Advanced Ventilation Approaches for Social Housing (AVASH)

Final Publishable Assessment Report

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AVASH Assessment Report
Advanced Ventilation Approaches for Social Housing

Intelligent Energy Europe

Funded by the Intelligent Energy Europe Programme

INTRODUCING AVASH

AVASH is a collaborative project funded by the Intelligent Energy Europe (IEE) Agency. The project partners are from the UK (University of Brighton), Denmark (Cenergia Energy Consultants, KAB Housing) and Ireland (Delap & Waller EcoCo Ltd, Cluid Housing Association). The project also leverages sub-contractors in the UK (Camden Council) and Poland (FLOP System) to provide housing samples and dissemination services. Its aim is to survey and sample social housing within the three participating countries - to assess their current performance in terms of insulation and air-tightness. Then to computer model the properties to ascertain the best ventilation and insulation upgrade strategy.

Surveying the properties entailed thermo-graphic analysis, backed up with an elemental method, to determine the extent of their thermal insulation, and a blower door test to check the air-tightness of the building fabric.

The full report of the Sampling & Survey work can be found at the AVASH project website: http://www.brighton.ac.uk/arts/avash, along with other details about the project.

AVASH OBJECTIVES:

- To determine the best ventilation strategy for existing social housing in the UK, Ireland and Denmark, from the point of view of energy efficiency and occupant comfort.
- To propose any additional low cost measures for immediate improvement of the building's thermal performance.

AVASH METHODOLOGY:

- The project involves the assessment of a broad range of social housing stock in each of the three countries.
- Advanced sensor equipment was used to discover the state of the thermal insulation by thermal imaging, and elemental calculations.

Fig. 1. A total of 18, 32 and 18 dwellings were surveyed in Camden, Dublin and Copenhagen.

- The results are being extensively disseminated throughout the participating countries and also within Poland, which is the flagship country for new building practice within Eastern Europe.
- The data will be provided, in particular, to social housing providers who are considering upgrading their housing stock. The project will contribute to reducing fuel poverty, whilst enhancing living conditions and comfort, and reducing the cost of heating and limit carbon emissions.
- The data will be shared with other EU projects within the Intelligent Energy Europe programme.

WHO'S DOING WHAT AND WHERE

The first phase of our work has been to isolate a representative range of dwellings from within the catchment areas of the project's participating housing providers (KAB-Denmark, Cluid-Ireland and London Borough of Camden-UK).

A consistent methodology has been used to promote detailed suggestions for appropriate ventilation solutions, to be adopted at refurbishment, in conjunction with improved insulation and other remedial measures.

SAMPLING & SURVEY PROGRAMME

A map was first produced showing the distribution of the housing stock within The London Borough of Camden's ownership, and the range of dwelling types.

They were classified typologically (detached, semi-detached, terraced etc) and by construction (materials and forms of roof, walls, windows, doors and ground floor).

Building Fabric Survey
The fabric survey was to establish the dwellings' insulation characteristics (U-values) by measurement using thermography, and by calculation from an investigation of their form of construction and specification.

Fig. 1. Comparison of a photo and thermographic image of the external surfaces of a sample flat in Ireland from which the internal temperatures and approximate insulation values of the walls and windows could be derived.

Building Infiltration Survey
The infiltration survey has established the dwellings' infiltration characteristics (in air changes per hour) by pressurisation tests, and by calculation from an outline dimensional survey of the dwellings.

Having established the format and methodology for the project similar surveys were carried out in Ireland and Denmark.

The next phase is to input the data to a computer simulation model that will establish:

i. An assessment of the feasibility of possible methods of insulation.
ii. An assessment of the probability of achieving and adequate level of air tightness.
iii. An assessment of the feasibility of remedially installing alternative advanced ventilation systems in terms of ease of installation, for example the location of clear vertical routes for ducts through the height of the building.
iv. The change in energy performance of each type after remedial insulation, sealing and installation of the different ventilation alternatives.
v. The resulting reduction in the Carbon Dioxide emissions for which each building is responsible.

Estimates will also be made of the likely costs of these measures in each country, and the projected payback periods relative to energy prices in all three countries.

The project will help to clarify the issues surrounding the choice of ventilation strategy to be made for compliance with building codes so housing authorities will know that remedial measures will give the buildings a useful life, at least for the medium term.

The arguments for and against mechanical or passive systems, under particular circumstances of building construction or climate, will be clarified by this project. Our intention is to provide the information that will ease the decision making process for housing providers.

CONTEXT OF THE PROJECT

Across Europe, achieving adequate wintertime ventilation in houses and flats has become a problem.

For new construction thermal insulation requirements have been made more stringent so now the loss of heat due to ventilation is a large proportion of overall energy consumption. As a consequence, buildings are being constructed to be more air-tight resulting in concerns about indoor air quality.

There is also the growing need to address the vast housing energy cost which is due to the existing stock. Given the feasible rates of renewal, the majority of existing builidngs are set to be with us for many years.

Upgrading the energy performance of existing housing means improving their levels of thermal insulation and improving their air-tightness whilst safeguarding indoor air quality and comfort for the occupants.

These initiatives will help the large number of residents, particularly the elderly, who are subject to 'fuel poverty' a problem set to increase as energy costs keep rising.

These issues are highlighted in Ireland where:

- Average household energy expenditure was €1,500 (in 2004)
- which was 4% of disposable income for an average income household
- but 10% of income for those in lowest income bracket

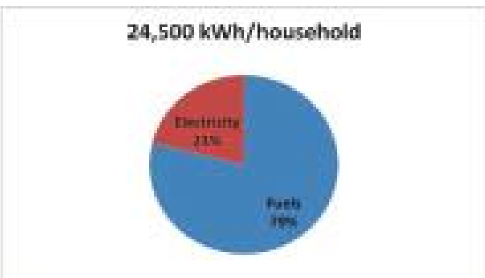


Fig. 1. Energy consumption mix for domestic buildings in Ireland.

ADVANCED VENTILATION STRATEGIES

Energy efficiency entails improving the housing stock by upgrading boilers, increasing insulation levels, reducing air infiltration, and the introduction of advanced ventilation systems incorporating heat recovery.

The most familiar method of domestic ventilation since the 1970s has been to install 'trickle' or slot ventilators over windows. Air is drawn in and out through these openings according to the direction of the wind. In the UK the size of trickle vents was doubled by a change to the building regulations in 1975 as a result of concerns about indoor air quality.

Indoor air quality (AIQ) has been cited by the US FHA as one of their top five health concerns. In the northern maritime regions of Europe IAQ is principally a matter of controlling humidity which otherwise results in condensation and mould - a cause of allergenic illness. Adequate thermal insulation is needed to raise surface temperatures, in conjunction with adequate heating, and adequate ventilation.

In addition there is the need to limit the buildup of volatile organic compounds (VOCs) that offgas from many contemporary building materials.

Advanced ventilation systems limit the amount of energy being thrown away when stale air is discharged from the building in winter. The amount of ventilation has to be geared to the occupancy of the building - not too much and not too little. In addition the spent moist air must have its heat removed, and reused, to limit heating requirements.

As a result trickle vents will soon to become an inadequate response to the problem. Their supply of air is too uncontrolled and lacks heat reclaim.

The necessary pre-requisite for all advanced ventilation strategies is that air leakage from cracks in the building fabric is limited so the ventilation system can be engineered to precise performance.

The Properties

Full details of the properties surveyed for the AVASH project can be found in the UK, Irish and Danish Survey reports on the AVASH project website at: http://www.brighton.ac.uk/arts/avash

UK

From the breakdown of Camden's social housing stock it was clear that the predominant property type was flats. Figure 1 shows a breakdown of Camden's

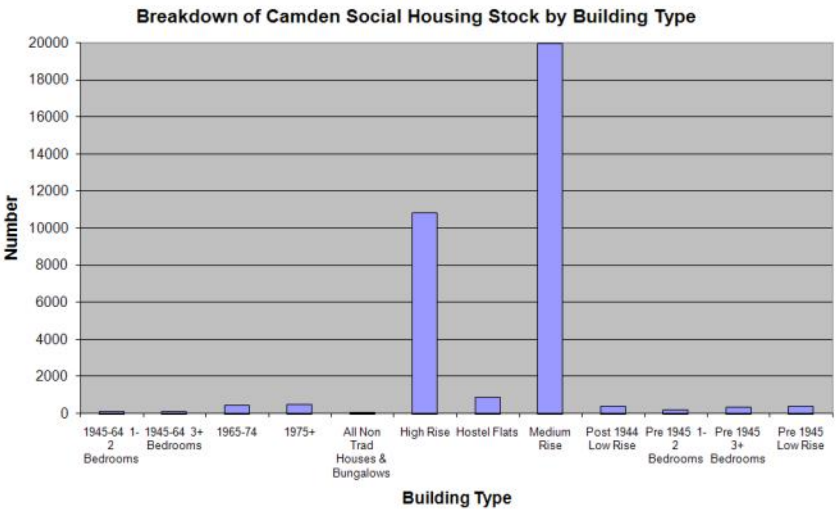


Figure 1. Camden housing breakdown.

properties and it's clear that low-rise (converted Victorian town house flats) and medium rise (bespoke blocks) are by far the most common property types, with houses very much in the minority. In summary, 18 of the UK's Camden Council properties were surveyed, ranging from converted Victorian town house flats to 1980's purpose built flats. The properties highlighted the large range in age of Camden's portfolio and the predominance of flats. Construction type also varied widely with examples of pre-war solid brick construction with wooden floors, to solid brick with concrete floors, to cavity wall with concrete floors and to solid concrete with concrete floors. Ventilation strategy was more consistent with intermittent mechanical extract fans, sometimes with trickle vents, the norm. One example of consistent mechanical extract was found. The sample reflected the profile of North London's social housing very well. A breakdown of the housing types is below.

Property 1 & 2. 1970's block of flats with concrete panel wall construction with solid concrete floors and timber single glazed windows. Intermittent extract fans and trickle vents.

Property 3, 4 & 5. 1950's block of flats with brick and block wall construction and solid concrete floors and modern u-PVC double glazed windows. Intermittent extract fans and trickle vents.

Property 6. Converted Victorian town house flat with solid brick wall, timber floor construction and original sash windows. Intermittent extract fans and infiltration.

Property 7. 1930's block of flats with solid brick wall construction with solid concrete floors and original timber single glazed sash windows. Wall vents.

Property 8. 1900's block of flats with solid brick wall construction with timber floors and timber single glazed sash windows. Intermittent extract fans with wall and trickle vents.

Property 9. 1970's block of flats with brick and block wall construction with solid concrete floors and modern u-PVC double glazed windows. Intermittent extract fans and trickle vents.

Figure 2. Example UK Flat

Property 10. Converted Victorian town house flat with solid brick wall, timber floor construction and original timber/metal single glazed windows. Intermittent extract fans and trickle vents.

Property 11. Converted Victorian town house flat with solid brick wall, timber floor construction and moderrn u-PVC double glazed windows. Intermittent extract fans and trickle vents.

Property 12. 1920's block of flats with solid brick wall construction with solid concrete floors and original timber single glazed sash/casement windows. Intermittent extract fans and trickle/wall vents.

Property 13 & 14. 1970's block of flats with concrete panel wall construction with solid concrete floors and metal single glazed windows. Wall and trickle vents.

Property 15. 1980's block of flats with concrete panel and block wall construction with solid concrete floors and aluminium single glazed windows. Consistent mechanical extract and infiltration.

Property 16. 1950's block of flats with solid brick wall construction with solid concrete floors and modern u-PVC double glazed windows. Intermittent extract fans and trickle vents.

Property 17 & 18. 1970's block of flats with brick cavity walls, concrete floors and modern u-PVC double glazed windows. Intermittent extract fans and trickle vents.

Denmark

In Denmark 18 properties were also surveyed in Copenhagen, belonging to the KAB housing group, with purpose built flats ranging in age from the 1950's to the present day and covers the majority of the age range of KAB's stock as can be seen from figure 1. Again flats are the dominant housing type here, but purpose built and not converted houses, and make up 70% of KAB's total. Construction ranged from cavity brick walls to timber frame with thermal insulation panels to pre-fabricated building elements. Ventilation strategy ranged from passive stack to mechanical extract to mechanical extract with heat recovery, and reflects the more advanced atitude to energy efficiency in buildings than in the UK.

