CETIEB

D2.5 Guidelines addressing variety of stakeholders

Report

Grant Agreement number:	**285623**
Project acronym:	**CETIEB**
Project Title:	**Cost Effective Tools for Better Indoor Environment in Retrofitted Energy Efficient Buildings**
Funding Scheme:	**Collaborative Project**
Work-Package:	**WP2: Definition and Requirements**
Task	**Task 2.5: Indoor environmental quality guidelines**
Subject:	**D2.5 Guidelines for retrofitting**
Date of Report:	**30-09-2014**
Task Leader:	**DWE**
Tel.:	
Fax:	
Email:	
Authors:	**Sinead Cullen, Jay Stuart**
Partners involved:	**DWEcoCo Ltd**
Project web site address:	**www.cetieb.eu**
Doc. Name:	**2014-09-30 CETIEB D2.5 Guidelines addressing variety of stakeholders.pdf**

COOPERATION

Table of Contents

Indoor Environmental Quality Guidelines for Retrofitting

1 Introduction

These **Guidelines for Retrofitting** provide a step by step process for retrofitting any building for energy efficiency and improved indoor environmental qualities. They are written in plain language so that as far as possible they are accessible and usable by a variety of stakeholders considering a retrofit project. The objective is to assist any stakeholder in understanding how best to undertake a retrofit project and which measures are most likely to be most effective.

The Guidelines are followed by a list of the multiple benefits of retrofitting which may apply to the stakeholder. This is critical as often the retrofit process is evaluated in financial terms by considering only the energy savings. In fact the total value of all the benefits is estimated at anywhere from **2.5** [1] **times to 37** [2] **times the energy savings.** If this value was more widely understood there would be more opportunities to retrofit more buildings to meet national and EU targets for energy efficiency.

The Guidelines are applicable in general terms to any building but they make specific reference to the four types of buildings which are the focus of the CETIEB project: office buildings, schools, nursing homes and blocks of apartments. The **Matrix of Retrofit Measures** which accompanies these Guidelines is composed of worksheets for each building type which provide a more detailed set of measures and their impacts.

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 and explicit 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 IEQ characteristics should all be measured at the beginning and end of a retrofit project to understand, measure 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 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*[3] procedures to learn how to best use their retrofitted building. This feedback loop of information is critical for everyone to learn how to best 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 in the building envelope or Indoor Environmental Qualities.

[1] Reinaud, J. (2012), "Energy efficiency & industrial productivity – Gaining through saving". IEA-SEAI Workshop: Evaluating the multiple benefits of EE.
[2] Fulford, M. (2010), "How to Manage the True Costs of Sustainability and Rease its Value" Article in EC Harris magazine 'Built Asset Consultancy'
[3] www.softlandings.org.uk

The process, steps and retrofit measures in a 'deep', comprehensive and cost effective retrofit programme for any building type should include:

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, Glazing and Doors
11. Electric Lighting
12. Fans and Pumps
13. Electrical Equipment
14. Renewable Energy
15. Innovative Measures: CETIEB
16. 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.

'Deep retrofits' which implement a comprehensive set of measures following a detailed analysis of the building as a system are more cost effective because the analysis, transaction and contracting costs of one retrofit project are significantly less than a series of incremental improvements. A single deep retrofit also avoids the potential cost of having to replace a previous measure which is made redundent by subsequent retrofit measures.

2 The Retrofit Process

The following **16 Measures**, or steps, for a comprehensive retrofit project are set out in a logical sequence with a clear beginning and end which connects the 'retrofit team' with the occupants and building users. Ideally this will create a positive feedback loop of knowledge and experience. The more technical measures in the middle of the sequence do not have to be followed in the same order as presented but they do generally represent a relative order of cost effectiveness and impact. The CETIEB Innovative Measures at No. 15 are project specific but there will always be innovative measures appearing in the retrofit industry which should be considered. This is a 'placeholder' for any such innovative measures.

The "Impact Grading" referred to in each measure is the average relative impact the measure has across a series of impacts analysed in the accompanying spreadsheet of the Matrix of Measures and Impacts.

The International Performance Measurement and Verification Protocol (IPMVP) is utilised to calculate in a standard and normalised way the energy efficiency savings (energy, cost, CO_2) as a result of an energy efficiency investment or retrofit. Typically this standard serves as an honest broker between ESCO and its client who share energy savings profit.

A cornerstone of IPMVP is a 13 step measurement and verification planning process as prescribed in IPMVP Vol 1. This process looks through a planned investment from start to finish and roadmaps how that energy conservation measure or renewable energy technology investment will be isolated, measured, normalized (from changes in weather, building usage, infrastructure changes, etc), calculated, and reported. Although organisations may not choose to adopt IPMVP in its entirety, basic steps that should be considered for all renovation measures include:

- Assessment of the existing building (audit + all information necessary to design and verify energy conservation measures).
- Baseline: Through pre-retrofit measurements, energy bills, simulation, or some combination, establishing the pre-retrofit performance indicators that will serve as the comparison other during the before and after comparison.
- Measurement Plan: Developing the measurement or instrumentation plan to be able to assess the before and after performance indicator values with respect to also the adjustment method selected (e.g. the method in which to normalise the data for influences aside from the retrofit such as different weather conditions, changes in energy contract prices, etc).

Measure 1: Baseline Assessment

Definition:
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.

Metric: Quality and completeness of information

Impact Grading: 6

Impacts:
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.

Commentary:

Typical Specific Actions:
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 'Sensor 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.[4]
5. a pre-retrofit Post Occupancy Evaluation with the occupants and building management.

Measure 2: Management Procedures

Definition:
'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.

Metric: kWh/m2/yr

Impact Grading: 10

Impacts:
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[5] outlined in Measure 16.

Commentary:

Typical Specific Actions:
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.

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

Measure 3: Building Cleaning Products

Definition:
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.[6] 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.

Metric: IAQ for TVOC's

Impact Grading: 11

Impacts:
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.

Commentary:
A 2006 study by the Air Resources Board of the California Environmental Protection Agency[7] 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[8] 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.

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 around the building by the ventilation system, particularly if it is a mechanical ventilation system.

[6] WHO Guidelines for Indoor Air Quality: Selected Pollutants 2010, WHO Copenhagen, ISBN 978 92 890 0213 4
[7] "Indoor Air Chemistry: Cleaning Agents, Ozone and Toxic Air Contaminants" April 2006, W Nazoroff, University of California, Berkeley
[8] 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.

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[9] 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[10] 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.

Typical Specific Actions:
Replace all cleaning products and air fresheners with products with low chemical content and look for commercial 'eco-products' on the market which use the traditional cleaning substances of vinegar lemon, bicarbonate of soda 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.

Measure 4: Airtightness, or Air Permeability

Definition: The measure of the 'leakiness' or air permeability of the building's external envelope. A blower door test measures the accidental undesigned passage of air through the building envelope using standardized test procedures. A fan is used to pressurize and depressurize the building and the rate of pressure drop is used to calculate the air permeability of the building envelope.

Metric: Air Permeability in ACH or $m^3/hr/m^2$

Impact Grading: Average **12** from T2.1 Matrix of energy efficiency measures

Impacts:
1. Increase knowledge of building performance : air tightness test before and after retrofit
2. Reduce energy use by reducing infiltration /exfiltration losses by up to 30% - people via bills
3. One of the most cost effective measures for improving the energy efficiency of the external envelope. - bills
4. Improve efficiency of ventilation system by controlling airflow routes - bills
5. Improve thermal comfort by reducing draughts - people
6. Improve acoustic separation from outside by excluding noise - people
7. Improve IAQ by reducing PM10 and PM2.5 infiltration - sensors
8. Improve IAQ potentially by reducing infiltration of external pollutants - sensors

Commentary:
The most cost effective physical measure to reduce energy use in a building is usually 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

[9] http://www.epa.gov/epp/pubs/cleaning.htm
[10] http://www.arb.ca.gov/research/indoor/cleaning_products_fact_sheet-10-2008.pdf .

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.

Office buildings are more complex and 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 for the temperate climate of the UK, Ireland and similar climates. These recommendations will vary depending on the climate zone and a dynamic thermal analysis should be conducted to develop recommended levels of airtightness for each climate.

In warmer climates and air conditioned buildings the 'free cooling' from a degree of 'leakiness' can be an efficient means to reduce the cooling demand, but this has to be balanced with the heat losses. A detailed thermal dynamic simulation 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.

