreased in comparison to the regular mortars/plasters used for indoor. With the addition of PCM, the heat capacity of the mortars will be increased and walls will adsorb excess heat and will release the stored heat when the building starts to cool down creating thus a comfortable indoor environment for humans.

Impact

This cost-effective, insulating plaster is expected to decrease the thermal energy passed by convection, due to the added expanded perlite. Furthermore a smaller weight percentages of PCMs will be needed to keep the temperature in a range of 24-26oC than the 20-40wt% reported in the literature leading to a cost effective multifunctional building material. The result will be a thermal insulating mortar with a thermal conductivity of the same or lower than the current thermal insulating plasters/mortars available in the market but with at least 20% larger heat capacity.

15.2 Photoactive Paints

A novel, cost-effective and nano-functional structured indoor paint based on the TiO2 will be developed. The increase in the efficiency of the synthetic materials will be achieved by dispersion of TiO2 on the expanded perlite's surface as this white and transparent substrate offers sufficient porosity and will thus increase the photonic efficiency of TiO2 because of the back irradiation and the unhindered exchange of mass and energy.

Impact

Photoactive paints will oxidise NO_x and VOC's in indoor and improve indoor air quality. Its effects may be finite and limited by time and the thickness of the paint and washing maintenance. Internal painting and decoration is a repetitive maintenance activity and the benefits of a photoactive paint can be easily lost if the next time the non-photoactive paint is used to paint over the photoactive paint.

15.3 Air Biofilter

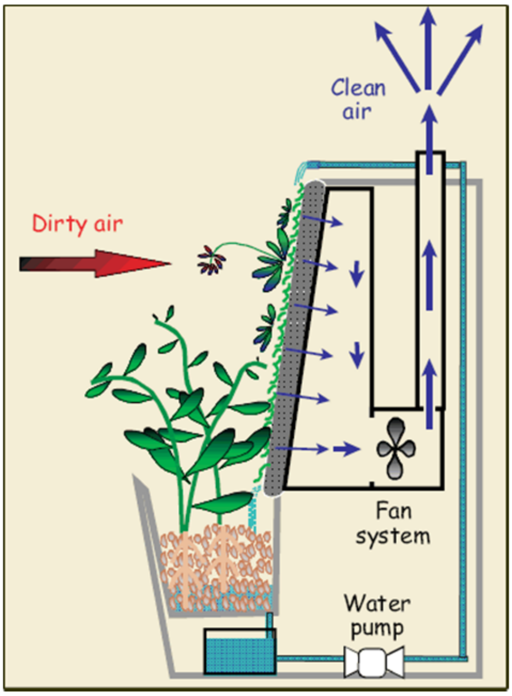
Install the air biofilter in a space or room where indoor air quality has been monitored and problems identified which cannot be solved by the ventilation system.

The air biofilter system was developed in the University of Guelph and commercialised by Nedlaw Ltd.[19] in Ontario. It has been installed in universities, banks and office buildings in Canada. One (1.0) m^2 of vertical planted area of the air biofilter system treats about 100 m^2 of floor area so it can be a very efficient part of a retrofit project. The system uses plants specially selected for their unique ability to remove certain contaminants in the air including a range of VOC's. The plants are grown in a vertical array with their roots in a mineral wool root zone which is kept wet with a hydroponic system which provides the nutrients for the plants. Air is pulled through the plants and their root zone by a fan and is recirculated into the space.

Impact

The mineral wool acts a mechanical filter removing airborne particles; the mycorrhizal bacteria in the root zone convert the VOC's into benign substances; the wet mineral wool in the root zone rehumidifies the air as it passes through; the leaves of the plants convert the CO2 into O2 and re-oxygenate the air.

[19] http://www.naturaire.com



Concept diagram of the Air Biofilter

This recycled treated air reduces the amount of fresh air that needs to be brought into the building and conditioned thus reducing energy use. It also reduces the amount of air that needs to be exhausted thus reducing fan energy use.

The aesthetic impact is also notable as these biofilters are usually large attractive features within the building.

Air Biofilter at University of Guelph, Ontario

16.0 Soft Landings Handover

The 'Soft Landings Framework' [20] has been developed in the UK to bridge the gap between *building construction* and *building operations.* The building industry is organised to deliver completed buildings but is not involved in the operations of the building. Occupants of buildings have no contact with the design team who never have the opportunity to explain to the occupants how they intended the building should be used and how the design works. The commissioning of the services at the end of the construction process is completed with an empty building still drying out from wet concrete, plaster and paint. There are often many problems during the handover process when the occupants move in to a new or newly retrofitted or refurbished building.