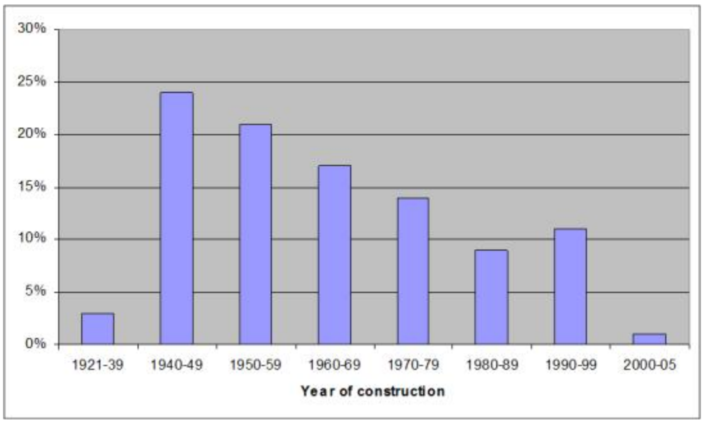


Figure 1. KAB housing breakdown.

The breakdown of the Danish properties are as follows.
Property 1, 2 & 3. Stationsgården. 1950's block of flats with external wall of cavity brick construction with insulation between with concrete floor slab and modern double glazed windows. Passive stack and trickle vents.

Figure 2. Stationsgården

Property 4, 5 & 6. Kildevænget. 1950's block of flats with external wall of cavity brick with insulation between with concrete floor slab and modern double glazed windows. Passive stack and trickle vents.

Figure 3. Kildevænget

Property 7, 8 & 9. Mørkhøjvænge. Terraced 1960's block of flats with heavy double brick cavity and lightweight eternit rockwool construction. Modern double glazed windows. Passive stack ventilation and trickle vents.

Figure 4. Mørkhøjvænge

Property 10. Egebjergvang. 1980's detached house with timber frame and insulation panels or brick external construction with modern double glazed windows. Mechanical air extract with trickle vents.

Property 11 & 12. Egebjergvang.1980's flat with timber frame and insulation panels or brick external construction with modern double glazed windows. Mechanical air extract with trickle vents.

Figure 5. Egebjergvang

Property 13, 14 & 15. Bøgehegnet. 1980's flat with timber frame/concrete with concrete/ gypsum cladding with modern double glazed windows. Mechanical air extract with wall vents and dampers.

Figure 6. Bøgehegnet

Property 16, 17 & 18. Skotteparken. 1990's block of flats with timber frame and eternit or outer brick cladding. High specification windows. Ventilation is MVHR.

Figure 7. Skotteparken

Ireland

In Ireland 32 properties, mostly belonging to Cluid Housing Association were surveyed, but because of the relatively narrow range of their stock in terms of age (1999 onwards), reflecting the recent Irish housing boom, some 1950's and modern best practice houses were also tested. Construction ranges from solid block to brick and block cavity, to full-filled cavity. Ventilation strategy consisted mainly of intermittent mechanical extract and passive stack ventilation. In Ireland houses are the predominant social housing type. Figure 1 shows the breakdown of Cluid's housing stock by bedroom number.

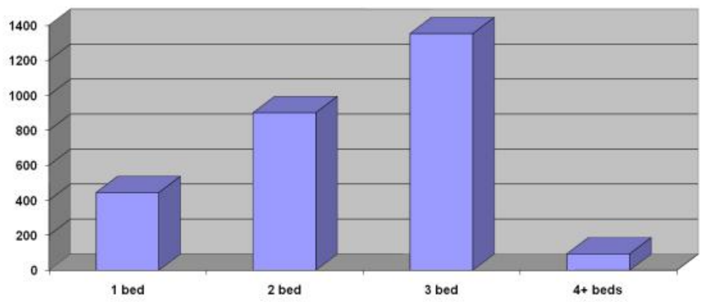


Figure 1. Breakdown on Cluid housing

The breakdown on the Irish sampled housing is as follows.

Property 1, 2, 3 & 4. Block of flats with brick and block construction and 60mm insulation with double glazed metal framed windows. Extract fans with trickle vents.

Property 5, 6 & 7. Block of flats with timber frame construction, full fill insulation with plywood cladding and concrete floors. Timber double glazed windows.

Property 8, 9, 10 & 12. Semi detached house with brick and block wall and concrete ground floor with metal framed double glazed windows. Closeable permanent vents.

Property 11. Block of flats with brick and block construction with concrete floor and metal double glazed windows. Intermittent extract fans and closeable permanent vents.

Property 13. Semi detached house with brick and block wall and concrete ground floor with metal framed double glazed windows. Intermittent extract fan and closeable permanent vents.

Figure 2. Property type 13.

Property 14, 15 & 16. Block of flats with metal frame construction, partial fill insulation and concrete floors. u-PVC double glazed windows. Intermittent extract fans and trickle vents.

Property 17 & 18. Terraced house timber frame with brick and block work, concrete slab floors with modern timber double glazed windows. Intermittent extract fans and trickle vents.

Figure 3. Property type 17.

Property 19. Block of flats with timber frame with brick and block work, concrete slab floors with modern timber double glazed windows. Trickle vents.

Property 20. Block of flats with timber frame with brick and block work, concrete slab floors with modern timber double glazed windows. Intermittent extract fan and trickle vents.

Figure 4. Property type 20.

Property 21 & 22. Semi-detached house of brick and block construction with concrete ground floor and timber first floor, with modern timber double glazed windows. Trickle vents.

Figure 5. Property type 21

Property 23 & 24. Semi-detached house of brick and block construction with concrete ground floor and timber first floor, with modern timber double glazed windows. Intermittent extract fans and trickle vents.

Figure 6. Property type 23.

Property 25 & 26. Semi-detached house, brick anf block construction with full fill insulation, timber floors and timber supply air windows. Passive stack ventilation and trickle vents.

Property 27, 28, 29, 30, 31 & 32. Terraced house with uninsulated brick and block construction, concrete ground floor and timber first floor with single glazed metal windows. Permanent wall vents.

The Survey Results

UK

A wide range of Camden's social housing stock has been sampled for their air-tightness and thermal insulation values. The breakdown of Camden's social housing stock indicated that flats (both purpose built and converted Victorian town houses) were the dominant housing form and so 18 flats were sampled here. Figure 1 shows a breakdown of the air-tightness values for the 18 sampled properties in terms of ACH@50Pa.

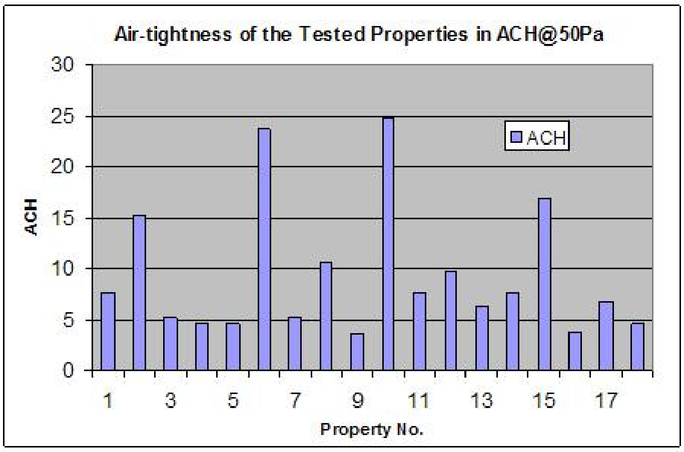


Figure 1. UK air-tightness summary (ACH).

There is a wide range of air-tightness metric exhibited by the properties, which is largely due to the variety of construction and window type. Concrete wall/floor based constructions tend to have a much better air-tightness than brick timber constructions, and indeed most of the concrete constructions are below the average for UK housing of 13ACH@50Pa. These flats were the purpose built multi-storey flats, both pre and post war. The air-tightness of these flats is also improved as most are located with other flats around them making the fabric generally more airtight. Flats with windows that have already been modernised tend to have the best air-tightnesses, and in this context the condition of the windows was a strong factor in the overall air-tightness.

Brick timber constructions, which tend to be the older converted Victorian town house properties, can have very high leakage of up to 25ACH@50Pa.Leakage in these cases tends to come from between the floorboards but there is also significant leakage from the windows as these buildings are often listed, and the window type is the orginal sliding sash window.

Other significant points of leakage tended to be around service pipe penetrations. A common source of leakage in modern housing i.e. from behind the plasterboard, was not an issue here as none of the properties had drylined plastering.

Figure 2 shows the air-tightness in terms of $m^3/hr/m^2$. The variation in result is much greater with this metric as some properties have a very low external surface area compared to their volume, due to the location of other flats on one or more sides, which raises the value to as high as $80m^3/hr/m^2$. This metric is good for quantifying a fabric's performance but is not so useful for gauging the overall contribution of leakage to a building's ventilation rate. ACH@50Pa has therefore been used during the rest of the project.

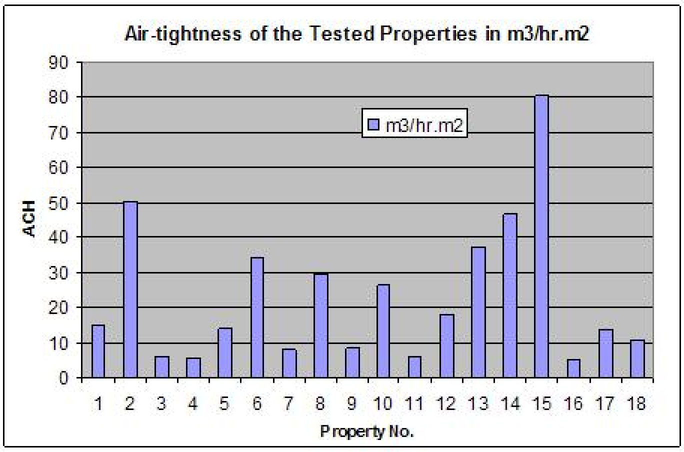


Figure 2. UK air-tightness summary (m3/hr.m2).

Insulation values for the external walls are shown below in figure 3. Thermographic imaging was used to generate these u-values, but variations in external heat transfer coefficient due to the prevailing winds and the long time constant associated with thermally massive walls made accurate prediction of values difficult, so values were checked with an elemental method using ESP-r.

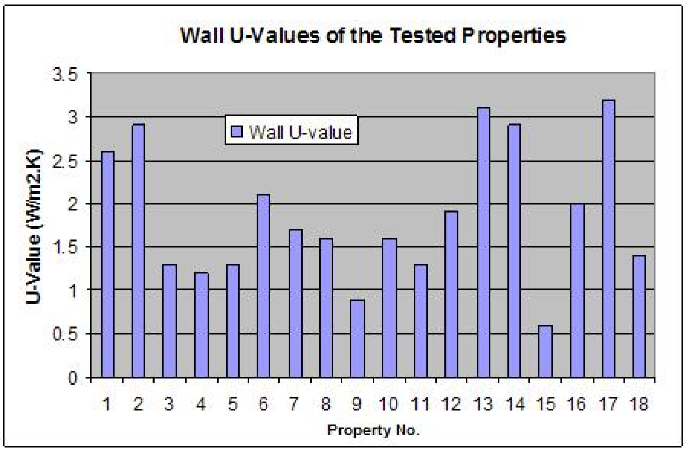


Figure 3. UK wall U-Values.

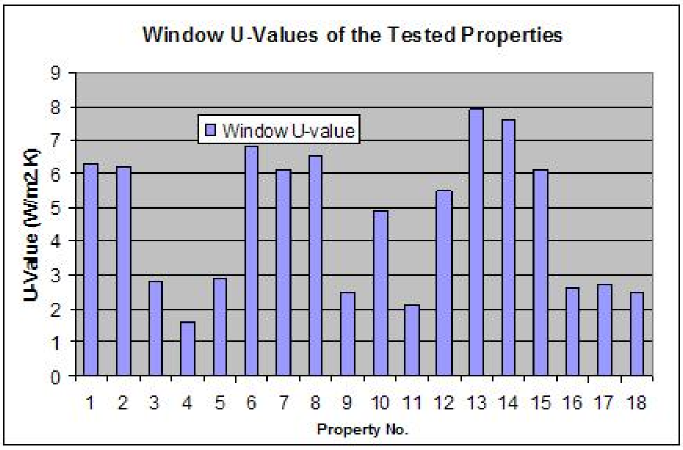


Figure 4. UK window U-values.