Typical Specific Action:

1. Adjust opening windows and doors so they close tightly against draughtproofing.
2. Install or renew draughtproofing to all opening windows and doors.
3. Seal all window and door frames to adjacent airtight construction with a proprietary airtight sealing tape or system.
4. Remastic as necessary all joints around openings in the external envelope.
5. Seal around all services entry points into the building to make them airtight.
6. Install chimney damper to all open fireplaces.
7. Install airtight dampers to all ducted vents through the external wall.
8. Install airtight membrane to the warm side of all insulation in the roof, floor and walls of the external envelope.
9. Install or replace all fuel burning appliances with 'sealed appliances' with combustion air provided to the burner /firebox in a sealed duct and fit a sealed flue.

Schools:

Generally seek to achieve the highest level of airtightness possible to prevent drafts and reduce energy demand.

Apartments:

Generally seek to achieve the highest level of airtightness possible to prevent drafts and reduce energy demand.

Nursing Homes:
Generally seek to achieve the highest level of airtightness possible to prevent drafts and reduce energy demand.

Offices:
Seek specialist advice on the recommended level of airtightness for the type of office building, climate zone and location. If possible simulate the performance of the building in an industry standard dynamic thermal analysis computer model to test which degree of airtightness reduces the energy demand the most.

Measure 5: Ventilation

Definition: Good ventilation in a building requires a designed controllable system for bringing fresh air in to a building and allowing stale air to be exhausted to remove pollutants. The objective is to achieve and maintain a high standard of Indoor Air Quality.

Metrics:
Air change rate : litres/sec/person or m3/hr
RH : 30% to 60% relative humidity depending on climate and building type
Air Contaminants:
1. CO_2 : >1000 ppm
2. CO : >10 mg/m3 over 8 hrs
3. TVOC's : > 10 mg/m3
4. NO_2 : > 0.200 mg/m3
5. PM2.5 and PM10 : > 0.025 mg/m3 and > 0.05 mg/m3
6. Ozone: 0.0 There is no acceptable threshold.

Impact Grading: 10+ Critical Measure

Impacts: Improved IAQ; Energy Efficiency via Recovery
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 improves 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.

Commentary:
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.

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 because they cause cold 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. However there are HVAC systems and controls which can increase the efficiency and effectiveness of installed systems.
Measure 6: HVAC Retro-Commissioning (RCx) should be implemented.

The options for a designed natural ventilation systems will depend on the building but generally a passive stack ventilation (PSV) system or a demand controlled extract system (DCV) in a hybrid PSV system are the two most common 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.

Typical Specific Actions:

Natural Ventilation:

1. Design and retrofit a natural ventilation strategy where suitable / possible.
2. If there is no other possible alternative ensure openable windows and permanent vents provide sufficient background ventilation
3. Install a suitable Passive Stack Ventilation (PSV) system.
4. Install a passive system with demand controlled air intake vents.
5. Install a suitable hybrid system of a demand controlled assisted passive system using low fan power.
6. Consider wind cowls and solar chimneys to power a natural ventilation system.

Mechanical Ventilation:

1. Install a mechanical ventilation system with heat recovery.
2. Install a crossflow heat exchanger where appropriate.
3. Install and maintain appropriate filters in all HVAC systems.
4. Install a demand controlled ventilation sensor control system to the HVAC system.

Schools:

Due to the high density of occupation and the reliance on a manual natural ventilation strategy schools often have difficulty achieving a high standard of indoor air quality. High CO_2 several times the acceptable limit have regularly been recorded in school classrooms which results in drowsiness and poor concentration in students who should be supported by a high quality indoor environment.
There are now several ventilation systems specifically designed for schools which address the many issues, including cost, of providing suitable ventilation in classrooms. One of these avoids cold draughts by delivering fresh air through the middle of a double convector radiator where it is heated before entering the classroom.

Apartments:
Due to the restrictions of retrofitting services vertically in apartment buildings a heat recovery ventilation system running horizontally at ceiling level for each apartment is probably the best solution in apartments in temperate and northern European climate zones. A summer bypass must be included in the system to prevent summertime overheating when heat recovery is not necessary.

Nursing Homes:
Due to older peoples' need for high thermal comfort and their sensitivity to cold draughts a ventilation system should include heat recovery to ensure the fresh air entering the room is not perceived as a cold draft. There are HRV units for single rooms and systems for whole buildings that can be retrofitted.
Some country's regulations for nursing homes require individual control of heating and ventilation for each residential room. A ventilation system with a 'heating battery' (electric or hot water) can heat up the incoming air under the occupant's control thus achieving the regulation's objectives with one system.

Offices:
Consider the impact all other retrofit measures will have on the demand for heating, cooling and ventilation before starting the design process for retrofitting the HVAC system.
Integrate a thermal wheel heat exchanger into the HVAC system of larger office buildings.
Integrate an enthalpy wheel heat/humidity recovery into the HVAC system of larger office buildings.

Measure 6: Retro-Commissioning (RCx) HVAC Systems

Definition: Retro-commissioning' (RCx)[11] is the application of the commissioning process to the HVAC services and controls in an existing building.

Metric: Improved IAQ and reduced HVAC bills

Impact Grading : 14

Impacts: Improved IAQ and reduced HVAC bills

Commentary:
The successful operation of a building's ventilation system is very important in achieving a high standard of IAQ. 'Retro-commissioning is a cost-effective retrofit 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.

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

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.

Typical Specific Actions:

1. Investigate building system performance to identify inefficiencies
2. Provide adequate O+M Manuals and train staff in optimal use of system
3. Insulate all hot and cold water pipes
4. Insulate all air supply ducts where EE possible
5. Use free cooling wherever possible
6. Instal interlock on heating and cooling systems so they never operate at the same time
7. Upgrade or instal controls and maximise zoning of systems

Schools:

Turn down all systems during weekends, school holidays and breaks
Purge ventilate all unoccupied classrooms between classes and at the end of the day to remove stale air and humidity without causing discomfort

Apartments:

Adjust heating controls programme every season
Regular maintenance of boiler and heating system
Change or wash filters in heat recovery ventilation system

Nursing Homes:

Monitor thermostat settings in all rooms to maintain constant temperatures

Offices:

1. Optimise Building Management System controls
2. Upgrade or instal heating controls and maximise zoning of systems
3. Consider installing sensored control system to HVAC system
4. Use free cooling wherever possible
5. Optimise use of cooling towers

Measure 7: Exposed Thermal Mass

Definition:

The 'thermal mass' of a building is composed of the internal heavyweight elements of construction which can absorb heat energy from the indoor air.

Metric: Total area of exposed thermal mass within the building.

Impact Grading: 13

Impacts:
Exposing the thermal mass inside a building will generally increase thermal comfort and reduce energy use. However it can cause acoustic problems which will need to be solved with the probable addition of other sound absorbing materials during the retrofit.

Commentary:
Exposing the thermal mass of a building allows heat to be absorbed by the thermal mass of the building interior which then releases it slowly when internal temperatures are lowered. Thermal mass can balance and 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.

Typical Specific Actions:
1. Remove suspended ceilings to concrete soffits and cladding to internal heavy weight elements with high thermal mass wherever possible and leave the materials exposed to the indoor air.
2. Plaster and cladding provide a degree of insulation and separation of the thermal mass from the indoor air from which it can absorb heat energy.

Schools:
Can be used effectively with high level ventilation or openable rooflights to cool the thermal mass and purge the spaces of stale air.

Apartments:
Commercial and industrial buildings converted / retrofitted to apartments can and do successfully integrate exposed thermal mass of the existing buildings into the environmental strategy for the converted apartments.

Nursing Homes:
The benefits of thermal mass can apply to all building types including nursing homes, depending on the building design.

Offices:
Exposing the thermal mass is most commonly considered for office and commercial buildings due to the high internal heat gains and usually needs to be combined with a night time cooling ventilation strategy.

Measure 8: Insulation

Definition: Insulation is any material which slows the passage of heat through the external envelope of a building.

Metric: U-value in W/m2k

Impact Grading: 10

Impacts:

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.

Commentary:

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. For office buildings the controls and management of lighting and HVAC are the most cost effective measures.

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 analyzing the behaviour of moisture and energy flows through a wall over time is by a simulation using the WUFI[12] software developed by the Fraunhofer IBP Institute of Building Physics.

Typical Specific Actions:

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 is of 'heavyweight' construction and insulated above the thermal mass elements.

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

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.

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 in crease 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.

External wall insulation

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 Agrement 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 narrow 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, as a first step, to protect it from wind driven rain.

Photo of cavity 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.

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.

Photo of internal wall insulation fitted with internal vapour control membrane to prevent condensation on the cold side of the insulation

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 cannot 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.

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.[13] 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

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

Schools:

Due to the requirements for high levels of daylight in schools there are usually large windows to classrooms. Replacing windows or glazing is one of the least cost effective retrofit measures so increasing the insulation to the solid areas of the external envelope is possibly one of the few insulation retrofit measures.
External insulation is extremely robust and concerns over its use in a school environment are unfounded as there are many examples where it has been retrofitted to school buildings and proven to be very durable.