The *Soft Landings Framework* was developed by BSRIA[21] (The Building Services Research and Information Association), the *Usable Buildings Trust* [22] and architect Mark Wray. The framework provides guidance and a methodology for bridging the gap between the construction stages of a building and the occupancy and operations stages of a buildings life. A retrofit of a building can create the same problems as new construction and the Soft Landings strategies can be as useful and effective in a retrofit. The Soft Landings Framework is a necessary retrofit measure for a successful retrofit project or programme.

Essentially the Soft Landings framework creates an overlap between the retrofit team and the occupants and management of the building and ensure that the building is properly commissioned for the actual use and occupation of the building. Everyone shares information and there is good communication to prevent problems from developing or escalating during the initial handover and occupation stages.

Impact

The Soft Landings Framework provides a virtuous circle for all stakeholders and offers the opportunity to develop integrated, robust and sustainable retrofits which achieve their objectives of energy efficiency and a high indoor environmental quality.

16.1 Post Occupancy Evaluation

Post Occupancy Evaluation (POE) is a survey of the occupants and management of a building to capture and evaluate the level of satisfaction with the indoor environment. POE is an intrinsic part of the Soft Landings approach and provides the essential feedback to the retrofit team who designed and managed the retrofit measures. It connects and completes the process which starts with the initial Baseline Assessment of performance of the existing building. The feedback of information from the POE to the beginning of the retrofit process is crucial if we are to develop a more cost effective and efficient retrofitting industry which ensures a high quality indoor environment.

Predicted Mean Vote (PMV) is the relative comparison metric used to describe the level of satisfaction with any one aspect of a building's performance. It is the key metric used to describe occupants' levels of satisfaction with a building and is expressed as a percentage. The PMV index predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale where:

[20] www.softlandings.org.uk
[21] www.bsria.co.uk
[22] www.usablebuildings.co.uk

+3 = hot
+2 = warm
+1 = slightly warm
0 = neutral
-1 = slightly cool
-2 = cool
-3 = cold

The PMV index is expressed by P.O. Fanger as $PMV = (0.303\ e - 0.036M + 0.028)\ L$
where PMV = Predicted Mean Vote Index and M = metabolic rate.

*[**L = thermal load** is defined as the difference between the internal heat production and the heat loss to the actual environment for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level.]*

Building Use Studies Ltd. (BUS) is a UK company that has developed a Post Occupancy Evaluation methodology that has been used internationally to evaluate hundreds of buildings. It has built up a substantial database of evaluations and key performance indicators which it uses statistically to create benchmarks for buildings of a similar type and situation. It has a survey template which is completed by occupants in a user's survey and the forms are submitted electronically to BUS Ltd. who feed the standardized information into their database. The BUS evaluation software then generates the PMV outputs and a report describing the survey results in layman's terms.

In *WP7: Demonstration* we will use BUS Ltd.'s POE system and Building Use Studies Ltd. as a subcontractor to the CETIEB project to evaluate our retrofit demonstration projects.

Since building cleaning products have such an immediate and persistent impact on IAQ we propose to add questions to the BUS POE survey template to capture information on whether management have changed their cleaning products. Similar survey information will have been captured during the Baseline Assessment process so that a comparison can be made. We should thus be able to compare the 'before' and 'after' situation with the same metrics.

Impact
The POE survey will help us to evaluate the impact of the retrofit measures. The subjective assessment of the indoor environment by the occupants will identify the expected improvements and their evaluation can be compared to the monitored improvements in IAQ.

16.2 Measure Airtightness

To assess the impact of all the retrofit measures on the airtightness of a building a blower door test should be undertaken at the end of the retrofit programme to see how much the airtightness has been improved. In some countries the Building Energy Rating (BER) methodology to satisfy the EPBD Directive incentivises an airtightness test by using a poor default value for airtightness in the software used to generate the BER rating. It is therefore usually a practical and cost effective measure to include an airtightness test at the end of the retrofit process.

Impact
The degree of airtightness following the retrofit will provide useful information for optimising the ventilation system and HVAC system to achieve a high standard of IAQ and energy efficiency. The result is likely to impact on the Building Energy Rating achieved. It may trigger additional remedial work to achieve any airtightness target that was set by the retrofit specification.

16.3 Monitor Energy Use

To capture and understand the impact of the retrofit measures it is essential to monitor the energy use in the building following the retrofit. A Monitoring and Targeting (M&T) [23] programme should be implemented to record energy use as specifically as possible so that a comparison can be made with the Baseline Assessment of energy use.