The age of most of the flats can be seen in the U-value figures which are much higher than would be allowed by current regulations. Most of the flats have no insulation, or even cavities within the wall structure, often being just solid brick or solid concrete. Purpose built blocks tend to have solid walls if they were of pre-war construction, brick cavity if post war but the most modern flats had solid concrete walls. Without a cavity the potential for easily increasing the insulation values of the properties are more limited. The differing constructions have led to significant disparity in the resultant U-values which ranges from over 3W/m²K to 0.6W/m²K and with an average value of 1.9W/m²K, much higher than the 0.25W/m²K specified today in the UK. The higher u-values tend to belong to solid walled constructions, either brick or concrete. Mid range belong to uninsulated cavity construction associated with post-war blocks. The lowest value is the most modern construction that was built after building regulations began to specify maximum wall u-values. Property 1 & 2 were however the next newest constructions (solid concrete) but have amongst the worst u-values. In summary before the regulatory age there is no strong relationship between construction period and u-value.

Below in figure 4 are the window U-values for the tested properties.

Window u-values are strongly connected to the type and age of the windows installed. Older single glazed windows tend to have a u-value around 6W/m²K, whilst newer replacement windows tend to have u-values of around 2.5W/m²K. Some variation is also due to the frame type, with metal frames delivering higher overall u-values than wooden ones. Whilst the upgrading of windows is usually a trivial affair the listed status of many of the converted Victorian town houses prevents the upgrading of the windows with anything but a similar design that may have much better air-leakage characteristics but is limited in the u-value improvement that can be achieved. It is surprising that most of the windows in the sample still retain the original single glazed windows, even where planning restrictions would not prohibit upgrade.

It is clear from the flats sampled that significant improvements can be made in the insulation and air-tightness performance of all properties. There is also significant scope for ventilation improvements as all properties have simple intermittent extract fans as their ventilation strategy apart from the most modern property that has a consistent centralised mechanical extract and one of the older properties that relies purely on infiltration. Trickle vents appear in most properties with newer windows, and in some with older windows.

Ireland

A wide range of Irish social housing stock has been tested for the air-tightness and thermal insulation values. Following figure 1 shows a breakdown of the air-tightness values for the 32 sampled properties, in terms of AirChanges per Hour AC/H @50Pa.

these interfere and some are quite individual for each house.
However, results were consistent for properties within developments.

Average air-tightness of Irish dwellings surveyed was 9.45 AC/H @50Pa.

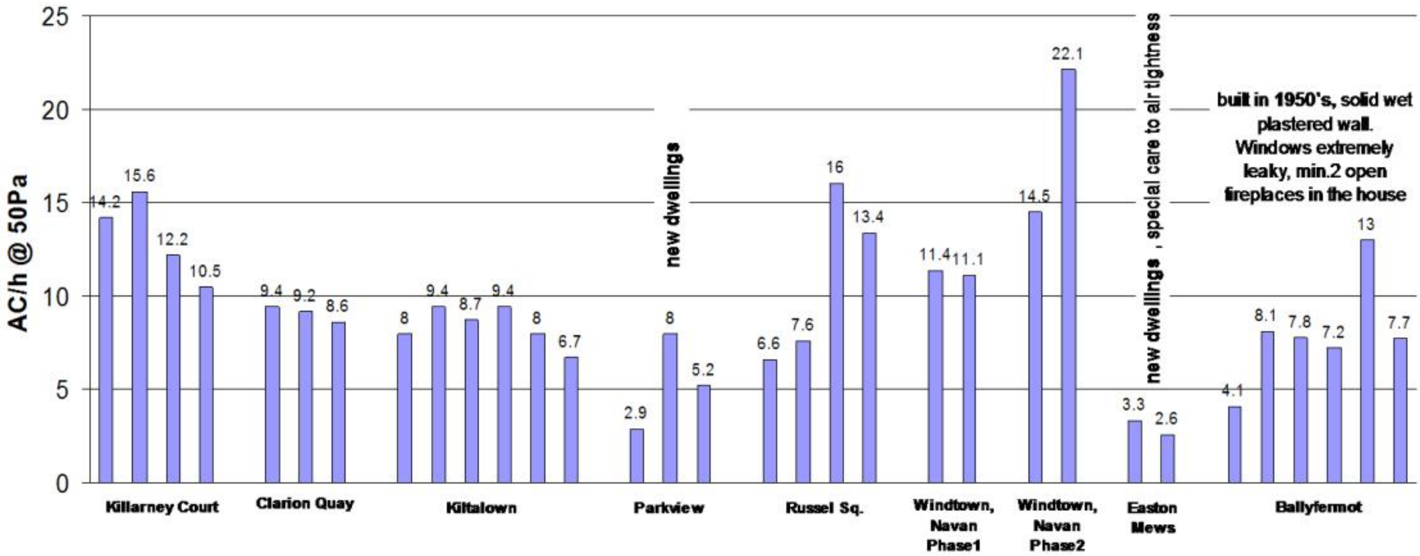


Figure 1. Air-tightness of tested Irish properties.

The wide range of air tightness values is shown by properties, probably due to so many factors affecting the performance, and to variety of construction, window and ventilation type, construction detailing, building maintenance, etc.
There were many analyses done, trying to find out which is the most important factor influencing performance. The following were considered:

- apartments versus houses
- wall type
- window type
- year of construction
- existence of open fireplace
- existing ventilation strategy
- number of bedrooms
- no of floors within the dwelling
- floor area
- ceiling – slab type

It must be noted there could be no straightforward correlation established for any of these factors, as

Generally, older refurbished houses show the worst performance, even having installed relatively new windows. This is probably due to technical problems with connection/joints between the old and new constructions, and type of internal finish – plasterboard (dry lining) – 13.3 AC/H@50Pa in average.
The recently built dwellings show relatively consistent results, only locally affected by defects during construction (unsealed cracks, unadjusted door hinges, excessive openings for service pipes) – 9.81 AC/H@50Pa in average.
Houses built with special care to air-tightness proved to be the best because of proper detailing and construction, 2.94 AC/H@50Pa in average.
Interestingly, houses built in 1950's showed even better performance compared to recently built and refurbished standard units (built in last 10 years), average 7.98 AC/H@50Pa compared to 10.36 AC/H@50Pa, despite those old units having extremely leaky old windows and service holes in some cases.

This is the most likely due to the method of construction, when these old houses have solid wall construction, wet plastered.
As a conclusion, wall constructions with an internal plasterboard finish proved tio be not as good in terms of air-tightness, as during the test important air leakage from outlets, light fittings and skirting board could be observed.
Explanation: As air gets behind the plasterboard (because of porous structural construction, service openings, etc.), it is then redistributed through the wall and ceiling cavity to all parts of apartments, and tend to flow in through possible openings in the plasterboard.

Insulation values for the external walls are shown below in figure 2.
The level of insulation varies greatly, as can be seen in figure 2. The performance would not be satisfactory with the introduction of a new set of Irish building regulations for domestic buildings. As the properties are in general more recently built than the UK properties u-values are generally lower.
It must be noted, that excessive infiltration into the cavity can significantly affect the thermal resistance of the wall, so proper detailing and air-tightness is required as a basic standard.

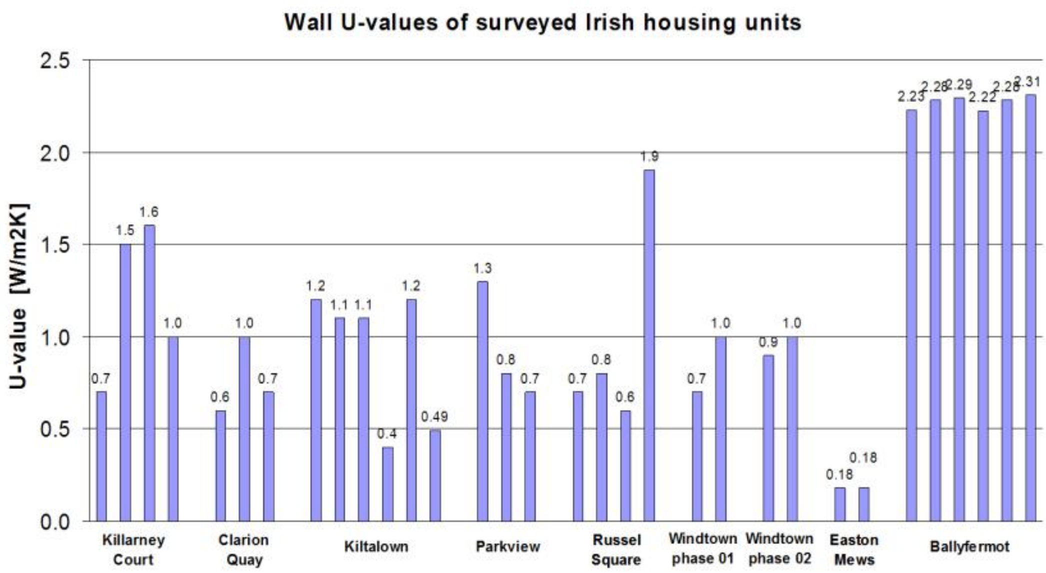


Figure 2. Wall U-values of tested Irish properties.

Below in figure 3 are the window u-values for the tested properties

The values are strongly connected to the type of the frame and glazing unit. Generally, metal windows tend to have higher values caused by the thickness of the frame and the glazing unit, around U = 4.5 Wm²K. Wooden windows provide important improvement to U of approximately 2.8 W/m²K.

The most recent PVC windows achieved the best U-value of approximately 1.1 W/m²K. None of the buildings have window upgrade restrictions.

There are naturally variations due to shape, size and installation.

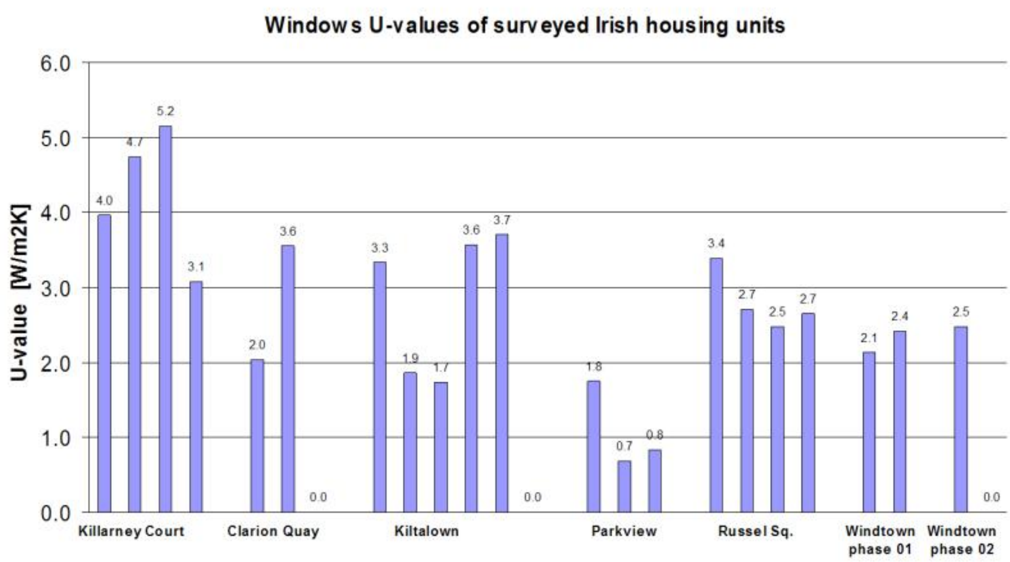


Figure 3. Window U-values of tested Irish properties.

Denmark

The first six properties are constructed in the 1950s and have identical construction. They are multi dwelling houses with double brick wall and with concrete floor slap. The windows are all replaced by new double pane windows and the blower door tests show no leakage around the window. Also the sealing between windows and window frame were truly air tight. With the exception of property no 1 the air infiltration at 50 Pa is very much lower than the present requirement in Danish building regulation which is 1.5 l/sm². The dwellings are all ventilated by natural stack ventilation and the measured air infiltration contributes only a small fraction of the necessary ventilation flow rate.