Apartments:

The retrofitting of the external walls of whole apartment buildings can be cost effective as the costs are shared by all the apartments yet each has a relatively small external wall area to pay for. A new storey of apartments is often added at roof level and the profits from selling these apartments can often pay for the retrofit of the existing building.

Nursing Homes:

Most nursing homes are kept at relatively high indoor temperatures as older people feel cold more easily and are more susceptible to cold. The heating costs can therefore be quire high as can the savings and benefits of adding more insulation in a retrofit.

Offices:

Adding more insulation to an office building requires very careful consideration as offices have high internal heat gains from people, lights, office equipment and solar gain and usually spend more on cooling and ventilation than heating. It is recommended that dynamic thermal simulations are performed on a computer model of the building to test what the best overall insulation measures might be for a particular building in a particular climate location.
To save energy in offices cost effectively the focus is usually first on lighting, then controls, building management systems and retro-commissioning of the HVAC system. Insulation to the external envelope is relatively expensive for the return on investment.

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

Measure 9: Thermal Bridging

Definition: Thermal bridging, or cold bridging, is the high heat loss caused by a material connection, usually structural, that crosses the insulation layer in the external envelope.

Metric: Linear Thermal Bridging Factor; PSI Factor

Impact Grading: 3

Impacts:
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.

Commentary:
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 certification process and recently by the Irish and UK Building Regulations to demonstrate compliance with minimum standards.

Typical Specific Actions:
1. Structural connections of balconies, canopies and architectural features on the external envelope are often redesigned with plated connections sandwiching high performance rigid insulation with widely spaced bolts to minimize the extent of the thermal bridging.
2. In other situations insulation is continued around all sides of a feature (such as a parapet) to prevent thermal bridging.
3. The strategy when retrofitting is often a compromise and building physics would support the adage that "if you can't insulate, then isolate". In other words if thermal bridging can't be avoided then minimize it with, for example, a structural plastic (dense polypropylene) spacer between two structural steel connections. Isolating the material connection limits the amount of thermal bridging.

Measure 10: Windows, Glazing and Doors

Definition: The heat loss and solar gains through windows, glazing and doors is significant and reducing these losses by retrofitting with high performance versions of these products is recommended.

Metric: U-value in W/m2k

Impact Grading: 3

Impacts:
Replacing windows, glazing and doors 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 of the glazing can also be affected by the increased energy performance specification and the impact on the demand for electric lighting should be considered.

Commentary:
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' [14] which adds a new layer of high performance glass internally to the curtain wall system with a simple installation process.

There are very sophisticated glazing systems available with two, three or more layers[15] 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.

Typical Specific Actions

1. Install new high performance windows with high performance glazing or retrofit high performance glazing system into existing frames.
2. Install specialist high quality films to the existing glazing to improve their performance for specific environmental effects.
3. Make the window and doorframes airtight to the adjacent construction by sealing with tapes and mastic from a proprietary airtightness sealing system.
4. Install new insulating doors with low U-values and a draught lobby wherever practical.
5. New window and door frames should be thermally broken and extremely airtight and tested to certify that they achieve airtightness standards. Window frames should be as 'thin' as possible to minimize their aspect ratio as the heat loss through the frames is greater than through the glazing.
6. If there is a national window energy rating system in place the windows with the best rating should be used.

Schools:
Natural ventilation via opening windows is the most common way to ventilate schools so any intervention involving the windows needs to carefully consider ventilation and the opening windows. The relatively large glazed areas of schools means improving the glazing specification will both have a large impact and be expensive.

Apartments:
Retrofitting new windows is usually the least cost effective measure in terms of energy efficiency in apartments. However if the windows need extensive maintenance or replacing then it is worth investing in the highest performance windows possible.

[14] http://www.seriouswindows.com/commercial/products/retrofit-glass-system.html, [last accessed 2012_01_26]
[15] 'Suspended Film Glazing' by Southwall Technologies at http://www.southwall.com

Nursing Homes:
Retrofitting new windows is usually the least cost effective measure in terms of energy efficiency. However if the windows need extensive maintenance or replacing then it is worth investing in the highest performance windows possible.

Offices:
The glazing to opaque wall ratio in office buildings is usually high to capture as much daylight as possible. It has also been the architectural fashion for many decades for office buildings to have as much glass as possible. This results in high heat losses and high solar gains requiring both heating and cooling in most office buildings.
Retrofitting the windows in an office building is therefore usually very expensive so the specification should be optimized for each façade depending on its orientation. North facing glazing does not usually need low G factor specification because the sun would only hit it in the early morning or late evening when the building isn't occupied.
The Serious Windows "iWindow" concept for retrofitting offers a cost effective way to upgrade the glazing in an office building.

Measure 11: Electric Lighting

Definition:
Electric lighting is an easy retrofit measure with immediate benefits. As light bulbs burn out they can be simply replaced with the latest most energy efficient product on the market. These typically reduce the energy consumption by 80% compared to the previous generation of bulbs.

Metric: Watts/m2 used for electric lighting.

Impact Grading: 3

Impacts:
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 planned maintenance and replacement programme that installs high efficiency luminaires with simple and easy to use controls. Increasingly wireless systems are being used to maximize control, energy efficiency and minimize the cost of retrofitting.

Commentary:
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 office buildings install all the retrofit measures listed below and implement the management changes referred to in Measure 15.0.
The savings possible with efficient lighting typically generate an ROI of less than 2 years. The technology is improving all the time and LED lights are now colour controlled and reducing in cost continuously.

Typical Specific Actions:
A complete lighting system retrofit 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
9. Default to “OFF” on all controls
10. If replacing wiring and light positions in a major retrofit use EnOcean wireless components to save on copper wire and installation costs, create future flexibility and integrate an effective control system. EnOcean components include wireless light switches that can be fixed and moved to any location as requirements in the space change.

Schools:
Presence detection in toilet areas and classrooms and planned maintenance replacement with the latest efficient light bulb are low cost measures with short payback periods.

Apartments:
Occupants can easily replace bulbs with the latest efficient technology. Home automation via smartphones and other mobile devices allows occupants to turn lights off remotely if left on by mistake.

Nursing Homes:
Presence detection and automatic controls are likely to produce savings as elderly people can be forgetful.

Offices:
Significant savings can be made with ‘no cost’ management changes. Significant retrofits can achieve major savings as lighting in offices typically accounts for 30% of the energy bill.

Measure 12: Fans and Pumps

Definition:
Fans and pumps often run intermittently in the water, refrigeration, heating, cooling and ventilation systems of a building using considerable amounts of electricity. They are rarely specified for their energy efficiency and significant savings are possible if sufficient research is invested in specifying the most energy efficient fan or pump available with a VSD.

Metric: kWh/m2/yr electricity

Impact Grading: 8

Impacts: 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.

Commentary:
All electric motors for fans and pumps can be replaced with high efficiency ECM motors (brushless DC electronically commutated 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.

Typical Specific Actions

Survey all fans and pumps in the heating, cooling, ventilation and water systems of the building and get expert advice on the most energy efficient alternatives which incorporate ECM motors and VSD's.

Measure 13: Electrical Equipment

Definition:

Managing and controlling all the electrical equipment that is present in homes, offices and all buildings can save a significant amount of electricity. Though not necessarily part of the 'building' proper their use is one of the biggest contributors to the total energy use of a building. It is often forgotten in retrofit projects because it is considered difficult to implement effective measures.

Metric: kWh/m2/yr electricity

Impact Grading: 2

Impacts:

Potentially significant reduction in electricity use and costs, depending on the building use and occupants beahviour.

Commentary:

Almost all electrical equipment has its switching position default to "ON" by either design or management. The 'standby mode' uses between 60% to 90% of the electricity of full operation and wastes a lot of electricity. Computers are often left on all the time as users either believe 'sleep mode' doesn't use much electricity or they are set up for updates at night when no one is using them. The net result is a significant total energy use that is unnecessary.

Typical Specific Actions

1. Install a system for automatically switching off electrical equipment and appliances and appoint a person to be the 'champion' of this initiative.
2. Implement systems of management and control with the default position to "OFF".
3. Implement a policy to only buy the most energy efficient equipment on the market.
4. Install 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.
5. Install a voltage optimization system for the building to make the most efficient use of the local grid's voltage variability. This usually achieves between 8% to 13% reduction in electricity costs as it optimizes the voltage fluctuations in the local grid.
6. Submeter specific significant electricity using equipment or circuits.
7. Consider installing wireless electricity monitors to each piece of equipment as part of a complete electricity monitoring and management system.

Measure 14: Renewable Energy

Definition:

Renewable energy systems can generate energy on the site of the building efficiently because there are not transmission losses and the energy can be used directly. This can be cost effective and reduce the reliance on 'grid' based energy supplies.