There are two industry standard protocols for energy monitoring called simply the Billed Energy Protocol (BEP) and the Monitored Energy Protocol (MEP) as developed in the EUROCLASS Project (2000)[24] in the SAVE programme. Essentially submetering and monitoring energy use can provide a more detailed understanding of where and when energy is used or the bills from the energy suppliers can be used to obtain a total energy use but without details of how the energy was used. The protocol chosen will depend on the building and the stakeholders concerned.

Impact

The information from monitoring the energy use can inform the occupants and management in their M&T or awareness programme of how much energy is being used and where more savings might be made. It will also provide useful information on the effectiveness of the retrofit measures and the payback period of the investment. Real time feedback from monitored systems has been shown by research to reduce energy use by up to 15% in dwellings.

16.4 Awareness Programme

An awareness programme for energy efficiency and a healthy indoor environment is a natural final step in the implementation of the Soft Landings Framework. A successful programme will keep the occupants of the building informed of the building's performance and allow them to have more control over their environment. It will provide useful feedback to the building's management who can use the programme to incentivise people to reduce their energy use and energy costs. A continuous programme will help to remind everyone to minimise energy use, use safer cleaning products and be aware and involved in creating and improving their own indoor environment.

Impact

Increased satisfaction with the building's indoor environment, an improvement in the IEQ and reduced energy use.

8 Conclusions

This report on the Matrix of Retrofit Measures and their Impacts on IEQ and IAQ explains in general terms the efficacy and impact of a comprehensive retrofit programme for a building. It is applicable in general terms to any of the four types of buildings being studied: office buildings, schools, nursing homes and blocks of apartments. The Matrix for each building type provides a more detailed set of measures and impacts appropriate to the building type.

To encourage an increase in the scale of retrofitting across Europe to meet EU targets for energy reduction through retrofitting buildings there is an implicit emphasis on explaining the most cost effective measures to reduce energy use. Every building is different and should be considered as a 'system' with a comprehensive *Baseline Assessment* as the first step in a holistic retrofit process.

[23] http://oee.nrcan.gc.ca/publications/commercial/5574

[24] Energy Performance of Residential Buildings: A Practical Guide for Energy Rating and Efficiency, 2005 Ed. by Mat Santamouris, James and James / Earthscan, ISBN 1-902916-49-2

Energy use, airtightness and IAQ should all be measured at the beginning and end of a retrofit project to understand and confirm the impact of the retrofit measures.

People use energy, not buildings. The most cost effective retrofit measures are achieved with changes in the behaviour of the users, occupants and management. At all stages of a retrofit process they should be involved so they increase their knowledge and understanding of how the building should be used for optimal energy efficiency and comfort. A good retrofit process will include the relevant stakeholders in assessing the building and identifying the most relevant problems for a cost effective retrofit. At the end of the retrofit works those same people should be involved in the *Soft Landings* procedures to manage the changes in their building.

Retrofitting the external envelope for airtightness and increased insulation requires a good understanding of building physics to ensure the retrofit measures do not create problems for the building fabric or its occupants. It is necessary to analyse the movement of energy, air and moisture in and through the building envelope to avoid mistakes and future problems.

We recommend 15 basic steps of retrofit measures for a comprehensive and cost effective retrofit programme for any building type:

1. Baseline Assessment
2. Management Procedures
3. Building Cleaning
4. Airtightness
5. Ventilation
6. Retro-Commissioning of HVAC Systems
7. Exposed Thermal Mass
8. Insulation
9. Thermal Bridging
10. Windows and Glazing
11. Lighting
12. Fans and Pumps
13. Electrical Equipment
14. Renewable Energy
15. Soft Landings Handover

If this general retrofit programme is developed in detail for each specific building then value engineering can be undertaken to achieve a cost effective retrofit specification which ensures that indoor air quality and indoor environmental quality is improved.

In CETIEB we will be developing and trialling some specific innovative measures which specifically address the issues of indoor air quality (IAQ) and energy efficiency. There are some passive measures combined into one product and one active measure and the demonstration of these measures in WP6 with monitoring and assessment will contribute to the potential to improve the environmental conditions in buildings while reducing their energy consumption. These innovative measures are:

1. an internal insulating plaster with Phase Change Material (PCM) and photoactive finish to insulate, store heat and remove some pollutants from the air.
2. an Air Biofilter using plants to clean the air.

The Matrix demonstrates that there are a large number of possible retrofit measures for each building type which can have a significant impact on the indoor environmental qualities and energy use of a building. However the most cost effective measures will be those that engage with, encourage and empower the people who use the building to make their own environment more comfortable, healthier and more energy efficient.

The Matrix will be used as a tool for developing the comprehensive set of Guidelines for Indoor Environmental Quality in Task 2.5 and as a base document for all stages of the project. It is therefore likely to be refined during the course of the project.

9 References

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