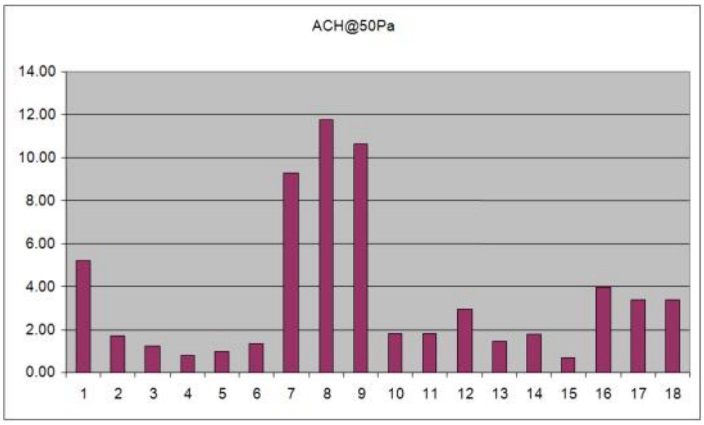


Figure 1. Air-tightness of Danish tested properties

Property no 7 to 9 were constructed in 1961. The external wall consists of double brick wall and light wood construction. The floor and the roof construction is also light wood construction with insulation. The monitored air infiltration is high and it corresponds to the high monitored energy for heating. It is assessed that the high air infiltration and a low insulation standards are the main reasons for the high energy consumption.
The property no 10 to 12 are constructed with light timber frame with thermal insulation. Half of the external wall has outside brick wall. The roof and the floor slap are light timber frame with insulation. A vapour membrane forms the air tightness barrier of the whole building envelope. From the survey the air leakage points were identified as the assembling of the vapour barrier was not properly fixed together and were not assembled properly to the building element like windows and doors. Property no. 12 is slightly leakier, caused by insufficient sealing between windows and the window frame. The properties are ventilated by mechanical exhausted air ventilation and the measured air infiltration contributes a small fraction of the necessary ventilation flow rate and does not cause unnecessary waste of energy for space heating.
The properties 13 to 15 are similar to the description above. The dwellings are airtight and only very few leakage point were identified.
Properties no 16 to 18 were the newest among the tested properties. They were constructed by prefabricated building elements and they also have mechanical ventilation with heat recovery. To obtain an energy saving by using MVHR it is important that the air infiltration is low corresponding to 1.5 l/sm² at 50 Pa or lower. The actual measurements are above this level and unnecessary energy losses occur from the ventilation system.
To achieve an average air infiltration of 0.3 l/sm² the air infiltration at 50 Pa must be 4.33 l/sm². Except the houses with MVHR all dwellings in the survey have an air infiltration below 4.33 l/sm² and no unnecessary energy losses appears from the ventilation system. In Skotteparken with MVHR the air infiltration is too high to obtain sufficient benefit from the heat recovery.

The main leakages can be grouped into four different types.

- Around installations.
- The assembly of the air tightness membrane and the building elements is not tight, typical around windows and doors.
- The assembly of the air tightness membranes is not sufficient.
- Sealing between windows/doors and frames.

The air leakage points which are identified in the Danish survey are listed in Table 1.

Property	Name	Number of rooms	lacation	No Floors	A - Floor area	Air Permeability	Volume	C	n	Qr50	ELA	NLA	Qr50/A	Installations	Building elements	Barrier	Sealings
					m²	m²	m³			l/s	m²	cm²/m²	l/sm²	rating			
1	Stationsgården	1	Intermediate	1	27	12	64	6.04	0.70	93	0.012	10.26	3.43				
2	Stationsgården	3	Intermediate	1	83	39	195	3.27	0.85	91	0.009	2.39	1.10				
3	Stationsgården	3	Top floor	1	83	146	199	1.28	1.01	68	0.005	0.36	0.81				
4	Kildevænget	3	Intermediate	1	79	35	189	1.47	0.86	42	0.004	1.22	0.53				1
5	Kildevænget	3	Intermediate	1	80	64	191	1.95	0.82	49	0.005	0.82	0.62				1
6	Kildevæmget	3	Top floor	1	79	119	189	4.95	0.67	69	0.009	0.78	0.87				
7	Mørkhøjvænge	2	Top floor	1	52	40	122	20.40	0.69	308	0.040	10.04	5.92		3	3	
8	Mørkhøjvænge	1	Top floor	1	35	35	82	11.24	0.81	269	0.029	8.35	7.68		3	3	
9	Mørkhøjvænge	4	Ground/Top floor	1	84	147	202	40.85	0.68	584	0.078	5.34	6.95		3	3	
10	Egebjergvang	3	End house	2	79	138	190	5.98	0.72	102	0.013	0.93	1.29		2	2	1
11	Egebjergvang	3	Ground floor	1	74	144	178	14.64	0.47	93	0.017	1.21	1.25		2	2	1
12	Egebjergvang	3	Top floor	2	85	95	205	18.70	0.61	204	0.031	3.22	2.39		2	2	3
13	Bøgehegnet I	3	Ground floor	1	84	64	203	2.37	0.90	81	0.008	1.19	0.96		1	1	
14	Bøgehegnet I	4	Top floor	2	95	104	228	1.36	1.12	109	0.007	0.69	1.15		1	1	
15	Bøgehegnet I	3	Intermediate	1	84	38	201	1.32	0.86	38	0.004	1.01	0.45		1	1	
16	Skotteparken	2	End house	2	70	114	168	11.50	0.70	180	0.023	2.04	2.56	3	2		
17	Skotteparken	2	Top floor	1	61	53	146	3.66	0.92	134	0.012	2.34	2.21	3	2		
18	Skotteparken	2	Ground floor	1	61	112	146	7.13	0.75	133	0.016	1.44	2.19	3	2		

Table 1. Danish air-tightness metrics.

Apart from properties 7, 8 and 9 the air-tightnesses of the properties are far lower than the properties sampled in the other countries. This is not only down to the type of construction but the way their construction is built. Airtight membranes are used in newer properties whilst the concrete floor plates and new windows in the older buildings also provide very good air-tightness. It is only in the period between these two techniques that the air-tightness levels are poorer.

U-values of the sampled properties follow a clear trend corresponding to the date of construction, with older properties possessing in general delivering higher wall u-values, as can be seen in figure 2. It should be note though that even the earliest constructions dating from the 1950's possess u-values better than most of the UK and Irish properties. By the 1980's wall u-values already surpass modern UK and Irish regulatory levels. Construction technique is also markedly different from the previous samples with the only the oldest constructions of brick cavity being similar to the other countries. Since then panel constructions with integrated insulation have become the norm.

With the properties in this initial condition there is limited scope for further improvement by utilising air-tightness or insulation techniques. There is some scope to improve the ventilation systems however as the older properties use natural stack ventilation and the newer ones have older MVHR systems, in three cases with too high an air-leakage to make them as effective as they should be.

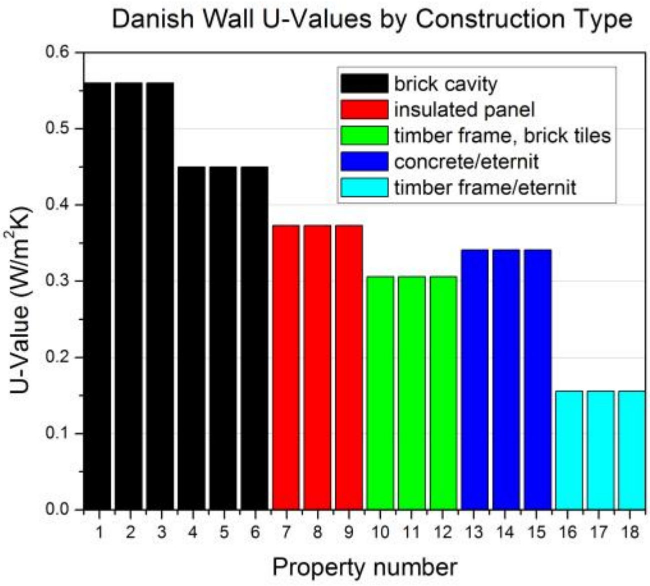


Figure 2. Danish wall u-values.

UPGRADE OPTIONS

The project has identified a number of ventilation and insulation upgrade strategies for the surveyed housing, the full details of which can be seen in the appendices at the end of this report. Upgrade options are broken down into three categories: Insulation, air-tightness and ventilation and include:

Insulation
- Loft Insulation
- External insulation
- Full Fill cavity
- Internal insulation lining
- Replacement windows
- Floor insulation
- Thermal bridging

Air-tightness
- Under-floor air sealing
- Service pipe sealing
- Replacement windows
- Draught stripping

Ventilation
- Mechanical ventilation with heat recovery (MVHR)
- Continous mechanical extract
- Passive stack ventilation
- Dwell-vent system
- Positive input ventilation (PIV)
- Hybrid systems
- Solar air systems
- Individual fans with heat recovery

These upgrade options are assessed and rated for feasibility and suitability to each building type surveyed, and cost of installation. The feasibility and suitability of each option is rated between 1-5 and multiplied to give a total score of between 1-25. This is presented in a matrix for each conutry's properties.

Representative properties are modelled with a whole house modelling tool to determine the current and upgraded energy consumption of the properties and related to the cost and energy prices to deliver a payback figure for the chosen interventions.

Figure 1. Full fill cavity insulation

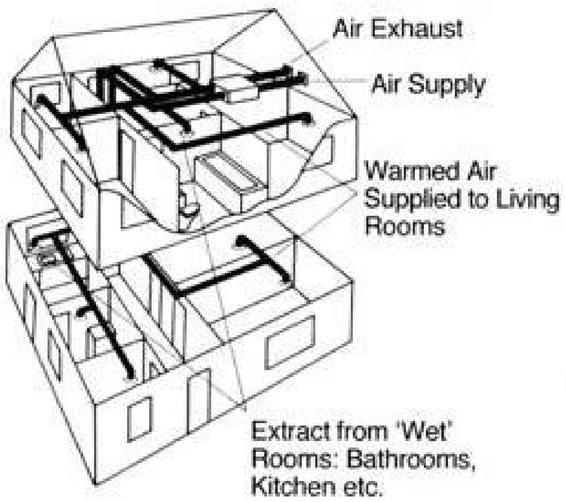
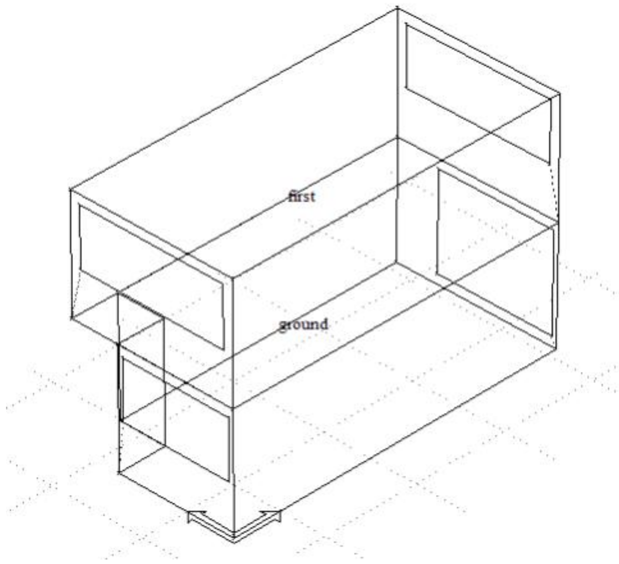


Figure 2. MVHR

Figure 3. NuAir Sunwarm System

Modelling methodology

The modelling program used to determine the energy consumption of the sampled properties was ESP-r, a comprehensive whole building energy modelling tool freely available from the University of Strathclyde (http://www.esru.strath.ac.uk/Programs/ESP-r.htm).



ESP-r utilises a nodal approach to the solution of the mass and heat flows within buildings with nodes being rooms or floors within a building. For this report floors have been modelled as single zones.

Structures are built in ESP-r in correspondence with the physical characteristics of the buildings modelled. Air-tightness is modelled by creating power law flow components within the external modelled facades that mimic the flow characteristics of the properties from the blower door tests carried out, and their predicted air-tightness after intervention.

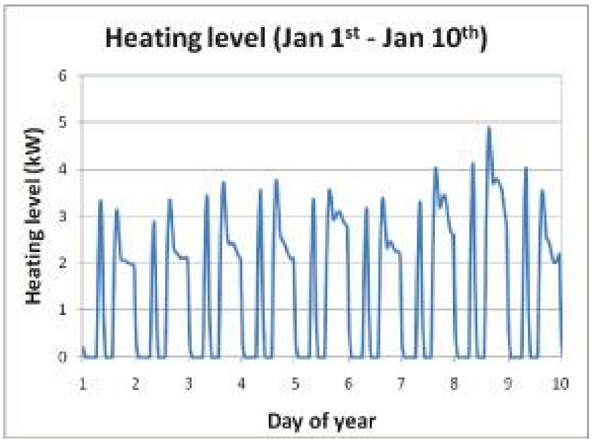
Models can be run over a whole year and external surfaces are subjected to winds and temperatures from an inbuilt climate file which contains measured weather data from the project locations.