Metric: kWh/m2/yr RE

Impact Grading: 5

Impacts: A suitable renewable energy system will reduce the use of fossil fuel energy in the building and its CO_2 emissions. Reducing CO_2 and associated emissions improves outdoor air quality generally and therefore indoor air quality indirectly.

Commentary:
Renewable energy (supply) systems are usually more expensive than energy efficiency (demand) measures in reducing the energy use in a building. Renewable energy should thus only be considered when the energy efficiency (demand reduction) measures have been optimized for the building.
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. For example 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 CO_2 emissions.

Typical Specific Actions
1. Complete a study of appropriate renewable energy systems that might be used on the specific building considering its location.
2. Seek specialist impartial advice from someone who can use the RETScreen software available free from www.retscreen.net. RETScreen is an Excel-based renewable energy project analysis software tool that helps decision makers quickly and inexpensively determine the technical and financial viability of all renewable energy systems.
3. Install renewable energy systems appropriate to the building, its location and local environment.
4. Submeter the RE system to record exactly how much renewable energy is being generated on site. This will be important and useful information to help decide if the system is cost effective and if additional renewable energy systems are required.

Measure 15: Innovative Measures: CETIEB

Definition:
In the CETIEB *project* three new retrofitting measures to improve indoor air quality and the thermal performance of walls have been developed. The three measures are:
1. New plasters with photocatalytic properties to improve air quality combined with phase change and insulating materials to improve thermal performance are now available.
2. An innovative Air Biofilter which uses selected plants to clean and condition indoor air is now available in Europe for the first time.
3. A CETIEB sensor toolkit is available to measure the air quality 'before' and 'after' the retrofit works are completed.

Metric: IAQ and U-values

Impact Grading: 15

Impacts:
The insulating plaster will improve the U-value of the external wall and provide thermal mass with the phase change particles.
The photoactive paint will improve IAQ by converting pollutants in the air into benign substances.

The Air Bio-Filter will clean the air of pollutants through the action of the bacteria in the root zone through which the air is passed.

Commentary:

Plaster the internal face of external walls with the photocatalytic insulating plaster that uses expanded perlite to increase the insulating properties. The perlite is also a substrate for a titania (TiO2) coating which will react with NOx, SOx and VOCs in the air to oxidize and form benign substances. The photocatalytic properties will also have an anti-bacterial effect on the finished surface of the wall.
The phase change (nano wax particles) materials added to the mix will increase the effective thermal mass effect of the wall by absorbing excess heat and releasing the stored heat when the building starts to cool down.

Impact

This insulating plaster with photocatalytic properties will contribute to a cleaner and healthier indoor environment by oxidizing and safely removing air pollutants and pathogenic microorganisms from the air and the building surfaces and by reducing energy use. The insulating properties and the airtightness of the external masonry walls will be increased with this application of a two coat plaster finish at least 15 mm thick.

Photoactive Paint Finish

Paint all the indoor surfaces with the photoactive finish to the replastered areas.

Impact

Photoactive paints will oxidise NOx, SOx and VOC's in indoor and outdoor air and improve both indoor and outdoor 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 a non-photoactive paint is used to paint over the photoactive paint.

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.[16] 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 CO_2 into O_2 and re-oxygenate the air.

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

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 reducing fan energy use.

The aesthetic impact is also notable as these biofilters in office and public buildings are usually large attractive features which people generally appreciate for their aesthetic appeal.

Typical Specific Actions:
Replaster all existing walls as necessary with the CETEIB plaster or CETIEB paint.
Install an air biofilter in each space to improve IAQ.

Schools:
Replaster all existing walls as necessary with the CETEIB plaster or CETIEB paint.
Install an air biofilter in each classroom to improve IAQ.

Apartments:
Replaster all existing walls as necessary with the CETEIB plaster or CETIEB paint.
Install an air biofilter in each apartment to improve IAQ.

Nursing Homes:
Replaster all existing walls as necessary with the CETEIB plaster or CETIEB paint.
Install an air biofilter in communal spaces to improve IAQ.

Offices:
Replaster all existing walls as necessary with the CETEIB plaster or CETIEB paint.
Install an air biofilter in each space to improve IAQ.

Measure 16: '*Soft Landings'* Handover Process

Definition: The 'Soft Landings Framework' [17] 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.

Metric: PMV**:** Predicted Mean Vote
(User Satisfaction Rating using Post Occupancy Evaluation methodology)

Impact Grading: 8

Impacts:
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.

[17] www.softlandings.org.uk

Commentary:

The *Soft Landings Framework* was developed by BSRIA[18] (The Building Services Research and Information Association), the *Usable Buildings Trust* [19] 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 very useful retrofit 'measure' to ensure a successful retrofit project.

Essentially the Soft Landings framework creates an overlap between the retrofit design and construction team and the occupants and management of the building. It ensures 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.

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.

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.

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.

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

[18] www.bsria.co.uk

[19] www.busmethodology.org

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.

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) [20] 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.

Submetering and monitoring energy use can provide a more detailed understanding of where and when energy is used. The bills from energy suppliers can be used to obtain a total energy use but without the knowledge of how the energy was used.

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.

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.

Typical Specific Actions:

1. Complete a Post Occupancy Evaluation
2. Measure airtightness post retrofit
3. Monitor energy use
4. Start an awareness programme for occupants

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

3 The Benefits of Retrofitting

The retrofit process is usually evaluated in financial terms by considering only the energy savings and the expectation is often that the energy savings alone should pay for the cost of retrofitting. This usually results in long payback periods which negatively affects the decision making process of stakeholders. They often then decide to undertake retrofit measures with short payback periods based only on the energy savings. Depending on the stakeholders' interests they may be missing the significant added value of some of the other benefits. In fact the total benefits are estimated at between **2.5[18] times and 37 times more than the energy savings**. This has been proven to reduce payback times from 4.2 years to 1.9 years for monetizing the multiple NEBs (Non Energy Benefits) in some situations.[21] If the benefits and added values were better understood there would be more opportunities to retrofit more buildings and meet national and EU's targets for energy efficiency. If politicians and governments understood the total added value of retrofitting they might implement a **publicly funded support programme for retrofitting at about 25% of costs.** This level of financial support for retrofitting programmes are about **cost neutral** and self-financing given the taxes and avoided social benefit costs.

We list below the multiple benefits of retrofitting from our research and experience:

1. **<u>Health</u>**
2. **Improved Quality of Life:** Indoor environmental qualities, indoor air quality, thermal comfort, light quality
3. Comfort, happiness, well-being
4. Reduced National Health Service costs
5. Reduced Personal medical costs
6. Reduced lost income due to illness
7. Reduced absenteeism in work and education
8. Improved learning capacity in schools
9. Increased productivity in the workplace
10. Reduced sick benefits costs for employers
11. Less stress due to ability to pay reduced energy bills
12. Reduced winter fuel payments to elderly and disadvantaged in cold weather
13. Reduced 'excess winter deaths' due to under heated dwellings.

14. **<u>Economics</u>**
15. Reduced energy costs for people, business and government
16. Increased property values supported by better building energy rating
17. Reduced maintenance costs due to reduced risk of condensation, damp and mould
18. Reduced property insurance costs due to insulated pipes and services
19. Employment creation in the retrofit industry
20. Reduction in social benefits / unemployment benefits
21. Increased business activity in renewable energy generation and products
22. Developing exportable skills, services and products.
23. Increased local economic output (GDP)

24. **<u>Self-sustaining government retrofit support system at about 25% of costs</u>**
25. Tax revenue from retrofitting makes public support cost neutral to government
26. Export value of energy if not used in the country of origin
27. Balance of trade benefit through reduced imports of energy.

[18] Reinaud, J. (2012), "Energy efficiency & industrial productivity – Gaining through saving". IEA-SEAI Workshop: Evaluating the multiple benefits of EE.

[21] Worrel et al (2001 and 2003)

28. **Carbon dioxide (CO_2)emissions reductions**
29. Improvement in indoor and outdoor air quality
30. Avoidance of carbon emissions penalties
31. Potential for carbon credits
32. Reduction in fines and taxes for CO_2 emissions

33. **Political benefits**
34. Achieving political environmental policies and targets
35. Job creation reducing unemployment
36. Reduced cost of heating public buildings
37. Addresses and reduces fuel poverty
38. UK Stern Report* conclusion: *"Doing it now is cheaper than doing it in the future"*
39. Single 'deep retrofit' more cost efficient and less expensive than incremental retrofits.

4 Summary and Conclusions

There are many conclusions that can be drawn from these Guidelines and the benefits of retrofitting that have been listed here. However the overriding conclusion that seems to be self-evident is that retrofitting creates such **significant economic** and **non-energy benefits** for all **stakeholders** that **all buildings** should undergo a **deep retrofit** as soon as possible.

A short summary of the 'headlines' from these Guidelines would be:

1. *"Doing it now is cheaper than doing it in the future."*
2. Deep retrofit more efficient and less expensive than incremental phased retrofits.
3. Significant improvement in the Quality of Life for all occupants and users.
4. Savings in health and energy costs for all stakeholders.
5. Increased productivity and reduced costs for public and private employers.
6. Self-sustaining, cost neutral government support system for retrofitting at 25% of costs.

Annexes

Annex 1.0 The Infrared System for monitoring and predicting thermal comfort conditions

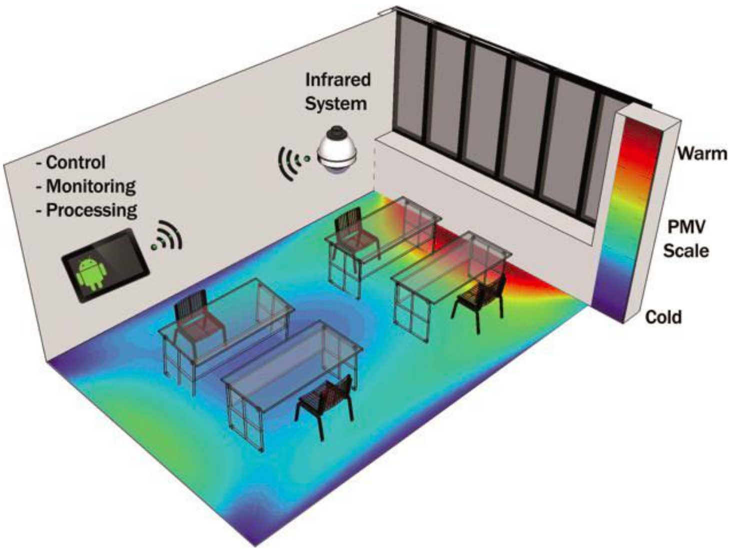
General Description

The infrared monitoring system uses digital infrared technology to scan a space and measure the surface temperatures of everything in the space. It then uses algorithms to calculate the PMV (Predicted Mean Vote) which is an industry standard calculation of whether most people will feel thermally comfortable in the space: i.e. whether most people will feel too warm or too cold. The PMV information can then be sent to the BMS (Building Management System) to control the building's heating, cooling and ventilation systems to create the desired comfortable conditions.

This more sensitive and responsive zoned control system can achieve energy savings of 10% while increasing comfort. In the workplace the non-energy benefits of increased comfort are very valuable as people are more productive and are absent less often if they are comfortable.

Technical Description

The heart of the device is a simple array of infra-red thermopiles to be installed on the ceiling of the occupied room. The embedded microcontroller together with the software allows the automatic scanning of each indoor surface to evaluate the temperature distribution. Algorithms provided by ISO 7726 and ISO 7730 are also embedded so that thermal and comfort parameters to calculate the Predictive Mean Vote (PMV) can be estimated for several positions in the room.



This innovative low-cost IR system for real-time monitoring of indoor thermal comfort was developed, assembled, tested and validated in different situations. Results confirm that the presented solution is able to measure the comfort level in the occupied space with an accuracy comparable to the usual microclimate station (0.1 ± 0.1 PMV units and 0 ± 0.5 °C for the MRT considering the office case study), but with a cost reduction of 1/10. In addition, it is capable of a real-time operation providing a spatial distribution. These capabilities make the IR device more suitable for the integration with BMS to actuate optimal control respect to the typical thermostat.

Benefits

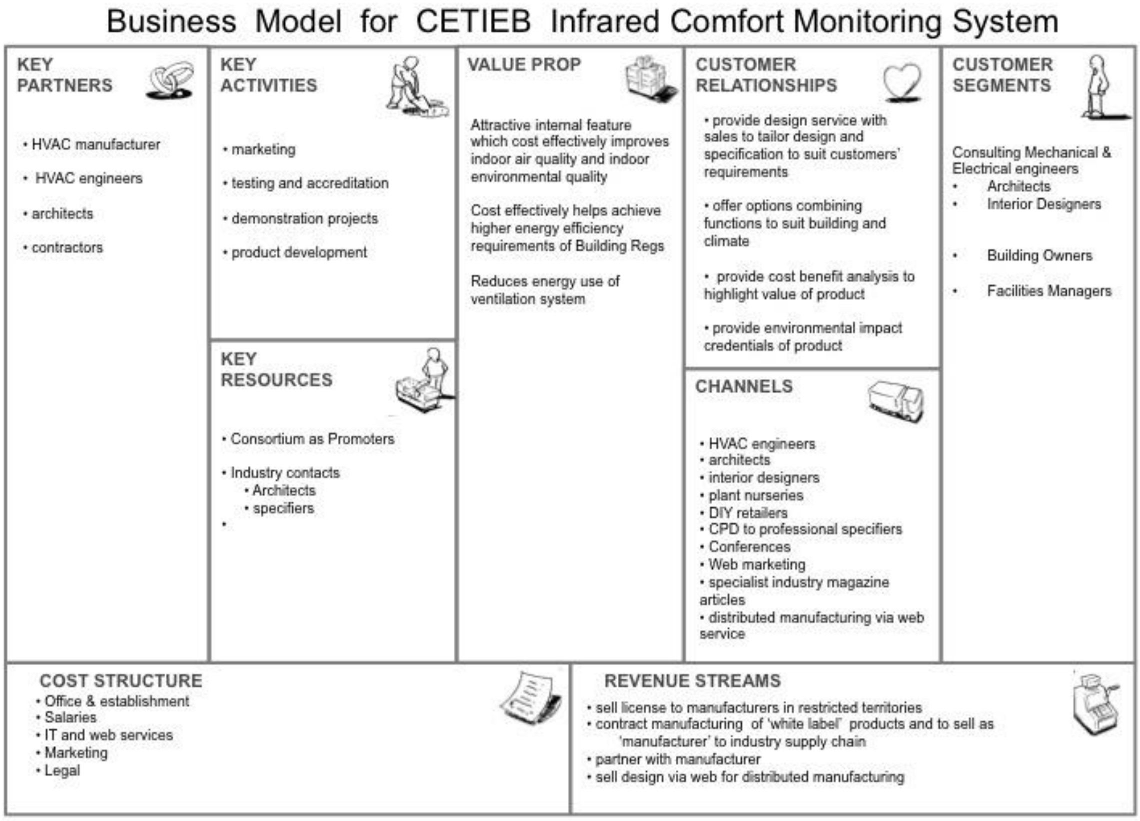
The main benefit derives from the possibility of a modular control of the environment that opens up new strategies to achieve the required energy efficiency in low energy buildings. Considering the case of the office room (see picture) the comfort map shows an increase of the PMV level in the zone close to the windows (around 0.6 units comparing with the zone where the thermostat is actually installed) indicating a higher cooling demand respect to the remaining zones of the space. Thus the increased load can be supplied only in the required zone with the consequent energy saving. Clearly, such a detailed information cannot be provided by a single-point thermostat.

The IR device has a set of additional functionalities that complete the system for improved control of the BMS. For example, algorithms for people detection are also embedded. These features can be used to improve the control capabilities through the knowledge of the real time occupancy: for example switching off the air distribution for the unoccupied workspaces or predicting the thermal load due to the number of persons for a predictive strategy of the HVAC system. The contribution of solar radiation entering the room and affecting MRT, with a consequent increase in the thermal comfort perceived by persons, is also considered and assessed by means of two different approaches, which are both suitable and prove able to improve the overall measurement accuracy in these areas.

1. Multi-point measurement: PMV values are derived in real-time and the computation can be performed for different positions of the subject in the room at the same time, with the consequent possibility of obtaining a discretization of the monitored thermal comfort.
2. Integration of several functionalities into a single solution: the system is able to measure the parameters needed for the calculation of the PMV. Particularly, Mean Radiant Temperature is derived through algorithms implemented in the microcontroller in order to elaborate the temperatures of all the indoor environment surfaces. Future studies will be carried out to extend the overall functionalities of the system to cover other fields of application: for example, the possibility of identifying heat sources could allow the device to be adopted also to perform internal surveillance.
3. Ease of installation and automation in the monitoring procedure: all the steps to be carried out to perform a complete monitoring of the environment, together with the processing algorithms are embedded on the microcontroller.
4. Excellent quality/cost ratio: the device is able to achieve the required accuracy with a potential reduction in costs of 1/10 in respect to a reference system (microclimate station).

Business Case

The business case for such a system is obvious and strong. Improving the IEQ of workplaces can increase staff satisfaction, reduce absenteeism, reduce time of work due to illness and increase productivity. Long term such workplaces may be able to retain valuable staff and reduce their HR costs (Human Resources cost of finding and hiring new staff) as well as reducing the energy use of the building through more efficient and targeted HVAC services. Research on the non-energy benefits of improving the IEQ indicate the total value of these benefits are between 2.5 and 37 times the value of the energy saved.