In modelling a sample of the tested properties certain assumptions have been made. These include:

- A heating regime has been assumed where the building is heated to 20°C between 7 and 9 in the morning, and 2 and midnight in the afternoon every day of the week.
- If intermittent extract fans are installed then a constant running fan with 1/10 of the peak flow has been modelled implying that any intermittent fan is on for 2.4 hours per day.
- Vent apertures are modelled with a regulatory open area and the stairwell as an opening of 2m².
- Windows are modelled but not doors.
- No heat loads from occupancy or other internal loads are considered for consistency.
- Modelled base cases include upgrades to insulation and air-tightness, but not the ventilation system.
- Modelled ventilation intervention cases include the name of the ventilation system in brackets.
- Ventilation systems modellled are Passive Stack Ventilation (PSV), Mechanical Ventilation with Heat Recovery (MVHR), single room heat recovery units (Room HR), Consistent Mechnical Extract (CME), Supply Air Windows (SAW), intermittent extract fans (Intermittent), Positive Input Ventilation (PIV), Innoventus system (Innoventus) and the Dwell-Vent system (Dwell-Vent).

Models are run over a whole calendar year and results summed for the whole period. Ventilaiton heat load is calculated by summing the product of air ingress levels with the temperature difference and specific heat capacity of air. Fabric heat loss is calculated by subtracting the ventilation heat loss from the total space heating consumption.

Results from ESP-r include hourly internal temperatures, heat consumption and ventilation flow rates. Overall heat consumption results are shown below in the analysis pages of the different housing types.



Intelligent Energy Europe
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UK PROPERTIES

The UK surveyed properties fall into one of five main construction types:

Solid in-situ concrete, painted internally
Brick and block-work, plastered internally
Solid brick, wooden floor, plastered internally
Solid brick, concrete floor, plastered internally
Concrete panel and block work, plastered internally

Solid in-situ concrete, painted internally

Insulation

This type of construction has considerable thermal mass, which it is beneficial to maintain. Internal insulation reduces the influence of the thermal mass and cavity insulation is not applicable in this case. External insulation is an appropriate intervention, as these properties tend to be flats in blocks so the external surface area per flat is relatively small, and the cost of this intervention is correspondingly small. External insulation is considered to bring the external wall U-value down to 0.2W/m²K. Assuming the whole block is done at the same time, minimising labour costs, then a cost per flat of £2100 is estimated for this method. For ground floor and top level properties floor level and ceiling level insulation can also be considered. 30mm of floor insulation is modelled here giving a resultant U-value of 0.8W/m²K at a cost off £605. Windows are replaced with double glazed units at a cost of £2800.

Air-tightness

The general fabric air-tightness of these properties is quite good with windows and doors being the main point of leakage and these should therefore be replaced (£2800 as above) and draught-stripped (£50).
Sealing around service pipes was also considered (£50). A resultant air-tightness of 3ACH@50Pa is considered achievable.

Ventilation

The difficulty in making holes in the concrete floors, and lack of appropriate space makes MVHR, PSV, Hybrid and PIV ventilation strategies unfeasible, despite the fact that the resultant air-tightness is good enough to allow optimal operation of these technologies. Ventilation options appropriate to this housing type are upgraded intermittent extract fans(£150), room fans with heat recovery (£800), or constant extract fans with supply air windows (£3400 saving £2800 on the cost of replacement windows). All have been modelled here.

Conclusions

Although much can be done to the insulation and air-tightness of such properties there is limited scope to take advantage of improvements due to an advanced ventilation strategy. Room heat recovery fans were considered for the wet rooms but their 'always on' nature delivers a 7% higher ventilation heat load (96kWh/year) than normal intermittent extracts. The heat recovery from the supply air windows is also not high enough to make constant extraction an energy efficient option, with that strategy delivering the highest ventilation heat loads. As the whole house ventilation rate is adequate with simple intermittent fans, and extra duct work and central plant are not feasible to install, it would appear that this is the cheapest and most energy efficient option. Energy savings are significant (54%) however, largely because of the use of effective external insulation and replacement of poor windows, which brings the energy consumption down to 70kWh/m²/year, a good figure. The total cost of the interventions, assuming an upgrade to the intermittent extracts is £5605.

	Space Heating (kWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost (£)	CO_2 Emissions (kg/year)	Intervention Cost (£)	Cost Savings (£/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	7747 (154)	6180	1567	343	1503	N/A	N/A	N/A	N/A
After	3619 (70)	2199	1420	165	726	3980	178	777	22
After (Intermittent)	3619 (70)	2199	1420	163	716	4130	180	787	23
After (CME + SAW)	4545 (90)	2199	2346	229	1023	4130	114	480	38
After (Room HR)	3715 (74)	2199	1516	165	862	4580	179	641	26

Brick and block-work, plastered internally

Insulation

The availability of a cavity within the external wall makes cavity wall insulation a viable option. Use of an expanded polystyrene bead filling for the 100mm cavity brings the external wall U-value down to 0.5W/m²K. The cost estimated for this is £263. As a ground floor flat was modelled 30mm of floor insulation could be fitted bringing the U-value down to 0.9W/m2K at a cost of £618. The windows are already double glazed, and in relatively good order and so were not upgraded in the model.

Air-tightness

The air-tightness of this property type was again quite good due to the concrete floor construction and newer windows. By draught stripping, costed at (£80), and service pipe sealing, costed at (£50) a level of fabric air-tightness of 3ACH@50Pa was considered to be achievable.

Ventilation

The presence of concrete floors, and the absence of a loft space, again makes it difficult to install an upgraded ventilation system that requires extra ducting, even though the good levels of air-tightness would make more advanced ventilation options feasible. PSV, CME, MVHR, PIV and hybrid systems would all require extra ducts to be installed between flats. Option that could be installed are upgraded intermittent extracts (£150), room fans with heat recovery (£800) and constant extract with supply air windows on the supply side (£2450). All these options have been modelled here.

Conclusions

The interventions on this building type gave the best simple payback period of all at 10 years. This is largely due to the fact that cavity wall insulation is relatively cheap but has a large effect on the total energy consumption of the flat as it has external walls on three sides. Ventilation heat loss was not reduced by a large amount as the already good air-tightness of the property, and the inability to install heat recovery, made the scope for improvement quite small. Intermittent extract fans were again the most energy efficient option as the heat recovery fans caused a140kWh/year extra ventilation heat load, and the constant extract with supply air windows resulted in even higher ventilation heat load. Again variant occupancy over the course of the day makes constant forms of ventilation perform poorly in energy terms, and background ventilation with intermittent extracts appears adequate for indoor air quality. Although the payback time is good, this is due to the cost-effectiveness of the upgrade strategies and not so much due to the absolute energy savings made. Heating energy reductions of 37% can be achieved resulting in a heating requirement of 90kWh/m²/year, a level surpassing the current level required by UK regulations, but probably not to the next revision. Larger energy savings could be made but at high cost and with diminishing returns, resulting in much higher payback figures.

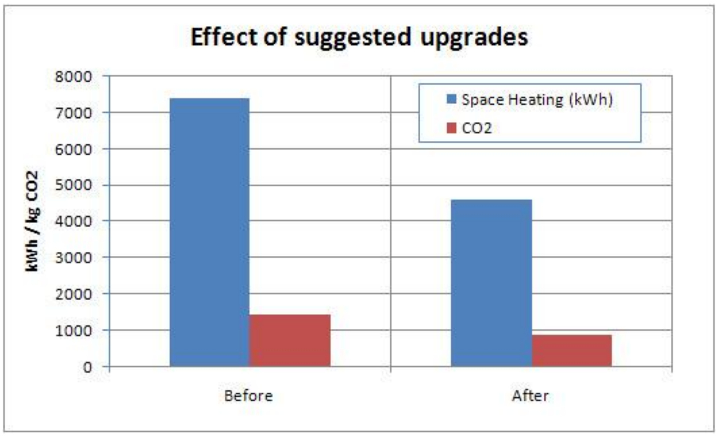

Figure 1. Annual energy and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost (£)	CO_2 Emissions (kg/year)	Intervention Cost (£)	Cost Savings (£/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	7388 (143)	6328	1059	327	1433	N/A	N/A	N/A	N/A
After	4676 (90)	3723	953	212	931	1380	116	502	12
After (Intermittent)	4676 (90)	3723	953	212	931	1530	116	502	13
After (CME + SAW)	5275 (102)	3723	1552	261	1165	2730	66	269	41
After (Room HR)	4757 (92)	3723	1034	238	1064	1980	89	369	22

Solid brick, wooden floors, plastered internally

Insulation

The property being listed, and the lack of a cavity, leaves internal insulation as the only option for wall insulation. As there are only two external sides to the flat the loss of floor space after installation should not be overly noticeable. 90mm of expanded polystyrene with a plasterboard finish has been modelled, reducing the wall U-value to 0.37W/m²K. This has been costed at £1344. As the property modelled is a mid-floor flat no ceiling or floor insulation has been considered. The listed nature of the building means the window's glazing cannot be upgraded.

Air-tightness

Replacement windows of similar design but with better sealing and vents have been modelled and costed at £2750. Draught stripping, service pipe sealing and under-floor sealing are also viable and costed at £50 and £1607. As these properties tend to have high leakage rates, fabric air-tightness was considered to be only brought down to 6ACH@50Pa by these measures.

Ventilation

The wooden floors do make possible the installation of extra ducting but the height of the block, and only average air-tightness after the upgrade, makes MVHR, PIV and central CME systems unsuitable. PSV, hybrid, intermittent extract fans and heat recovery fans could however be installed with self-regulating ventilators on the new windows. Hybrid systems would not be required however as the height of the building should provide adequate flow rates through normal passive ducting without fan back up. Room heat recovery fans again did not offer any energy benefits over standard intermittent extract and in fact caused a penalty of 110kWh/year and so have been omitted from the table below. Consequently, the zero-primary energy option PSV (with humidity control) and simple intermittent extract fans, are the two ventilation options modelled and costed at £850 and £150 respectively.

Conclusions

The expensive type of replacement window needed for this type of building, and the expense of sealing floorboards for air-tightness, makes the overall cost of the interventions quite high in this case, and so a poor payback figure results. Intermittent fans perform slightly better than the humidity-controlled PSV, but when considering fan secondary power requirements (19kWh/year), and maintenance, both are a viable option. The level of energy saved is quite good as this was the highest energy consuming property type in the sample, at almost 4000kWh, and over a tonne of CO_2 emissions are saved, but the percentage reduction is an average 39 - 42% bringing the property down to between 90 - 95kWh/m²/year. These properties represent a particular problem for upgrades as the air-tightness achievable is never likely to be good enough for advanced ventilation systems, and their often listed nature make upgrade of walls and windows problematic.

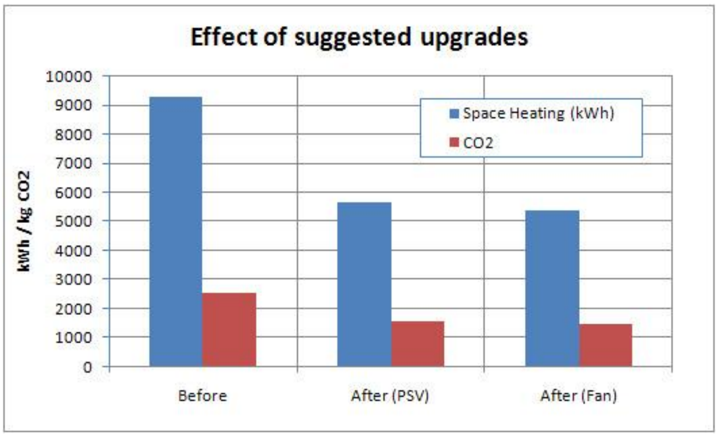

Figure 1. Annual space heating and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost (£)	CO_2 Emissions (kg/year)	Intervention Cost (£)	Cost Savings (£/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	9299 (143)	6333	2966	412	2577	N/A	N/A	N/A	N/A
After (Base)	5375 (90)	3900	1475	170	1513	5106	242	1064	21
After (Intermittent)	5375 (90)	3900	1475	168	1504	5256	244	1073	22
After (PSV)	5662 (95)	3900	1762	174	1555	5956	238	1022	25

Intelligent Energy Europe

Funded by the Intelligent Energy Europe Programme

Solid brick plastered internally with concrete floors

Insulation

The relatively low external facade surface area, non-listed status, and the lack of a cavity, make external insulation feasible in this case, bringing the external wall U-value down to 0.2W/m²K. By doing the whole block at the same time and minimising labour costs this has been priced at £1315. This method also has the advantage that the thermal mass of the external wall construction remains coupled to the internal space and helps the prevent over-heating in summer. The single glazed windows are replaced with double glazed at a cost of £1400. Whether this can be done in reality will depend on the age and conservation status of the building, but as the flat modelled here is not listed it has been considered feasible. Ceiling/floor insulation can be implemented on top/ground floors. A ground floor flat has been modelled here with 30mm of floor insulation, bringing the floor U-value down to 0.9Wm²K. This has been costed at £434.