The cost of the system is about €250 per monitoring station. To manufacture and market such a system a margin of 70% is usually necessary to cover all costs and make it a profitable enterprise so the retail price of the system would be €425 per station. Each station would cover a zone in a building which might have 10 people working in the space. A once off cost of €42.50 to achieve more comfortable working conditions per person is very good value and we believe this is a successful business opportunity.

Annex 2.0 The RGB Lighting System

General Description

People can see most clearly and accurately when using daylight as we evolved with natural light and electric lighting is of course very recent. The best lighting is very close in 'colour', or combined wavelengths of light, to daylight. The innovative lighting system developed within this project delivers light with the colour wavelength and intensity to balance and match the qualities of natural daylight using light sensors, innovative algorithms and a combination of LED and neon lighting.

The system is designed to produce the correct quantity of light in relation to the type of use in different spaces, taking into account daylight, the positioning of the lamps, their direct illumination profile, the reflected illumination and the light absorption from the surfaces. It achieves this by using light sensors to provide information to the control system.

A lighting design should be divided into zones so the illumination can be controlled with separate control commands which suit the changing daylight of the space and the needs of the occupant.

The main reasons to modify the illumination levels are:

- Integration of the external illumination and its variability; note that when modifying the

lighting level of lamps also the colour temperature of certain types of lamps changes
- Non continuously used and non-interacting zones
- Zones with activities requiring different levels of illumination

To adjust the colour of the light to be as close to daylight as possible a combination of LED's (RGB or White + RGB), with groups of neon lamps with different coloured phosphor coatings or conventional lamps with colour filters are used in this novel system. A control system is needed to control the RGB channels of the lights.

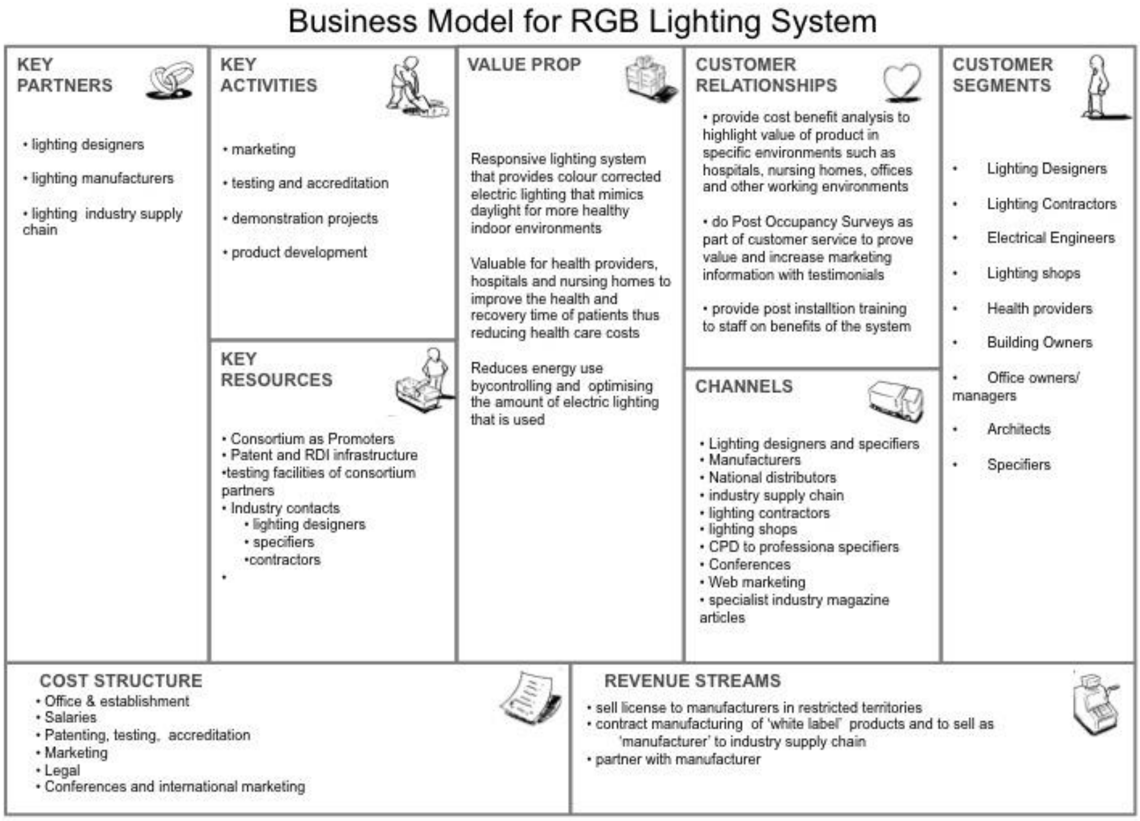
In the case of an on/off control of the individual lamps the change in colour, which is an additive process, is the result of the distribution of the coloured lamps and their switching on or off in the different zones in function of the total illumination level needed. In addition, an additional control function is necessary to avoid instability from inappropriate switching on and off of the lamps.

Technical Description of the System
To define a system for the control of the illumination, the corresponding standards need to be reclaimed with respect to the illumination levels and the lighting quality in terms of colour temperature, spectral distribution and diffusion (dazzling) of the light sources with respect to the activities and applications of the environment concerned.
To measure the main parameters, the sensor developed within the project measuring the illumination level and the colour temperature will be used.
The control characteristics of the system need to satisfy the management criteria of the system in line with the user and the energy efficiency requirements.

To describe the system in general we define a model with the following elements:
- Characterize the standards in profiles to simplify the user interface and subdivided in standard profiles and user requested profiles. Such a profile can be defined as fixed or variable over time (daily, weekly, seasonal, ...).
- Disposition of the light sources (1 to n) and sensors in the space; determine the necessary number of sensors in non-homogeneous spaces.
- Type of control of the light sources: grouping; continuous or stepwise variation of the power; variation of the intensity and or the colour temperature.
- Define the relation between commands and obtained effects: variation of the illumination or colour in relation to the activation steps; maximum speed of the transmission; sequence of actuation or deactivation in non-homogeneous environments.
- Presence of uncontrollable light sources (windows) and eventual shading systems (which can be activated by the building automation controls or the HVAC systems).
- Presence detectors to deactivate the illumination or activate an adapted profile when people are absent.
- Other parameters of the system: range of setting changes necessary to modify the state of the illumination system; response time of the light sources to control commands

The level of correspondence with the general model and the use of the variables will define the control algorithms.

Benefits
Light quality is an important IEQ which affects people's comfort and ability to work on tasks affected by lighting. The benefits of this RGB lighting system is improved indoor environmental quality, increased occupant satisfaction, increased productivity and reduced energy consumption for lighting. The reduced energy consumption results from the zoned lighting controls, the use of efficient LED and neon lighting and the 'proactive' recognition of daylight by the lighting control system.



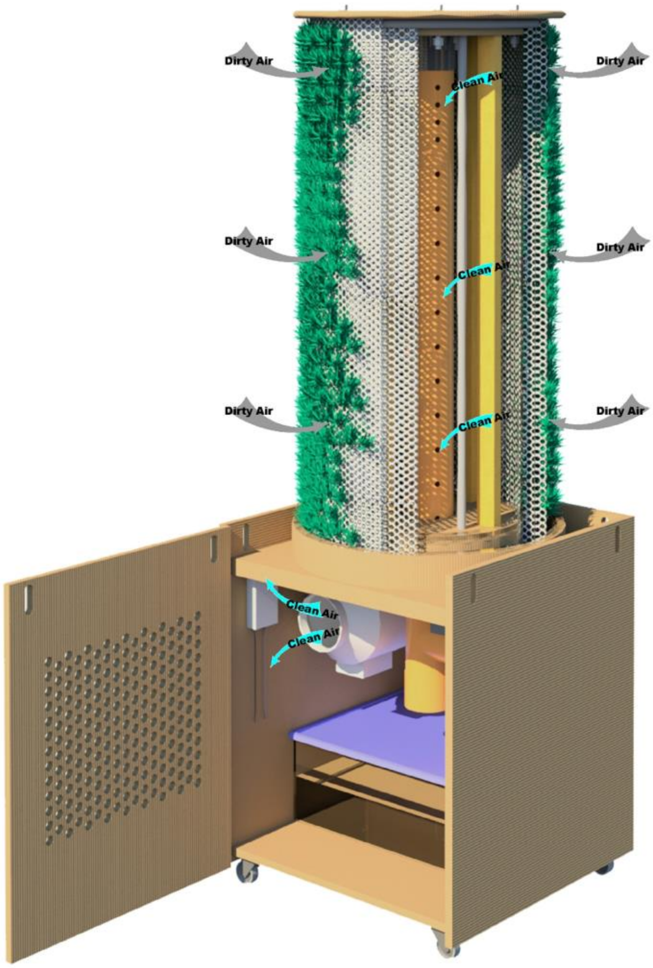
Annex 3.0 The Air BioFilter

General Description

The Air Bio-Filter is a vertical hydroponic green wall containing a range of specifically selected plants. The plant roots are embedded between two layers of woven, porous material similar to that of a kitchen-scrubbing pad. Nutrient rich water trickles down in this material, into which the roots of the plants are intertwined, providing plant roots with nutrients and hydration. The water is key to filtering the air: Fans running behind the wall continuously pull contaminated indoor air through the bio-filter's porous root zone material. As a result, VOC's naturally dissolve into the water and become available to bacteria and fungi on the plants' roots. These microbes then consume and break down the VOC's into benign products, primarily carbon dioxide and water. As the microbes remove VOC's from the water, more VOC's can be absorbed from the circulating air, and the cycle continues.