Air-tightness

Concrete floors result in the solid brick properties achieving much better air-tightness and this particular flat delivered one of the best air-tightnesses of all the properties sampled. With simple draught stripping (costed at £100) service pipe sealing, (costed at £50) and new windows, an air-tightness of 3ACH@50Pa is considered to be very achievable.

Ventilation

The presence of concrete floors and lack of roof space makes the installation of additional ducting and central plant unfeasible, even though the very good air-tightness that can be achieved with such properties would make advanced ventilation techniques such as MVHR viable. In this case intermittent room heat recovery fans, and constant extract fans with supply air windows are installable along with self-regulating ventilators in the new windows. All these ventilation strategies have been modelled here.

Conclusions

The already good air-tightness of these types of flats resulted in the majority of heating savings being due to improved insulation as the ventilation heat loss was already quite low. However the extra external insulation did not decrease energy consumption as much as expected because of the intermittent heating of the maintained thermal mass. This highlights the beneficial role thermal mass can have in moderating summer temperatures, but its lack of importance in a winter scenario. With intermittent extract fans the overall ventilation rates for the flat averages 10l/s, just below the 11l/s required by regulation. The 'always on' options guarantee adequate overall flow rates but come with an energy penalty. In the case of room based extracts this amounts to 129kWh/year and with constant extract and supply air windows 767kWh. 129kWh/year would appear to be a fair trade off for the better indoor air quality and room vent heat recovery units should be considered in this case. Overall a space heating reduction of 44% is achieved bringing the total consumption down to 103kWh/m²/year. This is not a very good final performance figure and is largely due heating of the exposed thermal mass.

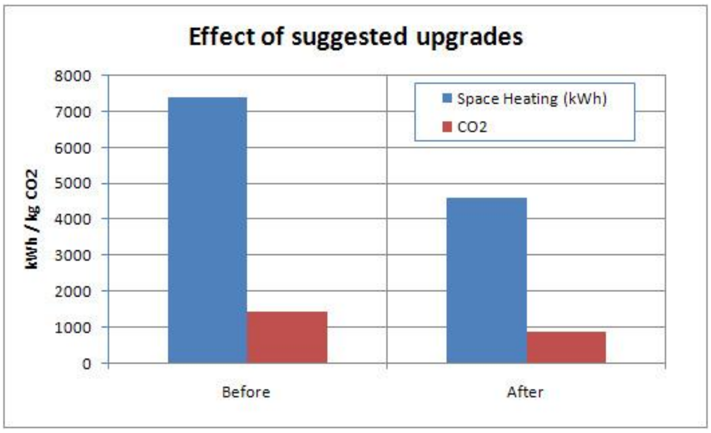

Figure 1. Annual space heating and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost (£)	CO_2 Emissions (kg/year)	Intervention Cost (£)	Cost Savings (£/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	6700 (185)	5831	869	301	1880	N/A	N/A	N/A	N/A
After (Base)	3732 (103)	2897	835	170	1058	3300	131	822	25
After (Intermittent)	3732 (103)	2897	835	164	1025	3450	138	855	25
After (CME + SAW)	4499 (124)	2897	1601	222	1374	3650	79	507	46
After (Room HR)	3861 (107)	2897	964	194	1188	4050	102	693	38

Concrete panel and block work, plastered internally

Insulation
As the external walls have partially filled cavities injecting further insulation to make the cavity fully filled is a viable upgrade strategy. Using expanded polystyrene beads to fill the remaining 50mm cavity brings the external wall U-value down to 0.3W/m²K and costs £95 if the whole block is done together to minimise installation costs. The very low external surface area of the flat accounts for the low price. The replacement of the single glazed windows with supply air windows is also a feasible upgrade strategy and is highly recommended in this case due to the good potential air-tightness of the property and the constant mechanical ventilation system already installed. The cost of this upgrade is £1800. The building sampled was a mid-floor property so floor or ceiling insulation have not been considered here.

Air-tightness
The fabric of these types of flats tends to be quite airtight because of their concrete construction, although the poor quality/fitting of the windows in this particular case has made the windows a significant contributor to the air-leakage, and the replacement of them would be advisable from an air-tightness as well as an insulation point of view. In this case therefore sealing around service pipes (£50) and the replacement of the single glazed windows are considered sufficient to bring the average air-tightness down to 3ACH@50Pa.

Ventilation
The concrete floor plates and the flats being multi-storey once again makes extra duct installation unfeasible, ruling out PSV, MVHR, PIV and other whole building mechanical or passive systems. In this case therefore keeping the existing constant mechanical extraction system is advisable, although there may well be scope to replace the existing centralised fan with a more modern and efficient model. Inlet ventilation is optimised by the use of supply air windows so some ventilation heat recovery can be achieved.

Conclusions
The space heating requirement of this type of flat is the lowest of the sampled set, largely due to the low external surface area and relatively low initial U-value. It also however makes the energy savings due to the chosen interventions the lowest of the sample, resulting in a high payback time of 30 years. The percentage reduction in space heating is quite good however with a 51% drop achieved. The reduction in ventilation heat loss is much smaller however especially as the heat reclaim from the supply air windows is counted as an improved window U-value, and thus lower space heating, rather than as a reduction in ventilation heat load. Energy consumption figures are the lowest of the sampled set however with a resultant space heating requirement of only 41kWh/m²/year - a very good value which is lower than current best practice standards. In addition the cost of the interventions is quite low, although the limited absolute energy savings do not make the interventions justifiable on purely economic terms.

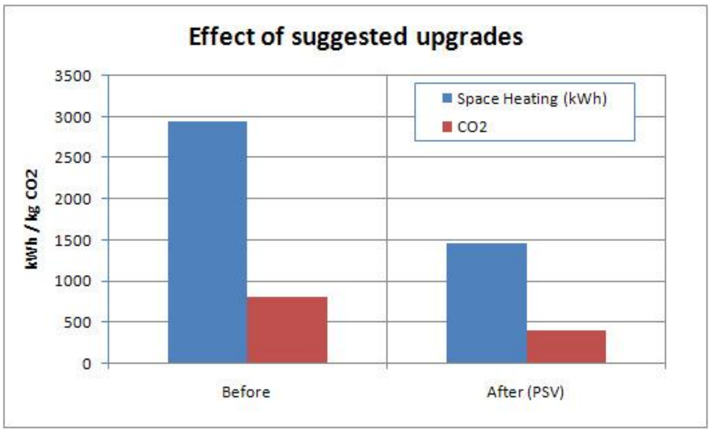

Figure 1. Annual space heating and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost (£)	CO_2 Emissions (kg/year)	Intervention Cost (£)	Cost Savings (£/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	2944 (82)	1613	1332	130	816	N/A	N/A	N/A	N/A
After (SAW)	1460 (41)	286	1175	65	405	1945	66	411	30

UK Property Matrix

On the next page is a matrix of suggested solutions for the housing types sampled in Camden, London.

Three main columns of the matrix table relate to the three intervention types: insulation, air-tightness and ventilation. The rows relate to the building type sub-sets from the sampling phase of the project.

For each housing type and intervention the possible specific upgrade options are listed. They are given an index number ranging from 1-25 that shows the general applicability of the specific intervention to the building type. The index number is generated by multiplying the feasibility score (from 1 to 5) and the suitability score (also from 1 to 5). The feasibility score rates the intervention in terms of how practical it would be to implement e.g. installing cavity wall insulation into a cavity wall would score highly but installing PSV into a concrete floored property would have a low score. The suitability score rates the intervention in terms of the its ability to achieve the aims of lower energy consumption in the property so internal insulation on a thermally massive wall would score lowly (although it may still be done if no other insulation options exists).

Finally a reference number is given so that details of the specific upgrade can be viewed in the appendices at the end of this report.

For example the building subtype 'Solid brick, plastered internally, concrete floors' (shown below) the first column 'Insulation' has external insulation listed first. The first number in this column ranks the intervention with first at the top, the second number (in this case 25) gives the point score for this intervention. This point score is derived by multiplying the next two numbers (5 & 5 in this case), which rates the intervention for feasibility and suitability respectively. Finally the last number identifies the chosen intervention in the report appendix where details of the technology can be checked.

Solid brick plastered internally, concrete floors	1	25	External insulation/thermal bridges	5	5	3	1	25	Seal cracks around windows	5	5	10	1	25	Installation of extract fans	5	5	18
	2	25	Insulation at top level ceiling	5	5	1	2	25	Check openings for pipes/ wires	5	5	12	2	10	Installation of PSV instead of fans	2	5	20
	3	20	Window replacement	4	5	7	3	25	Check/repair window hinges/locks	5	5	8	3	10	Upgrading of windows: SAWs/PSV	2	5	22
	4	4	Lowest floor insulation	2	2	5	4	25	Repair/install weatherstripping	5	5	9	4	9	Installation of self-controlled vents	3	3	21
	5	3	Thermal bridging separately	2	1	6	5	9	Refurb outlets to passivhaus level	3	3	4	5	4	Upgrading of windows:SAWs/CME	1	3	22
	6	3	Internal insulation	2	1	4	6	4	Windows replacement	1	3	17	6	4	Upgrading to controlled ventilation	1	3	23

The next column follows the same system for air-tightness, and the third ventilation.