Benefits

The removal of VOC's from indoor air is a significant improvement of IAQ and IEQ leading to health benefits. The visual and psychological effect of having attractive plants in a working environment are important to occupant satisfaction. The recycling of the 'cleaned air' can reduce the amount of outside air which is brought into the building by the HVAC system and this can create energy savings. The portable prototype built to demonstrate the system in this project is ideal for retrofitting projects as it is an independent system requiring only an electrical plug connection and manual top ups of water and nutrients.



Technical Description

The biofilter is generally made up of raised water catchments, a reservoir with an outlet, a circulating pump, vertical support structure, growing medium and plants. In order to construct the wall the basin at the base of the living wall is prepared first. A waterproof membrane is applied to the existing wall on top of which vertical diffuser ducts and horizontal manifolds are applied and connected to return air ducts. The growth media, which needs to be durable, lightweight and able to hold moisture, is then fastened to the diffusers in two separate layers. Then selected mature bare rooted plants are placed in between the two layers of the growth media.

For effective installation the system requires: water, power, light (artificial or preferably natural) and air handling i.e. on board fans and or connection to a HVAC system. The system needs a source and reservoir of water and this needs to be circulated throughout the growing media to provide nutrients to the roots of the plants. The system needs a water drain and adequate maintenance to ensure that the water is kept at a high quality with sufficient nutrients and without the build up of salts. The power requirements for the bio-filters relate to the size of the system, the size and number of pumps used. To avoid interruptions in power supply a separate power circuit is recommended. The preference for lighting is natural daylight but supplementary artificial light may be used, this may add an additional 100-200 watts per m^2 of electricity use to the installation.

The main structure weighs around 50-75kg.m^2. A formed concrete basin filled with stone can be over 600kg/m^2. A raised metal basin can weigh less than a few kg/m^2.

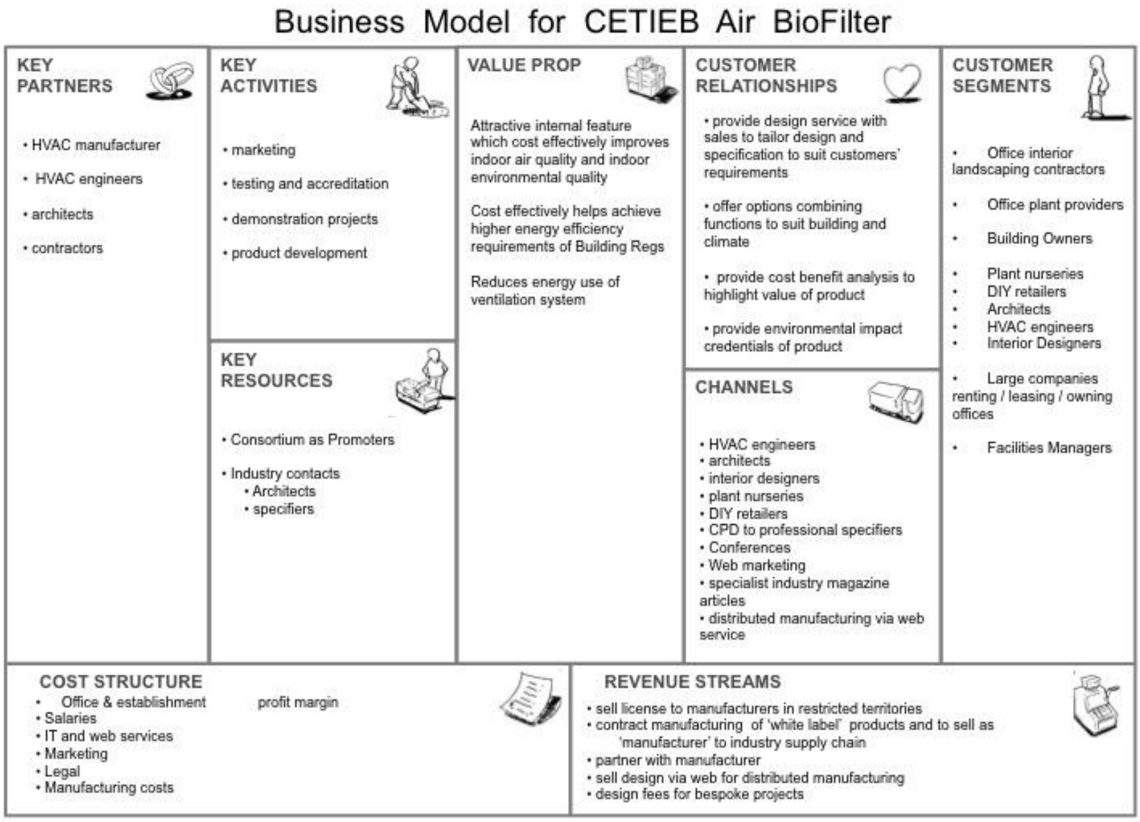
Similar to any botanical system, this system generates humidity and some dripping or splashing from foliage. This needs be taken into account when determining the placement and the choosing of surrounding finishes for the system.

Mature clean rooted plants are used in making a bio-filter. Plants are selected on their ability to form beneficial plant-microbe interactions and their ability to survive in vertical hydroponics. The selection of plants needs to match the site conditions i.e. temperature, light, water, and quality. Nedlaw have determined that some of the best plants to use are: Shefflera Arboricola, Dracena, Ficus Benjamin, Ficus Elastica, Hedera algeriensia (Ivy) and Philadendron Selluom all of these are commonly grown and easily available tropical house plants.

Business Case

Nedlaw Ltd. in Ontario, Canada is the developer of this system and has been very helpful in this project by providing much background information and design experience. On their large installations they have measured and calculated energy savings of up to 60% on ventilation energy when their system is installed and operating at optimum efficiency. Combined with the non-energy benefits and the attractive feature it provides to the indoor environment there is a strong business case for this system. Indeed Nedlaw are proof that the business can be successful as they are installing large systems across North America and now in Dubai.

The potential in the retrofitting industry to invest in portable BioFilters like the prototype demonstrated in this project is great but larger scale manufacturing will have to reduce costs significantly through detailed design for manufacturing and cost effectiveness. The lessons learned from this experience could be used to redesign a simpler, more cost effective Biofilter ready for the market. At this stage of development at about TRL 4.



Annex 4.0 Multi-Functional Plaster

General Description

The internal wall plasters developed within the project are designed to improve the indoor air quality, improve thermal comfort and reduce energy use with multi-functional properties including hypo-allergic, energy and humidity storage abilities with insulating materials, phase-change materials and photocatalytic nano-materials. The use of such materials in retrofitting buildings would be very useful and in new buildings the advantages would be similar. However more work and testing has to be completed to ensure these objectives are achieved.

Technical Description

The plaster is innovative by using nano-structured surfaces of the TiO2 semiconductor to contribute to a cleaner and healthier environment by oxidizing and safely removing air pollutants and pathogenic microorganisms from the air and the building surfaces. The increase in the efficiency of the synthetic materials will be achieved by dispersion of TiO2 on the expanded perlite's surface for enhancement of the activity and the efficiency creating this way a new generation building product.

The plaster incorporate phase change materials (PCM) in a lightweight thermal insulating mortar with expanded perlite. Expanded perlite is an insulator which will inhibit the transfer of heat through the external envelope and therefore the variation between maximum and minimum indoor temperature will be decreased in comparison to the conventional plasters. With the addition of PCM, the heat capacity of the plasters will be increased and walls will adsorb or release energy (heat) from the indoor environment creating a comfortable environment for the occupants. Due to the expanded perlite and the decreased variation between maximum and minimum indoor temperature, smaller weight percentages of PCMs will be needed to keep the temperature in a range of 24-26 °C than the 20-40 wt.-% reported in the literature leading to a cost effective multifunctional building material.
Expanded perlite was used as a lightweight aggregate for the production of thermal insulating plasters. PCMs of different working temperatures in the range 20-26 °C were supplied from the market.