UK Property Matrix

Proposals for improvements of Camden UK Social Housing, AVASH project																		
Construction type (ext.wall)	Insulation – U value						airtightness						Ventilation strategy (airtightness standard min4.0 AC/H)					
		index	description	feasibility	suitability	reference		index	description	feasibility	suitability	reference		index	description	feasibility	suitability	reference
Solid in-situ concrete painted internally	1	15	Insulation at top level ceiling	3	5	1	1	25	Check/repair window hinges/locks	5	5	8	1	20	Installation of extract fans	4	5	18
	2	15	External insulation/thermal bridges	3	5	3	2	25	Repair/install weatherstripping	5	5	9	2	20	Installation of self-controlled vents	4	5	21
	3	15	Lowest floor insulation	3	5	5	3	25	Seal cracks around windows	5	5	10	3	6	Installation of heat recovery vents	3	2	25
	4	8	Internal insulation	4	2	4	4	15	Check openings for pipes/ wires	3	5	12	4	2	Upgrading to controlled ventilation	1	2	23
	5	6	Window replacement	2	3	7	5	9	Refurb outlets to passivhaus level	3	3	4	5	1	Installation of MVHR-various types	1	1	24
							6	6	Windows replacement	2	3	17	6					
Brick + cavity + blockwork plastered internally	1	25	Insulation at top level ceiling	5	5	1	1	25	Check/repair window hinges/locks	5	5	8	1	20	Installation of extract fans	4	5	18
	2	16	Injected insulation	4	4	2	2	25	Repair/install weatherstripping	5	5	9	2	20	Installation of self-controlled vents	4	5	21
	3	6	Window replacement	2	3	7	3	25	Seal cracks around windows	5	5	10	3	20	Upgrading of windows:SAWs/CME	4	5	22
	4	5	External insulation/thermal bridges	1	5	3	4	15	Check openings for pipes/ wires	3	5	12	4	4	Upgrading to controlled ventilation	2	2	23
	5	4	Lowest floor insulation	2	2	5	5	9	Refurb outlets to passivhaus level	3	3	4	5	3	Upgrading of windows: SAWs/PSV	1	3	22
	6	1	Internal insulation	1	1	4	6	6	Windows replacement	2	3	17						
Solid brick plastered internally, wooden floors	1	25	External insulation/thermal bridges	5	5	3	1	25	Seal cracks around windows	5	5	10	1	25	Installation of extract fans	5	5	18
	2	25	Insulation at top level ceiling	5	5	1	2	25	Check openings for pipes/ wires	5	5	12	2	10	Installation of PSV instead of fans	2	5	20
	3	20	Window replacement	4	5	7	3	25	Check/repair window hinges/locks	5	5	8	3	10	Upgrading of windows: SAWs/PSV	2	5	22
	4	4	Lowest floor insulation	2	2	5	4	25	Repair/install weatherstripping	5	5	9	4	9	Installation of self-controlled vents	3	3	21
	5	3	Thermal bridging separately	2	1	6	5	9	Refurb outlets to passivhaus level	3	3	4	5	4	Upgrading of windows:SAWs/CME	1	3	22
	6	3	Internal insulation	2	1	4	6	4	Windows replacement	1	3	17	6	4	Upgrading to controlled ventilation	1	3	23
Solid brick plastered internally, concrete floors	1	25	External insulation/thermal bridges	5	5	3	1	25	Seal cracks around windows	5	5	10	1	25	Installation of extract fans	5	5	18
	2	25	Insulation at top level ceiling	5	5	1	2	25	Check openings for pipes/ wires	5	5	12	2	10	Installation of PSV instead of fans	2	5	20
	3	20	Window replacement	4	5	7	3	25	Check/repair window hinges/locks	5	5	8	3	10	Upgrading of windows: SAWs/PSV	2	5	22
	4	4	Lowest floor insulation	2	2	5	4	25	Repair/install weatherstripping	5	5	9	4	9	Installation of self-controlled vents	3	3	21
	5	3	Thermal bridging separately	2	1	6	5	9	Refurb outlets to passivhaus level	3	3	4	5	4	Upgrading of windows:SAWs/CME	1	3	22
	6	3	Internal insulation	2	1	4	6	4	Windows replacement	1	3	17	6	4	Upgrading to controlled ventilation	1	3	23
Concrete panel + cavity + blockwork plastered internally	1	20	Injected insulation	4	5	2	1	20	Windows replacement	4	5	7						
	2	20	Window replacement	4	5	7	2	20	Seal cracks around windows	4	5	10	1	20	Upgrading of windows:SAWs/CME	4	5	22
	3	4	Lowest floor insulation	2	2	5	3	20	Check/repair window hinges/locks	5	4	8	2	6	Upgrading to controlled ventilation	2	3	23
	4	3	Thermal bridging separately	2	1	6	4	20	Repair/install weatherstripping	5	4	9	3	9	Installation of self-controlled vents	2	2	21
	5	3	Internal insulation	2	1	4	5	9	Refurb outlets to passivhaus level	3	3	4						

Irish Properties

The Irish surveyed properties fall into one of five main construction types:

- Traditional Irish cavity construction, drylined internally
- Refurbished solid wall to cavity construction, drylined internally
- Timberframe construction, drylined internally
- Steel frame cavity construction, drylined internally
- Solid blockwork construction, wet plastered internally

Traditional Irish cavity construction, drylined internally

Insulation

As there is a cavity within the outer wall it is appropriate to fully fill it with blown insulation (polystyrene beads or fibre insulation) which would improve the U-value from 0.51 to 0.3 W/m²K and cost €1100. An additional 360mm layer of loft insulation was considered, delivering a U-value of 0.13 W/m²K, at a cost of €1200. Windows were replaced with double glazed low-E units for €5300 to give an improved U-value of 1.5 W/m²K.

Air-tightness

The measured air-tightness of this house type was relatively poor and the following measures were modelled to reduce the leakage: window replacement (mentioned above), loft hatch sealing (€80), sealing openings for services (€50),
sealing space behind plasterboard (€300), blocking of old unnecessary vents (€200), chimneys blocked by inflatable inserts (€70).These measures are expected to reduce the air leakage to 6.0 AC/h @50Pa.

Ventilation

As the air-tightness of the property is not very good MVHR, dwell-vent or other systems that require good air-tightness are not realistic options. CME, PIV, PSV with humidity control, intermittent extract and room fans with heat recovery have been modelled and the results shown in the table below. The air supply will be provided by self regulating ventilators to the windows which are included in the cost of windows replacement.

Conclusions

Not only does the Irish housing sample differ in its construction from the UK's but the climate is also very different from London's. Wind speeds are higher and the buildings tend to be more exposed. This makes PSV, even with humidity control, an expensive option in energy terms as the PSV stacks tend to draw much more flow in windy conditions. These high wind speeds cause greater leakage, especially when the house cannot be made very air-tight as in this case. This means that many advanced ventilation techniques have limited benefits as they do not dominate the ventilation regime as they should. In this scenario the blocking of chimneys can cause a significant reduction in energy consumption for little cost. The energy savings due to improved airtightness and insulation space heating result in a reduction of 60% to 66kWh/m²/year, a very good figure. Of the five ventilation strategies, upgraded intermittent extracts actually provide the lowest ventilation heat loss, followed by room fans with heat recovery, PIV, CME and PSV with humidity control. As the first is also the cheapest, it is the best option in terms of both cost and energy performance, whilst maintaining indoor air quality. Payback times are also very good, again largely due to the cost-effectiveness of the chimney dampers, with intermittent extract and the room heat recovery units achieving the next best result. If electrical heating is used, which is relatively common in Ireland, payback times become short enough for these measures to be considered purely from an investment point of view.

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost [Gas/Elec] (€)	CO_2 Emissions [Gas/Elec] (kg/year)	Intervention Cost (€)	Cost Savings [Gas/Elec] (€/year)	CO_2 Savings [Gas/Elec] (kg/year)	Simple Payback [Gas/Elec] (years)
Before	13403 (163)	6339	7064	1539/3071	3729/10296	N/A	N/A	N/A	N/A
After (Base)	5439 (66)	2432	3007	629/1250	1079/2944	8300	910/1820	2650/7352	9/5
After (Intermittent)	5439 (66)	2432	3007	626/1247	1069/2935	8500	913/1823	2659/7361	9/5
After (CME)	6877 (84)	2432	4445	828/1576	1475/3834	9700	711/1494	2253/6462	14/6
After (Room HR)	5630 (69)	2432	3198	685/1294	1233/3164	9100	853/1777	2495/7132	11/5
After (PIV)	6762 (82)	2432	4330	815/1553	1453/3772	9000	724/1518	2276/6524	12/6
After (PSV)	10173 (124)	2432	7741	1163/2325	1974/5604	9300	376/745	1755/4692	25/12

Refurbished solid wall to cavity construction, drylined internally

Insulation

The available cavity within the external wall makes the situation similar to upgrading traditional cavity construction -suitable to fully fill with blown insulation (polystyrene beads or fibre insulation) which would improve the U-value from 0.49 to 0.29 W/m²K at cost of €1,100 ("thermal looping" effect is also eradicated). Additional floor insulation was not considered, due to its high cost and minimal effect - there is already a certain amount of insulation within the floor. The ceiling was modelled with 360mm layer of laid/blown insulation providing an excellent U-value of 0.13 W/m²K (€1,200). Windows were replaced by double glazed low-E units for €5,300 to give an improved U-value of 1.5 W/m²K. This measure improved airtightness as well, as mentioned below.

Air-tightness

The air-tightness measured for this house type was the worst recorded, probably as a result of problems joining new and old main structure. Windows replacement (mentioned above), sealed loft hatch (€50), sealed openings for services (€SO), sealed space behind plasterboard (€300), blocked old unnecessary vents (€200) and sealed joints between structures (€200) are assumed to increase air-tightness to 6.0AC/h @50Pa, from original 13.1AC/h.

Ventilation strategy

As there were no chimneys, the focus was on designed supply - extract ventilation. Again a relatively poor achievable air-tightness precludes the installation of MVHR, Dwell-vent, Innoventus and other systems that require good airtightness. CME, PSV, PIV, intermittent extract and room fans with heat recovery, were considered with separate self-regulating vents for the PSV, CME and extract options. These options were

Conclusion

The relatively long payback periods are largely a result of the necessity to seal the old and new structure to achieve a reasonable air-tightness, and associated costs which are important to keep ventilation heat loss minimised in windy conditions. In addition, there was not such a simple and highly effective measure as blocking the chimneys as in the previous case. Although fabric heat loss was reduced by more than half, ventilation heat loss could not be reduced as significantly because leakage remains a problem and no advanced ventilation system achieved good results. Intermittent extract was the cheapest and most energy efficient solution of those tested. Again, this is largely due to the fact that the windy Irish climate results in significant leakage even with a relatively good air-tightness of 6ACH@50Pa, so the scope for reductions in ventilation heat loss with the adoption of advanced ventilation methods is limited. The heat recovering room vents were the next best in performance. Again PSV resulted in the worst energy consumption figures due to the very large ventilation rates they can cause, even with humidity control. Space heating was reduced however by 38% resulting in 63kWh/m²/year, a very good figure, helped by the larger floor area of the house.

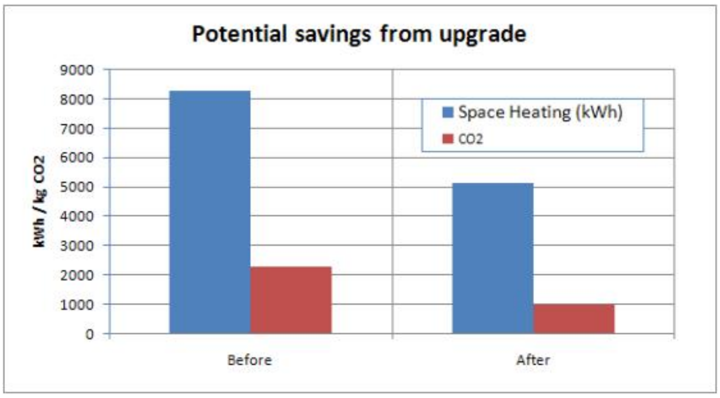

Figure 1. Annual space heating and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost [Gas/Elec] (€)	CO_2 Emissions [Gas/Elec] (kg/year)	Intervention Cost (€)	Cost Savings [Gas/Elec] (€/year)	CO_2 Savings [Gas/Elec] (kg/year)	Simple Payback [Gas/Elec] (years)
Before	8309 (101)	4505	3805	957/1906	2317/6389	N/A	N/A	N/A	N/A
After (Base)	5151 (63)	2283	2867	596/1184	1023/2789	8430	361/722	1294/3599	23/12
After (Intermittent)	5151 (63)	2283	2867	593/1181	1013/2780	8630	364/725	1304/3609	24/12
After (CME)	6612 (81)	2283	4329	798/1515	1424/3692	9830	159/391	893/2697	62/25
After (Room HR)	5343 (65)	2283	3060	653/1228	1178/3010	9230	304/678	1139/378	30/14
After (PIV)	6495 (79)	2283	4212	784/1492	1401/3629	9130	172/415	916/2760	53/22
After (PSV)	9966 (122)	2283	7682	1139/2278	1933/5493	9430	N/A	384/896	N/A

Timberframe construction, drylined internally

Insulation

This external wall construction already had a sufficient level of insulation, and therefore no upgrade was required. The ground floor presented a similar situation. Ceilings adjoining unheated spaces were however provided with 360mm laid/blown insulation, as the existing installation had often been omitted or improperly installed. This would give a U-value of 0.13 W/m²K costing €1200. Existing windows were modelled
to be replaced by double glazed units with a U-value of 1.5 W/m²K costing €3200. Generally, these dwellings were already insulated to an acceptable level, so the payback period for the upgrade will be longer than for other dwellings.

Air-tightness

The measured performance for this house type was better than Irish average, mainly because it doesn't have a cavity enclosed by masonry construction, and thanks to water vapour barrier (and wind barrier) installed within its walls. The interventions considered were windows replacement (as above), sealed loft hatch (costing €80) and sealed openings for services (costing €50) bringing down the target air-tightness to 5.0 AC/h @50Pa, from the original 8.3 AC/h.

Ventilation

The predicted air-tightness improvements are borderline for the use of advanced ventilation systems that normally require 4ACH@50Pa or less to be effective. In this case we have looked at non-balanced systems including upgraded energy efficient intermittent extracts (€250), room heat recovery systems (€1000), centralised consistent mechanical extract (€2100), positive input ventilation (€600) and passive stack ventilation (€1400).