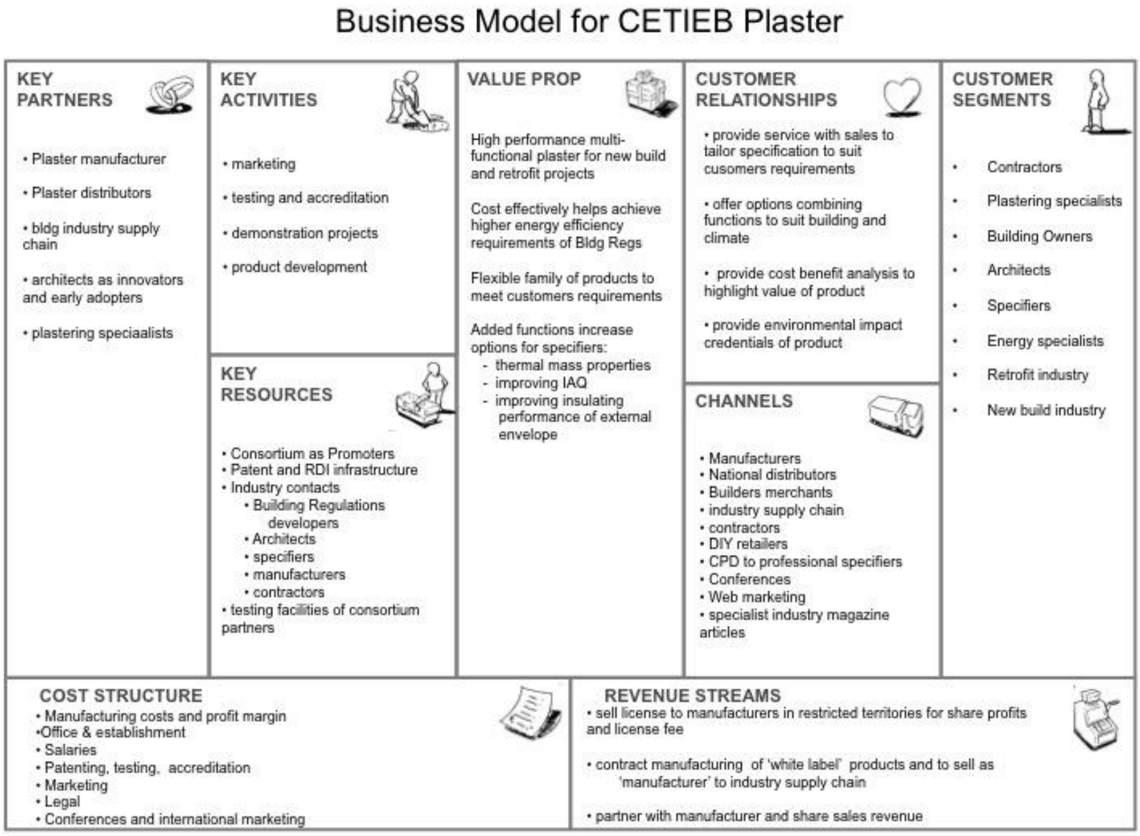
Benefits

The main benefits and objective of this family of plaster products is to provide a material which can improve the IEQ, IAQ and energy efficiency of the external envelope of an existing building during a retrofit. The plaster will improve the insulating performance of the external envelope, the effective thermal mass characteristics and the nano-material TiO2 will improve the indoor air quality.

Business Plan

The non-energy benefits of improving the IEQ and IAQ of existing buildings can be significant and if they are being retrofitted or refurbished the additional cost of using this multi-functional plaster will be minimal compared to conventional plaster. The plaster is for the internal face of the external envelope and its application does not affect the external appearance of the existing building which is usually critical to the building owner and the planning authority.

There is thus significant market potential for this product as there are about 210 million buildings in the EU-27 countries and the objective is to retrofit all of these in the next decades to meet climate change objectives.



Annex 5.0 The Sunlight Direction System

General Description

The Sunlight direction system consists of “light bricks” made of clear plastic, which using the physics of refraction of light and the characteristics of the plastic, captures and re-directs sunlight into buildings where windows or roof lights are not possible and where there is a lack of daylight. The “light bricks” are modular and connect together to form assemblies that can adapt to different situations. The light is directed through light pipes of highly reflective material to its ‘terminal’ which looks like a light fitting. The whole system is called “Sun Lego”.

The system is still under development with the current focus being the optimisation of a cost effective light tube to carry the light to its destination.

Benefits

If sunlight can be delivered into spaces in a building which lack adequate sunlight or daylight this will improve IEQ and reduce the energy used for electric lighting. In retrofitting buildings this could be a significant advantage as it may not be possible to create new windows or roof lights in many existing buildings.

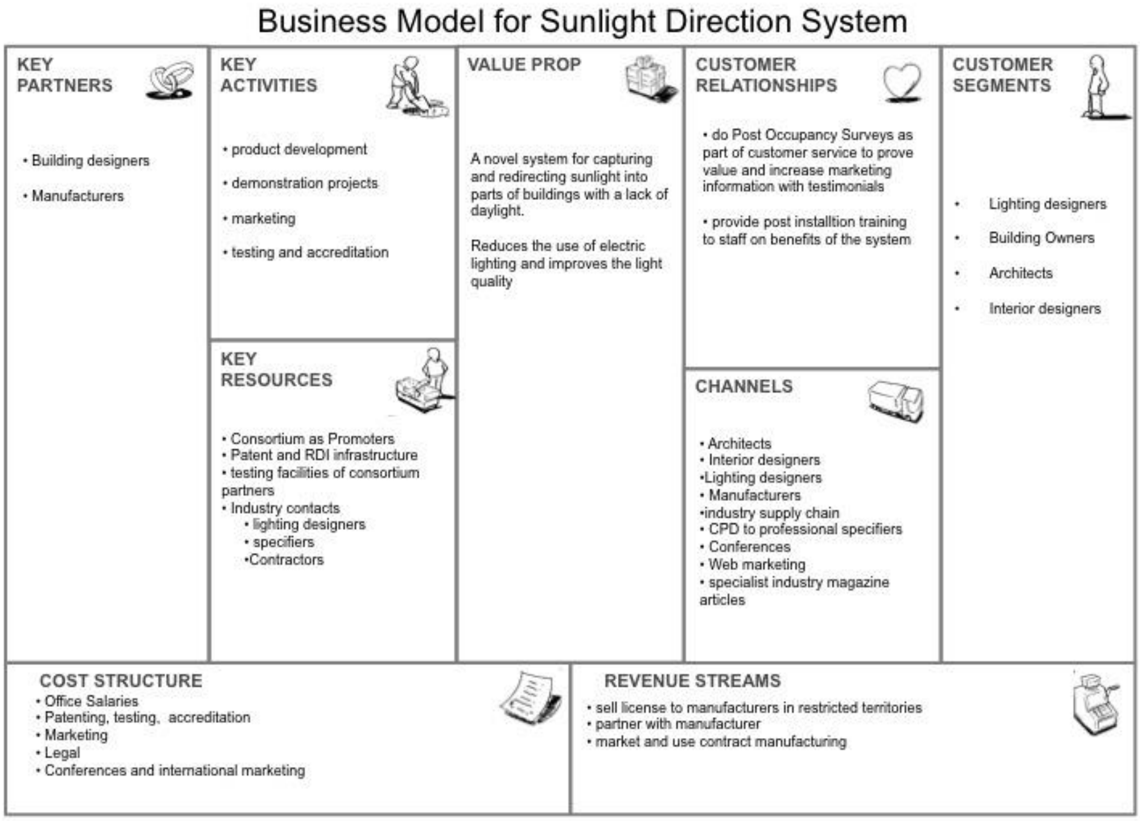
Technical Description

The whole system currently takes 100,000 lux of direct sunlight and delivers 2,350 lux, an efficiency of just 2.35%. This is due to the number of changes of direction of the light and the quality of the plastic that the light has to pass through. The losses of refraction are significant in any similar light directing system.

The system consists of “light bricks” and “light axes” which connect together to form what the developer calls the “Sun Lego” system. The modules are 115 cm x 120 cm x 12 cm thick.

Business Case

The current cost of the system delivers light at the cost of one euro per lumen. This is significantly more than the cost of electric lighting so more development is necessary to make this attractive to the market by reducing costs and increasing efficiency. This work is in progress.



In WP8 a detailed Business Plan has been developed for all of these innovative retrofitting technologies with indicative costs.