Conclusions

The already airtight and well insulated building envelope reduced the efficacy of the selected measures, generating the longest payback period from all the surveyed types. In two cases the ventilation systems proposed generated extra energy demand rather than savings (CME and PSV) and would never payback. The former performed poorly due to the lack of any heat recovery and the latter due to high wind speeds causing excess ventilation extraction. Once again simple intermittent extract fans provided the cheapest and most energy efficient solution, whilst providing the required ventilation rates, and again highlight the ability of air leakage in these cases to provide adequate ventilation to the properties without some form of consistent extraction. Room based heat recovery vents provided the next best performance. Energy savings amounted to only a 32% reduction in space heating requirements, with fabric and ventilation heat loss being reduced by about the same proportion, but at a reasonable intervention cost of €3630 and
upwards generating reasonable electric heating payback times. The relatively low reduction in space heating achieved is largely due to the good state of the original property in terms of insulation and airtightness. The already good 81kWh/m²/year was reduced to a best practice 6lkWh/m²/year with intermittent extracts.

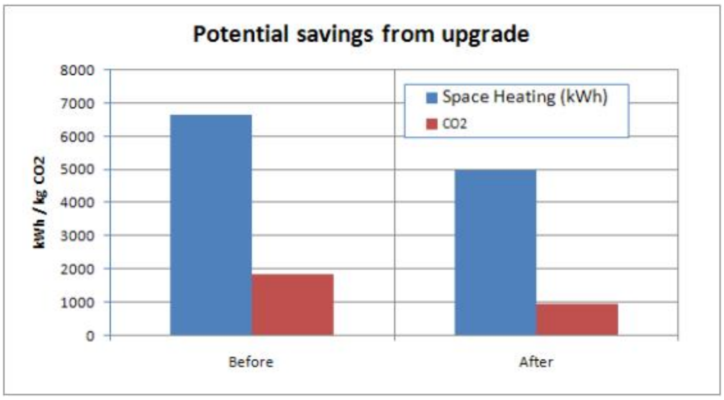

Figure 1. Annual space heating and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost [Gas/Elec] (€)	CO_2 Emissions [Gas/Elec] (kg/year)	Intervention Cost (€)	Cost Savings [Gas/Elec] (€/year)	CO_2 Savings [Gas/Elec] (kg/year)	Simple Payback [Gas/Elec] (years)
Before	6672 (81)	3602	3070	770/1532	1863/5132	N/A	N/A	N/A	N/A
After (Base)	4994 (61)	2266	2729	578/1149	992/2705	3630	192/383	871/2427	19/9
After (Intermittent)	4994 (61)	2266	2729	575/1146	983/2696	3830	195/386	880/2436	20/10
After (CME)	6455 (79)	2266	4189	780/1480	1393/3607	5030	N/A/52	470/1525	N/A/96
After (Room HR)	5187 (63)	2266	2921	635/1193	1147/2926	4430	135/339	716/2206	33/13
After (PIV)	6338 (77)	2266	4072	766/1456	1371/3545	4330	Mar-76	492/1588	N/A/57
After (PSV)	9742 (119)	2266	7477	1113/2227	1890/5373	4630	N/A	N/A	N/A

Steel frame cavity construction, drylined internally

Insulation

The existing external wall construction was by far the best (U-value 0.23 W/m2K) out of all the surveyed dwellings, and therefore didn't require upgrading. The same applied to the ground floor which was not upgraded either. The existing PVC windows were retained, since they achieved a good U-value of 1.8 W/m²K. The only upgrade required was to the roof. 360mm laid/blown loft insulation was modelled, as it was not clear how well the existing insulation had been installed. This resulted in a U-value of 0.13 W/m²K costing €1200.

Air-tightness

As well as the most recently built, this dwelling type proved to be the most airtight, therefore appropriate minor measures are proposed. The adjustments and sealing works that were modelled include: checking and re-set of window hinges costing €150, loft hatch refurbishment costing €80, sealed openings for services costing €50, sealing the space behind plasterboard costing €300. All the above measures are expected to reduce the air leakage to 4.0 AC/h @50Pa, to make the dwelling viable for the application of more sophisticated ventilation strategies.

Ventilation

The achievable air-tightness of 4ACH@50Pa makes advanced and balanced ventilation systems feasible to install. The ventilation strategies modelled and investigated included MVHR (€6000), Innoventus (€2250)) PIV (€800) and Dwell-Vent (€2800) all of which should begin to operate optimally at 4ACH@50Pa or below.

Conclusion

The good existing standard of insulation and airtightness meant that further large reductions in energy consumption were not possible, although a further 30% reduction in space heating loads was achieved, mostly by reductions in the ventilation heat load. Payback times are consequently quite long due to the cost of the advanced ventilation systems. Both the PIV and Innoventus system caused the consumption of more energy than the original case, both because of their low or non-existent heat recovery performance resulting in infinite payback times. With the Innoventus system it is difficult to assess the level of heating provided to the incoming air but it is assumed that the air is heated to room temperature, lowering the ventilation heat load but adding to the space heating load. MVHR performed the best in energy terms, reducing the ventilation heat load by 1000kWh/year, whereas the Dwell-Vent system had the best payback times, albeit of 45 years for a gas heated property. This payback figure would have been lower if the original windows were poor and needed to upgraded as well as the costs would have remained the same but energy savings would have been greater.

Overall energy consumption was reduced to 48kWh/m²/year with MVHR, which exceeds current best practice and is a very good figure. The high intervention cost of €7780 however makes this intervention not justifiable on purely economic grounds.

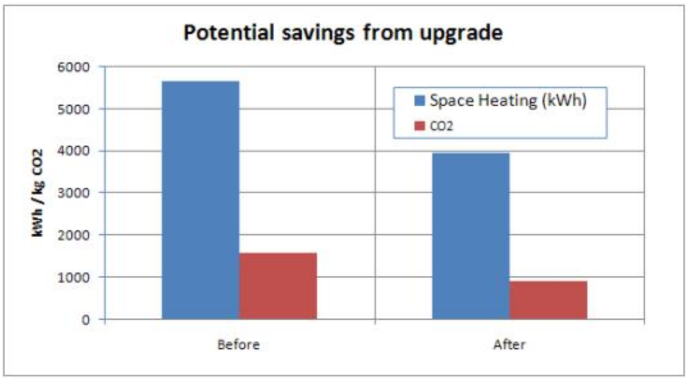

Figure 1. Annual space heating and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost [Gas/Elec] (€)	CO_2 Emissions [Gas/Elec] (kg/year)	Intervention Cost (€)	Cost Savings [Gas/Elec] (€/year)	CO_2 Savings [Gas/Elec] (kg/year)	Simple Payback [Gas/Elec] (years)
Before	5663 (69)	2796	2867	654/1301	1584/4359	N/A	N/A	N/A	N/A
After (Base)	4570 (56)	2104	2466	522/1045	910/2478	1780	132/257	673/1881	13/7
After (MVHR)	3951 (48)	2104	1846	508/909	955/2310	7780	147/393	629/2049	53/20
After (Dwell-Vent)	4827 (59)	2104	2722	552/1103	936/2592	4580	103/198	647/1767	45/23
After (Innoventus)	2077 (25)	2104	1555	888/1345	2277/3532	4030	N/A	N/A/826	N/A
After (PIV)	5127 (63)	2104	4240	767/1492	1372/3548	2580	N/A	212/811	N/A

Solid blockwork construction, wet plastered internally

Insulation

This house type, built in the 1950's, is the oldest and as such has the worst standard of insulation. The solid blockwork wall construction is appropriate for upgrading with external insulation, whereby thermal bridging is effectively eliminated, the advantage of thermal mass remains and the living space is not affected. An additional 100mm of external insulation was modelled, to give U-value of 0.30 W/m²K (compared with the original 2.28W/m²K) at a cost of €10,900. This was the most expensive measure, because layers of reinforcing mesh and proprietary external render must be used. An additional 30mm of insulation was applied to the floor giving a U-value of 0.32 W/m²K (€2,000), poor ceiling insulation was upgraded to 360mm of laid/blown insulation to give a U-value of 0.13 W/m²K (€1400). The original porous single glazed windows were replaced by double glazed low-E units reducing the U-value from 5.4 to 1.5 W/m²K - the upgraded windows also add to the safety and security of occupants.

Air-tghtness

Considering the dwelling's age and extremely leaky original windows, the recorded air-tightness was very good and well below the sampled average, mainly because of the wet plastered solid wall structure. Applying the upgrade measures - windows replacement (mentioned above), sealed loft hatch (€80), sealed openings for services (€50), sealed cracks between ceiling and walls (€50), and existing chimneys blocked by removable inflatable inserts (€70) an air-tightness of 4.0 AC/h @50Pa or better is expected, and therefore viable for any upgrade ventilation strategy.

Ventilation

Originally there were no extract fans installed, even in the wet rooms, so use of a balanced ventilation system would require less remedial work than usual, and these types of ventilation system have been considered here because of the good air-tightness of the property The performance of MVHR (€6000), Dwell-Vent (€1200), Innoventus (€1000) and PIV (€900) was investigated, and the results shown in the table below.

Conclusion

The proposed measures significant yearly cost saving as high as €3,000, and excellent payback periods considering high upgrade costs of almost €22,000. The payback period would have been even lower, if there was a cheaper option to external wall insulation upgrade, but relatively expensive external insulation is the only option in this case. Space heating loads have been brought down from over 200 to below 50kWh/m²/year.

MVHR performs the best of the advanced ventilation systems but only equates with the existing ventilation strategy of trickle ventilators. The Dwell-Vent system does not perform so well in energy terms but has a good payback period as the windows in the dwelling are being replaced anyway. Although the Innoventus system preheats the air before entering the space, and thus heavily reducing the ventilation heat load, this heating energy does come from the properties general heating system and so ultimately leads to high space heating loads.

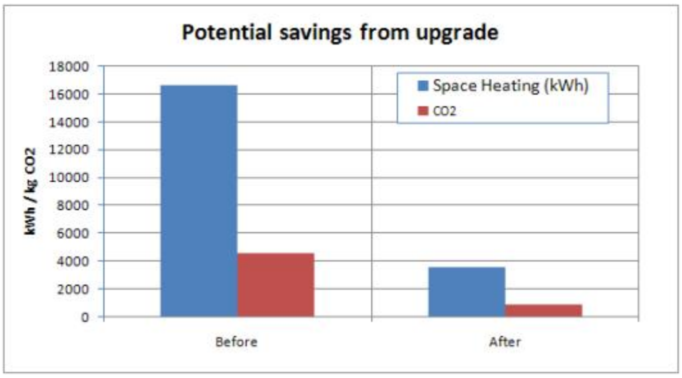

Figure 1. Annual space heating and CO_2 savings

	Space Heating (KWh/(kWh/m²/year))	Fabric Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Energy Cost [Gas/Elec] (€)	CO_2 Emissions [Gas/Elec] (kg/year)	Intervention Cost (€)	Cost Savings [Gas/Elec] (€/year)	CO_2 Savings [Gas/Elec] (kg/year)	Simple Payback [Gas/Elec] (years)
Before	16656 (203)	11158	5497	1911/3814	4630/12791	N/A	N/A	N/A	N/A
After (Base)	4101 (50)	1838	2263	469/937	819/2226	17980	1442/2877	3811/10566	12/6
After (MVHR)	3617 (44)	1838	1779	469/832	890/2131	26480	1441/2982	3740/10661	18/9
After (Dwell-Vent)	4439 (54)	1838	2601	507/1015	861/2384	19180	1403/2799	3769/10408	14/7
After (Innoventus)	6669 (81)	1838	1487	850/1269	2212/3353	19080	1061/2545	2418/9439	18/7
After (PIV)	5026 (61)	1838	4177	729/1417	1308/3371	18880	1181/2397	3322/9421	16/8

Irish Solution Matrix

Proposals for improvements of Irish Social Housing, AVASH project

insulation - U value

Construction type (ext.wall)		index (25-1)	description	feasibility	suitability	reference
Traditional cavity construction, drylined internally	1	25	insulation on ceiling level	5	5	1.
	2	16	injected insulation	4	4	2.
	3	6	windows replacement	2	3	7.
	4	5	external insulation (and thermal bridging)	1	5	3.
	5	4	floor insulation	2	2	5.
	6	3	thermal bridging separately	1	3	6.
	7	1	internal insulation	1	1	4.
Timberframe, drylined internally	1	25	insulation on ceiling level	5	5	1.
	2	4	external insulation (and thermal bridging)	2	2	3.
	3	4	floor insulation	2	2	5.
	4	1	internal insulation	1	1	4.
	5	1	windows replacement	1	1	7.
Refurbished solid wall to cavity construction, drylined internally	1	12	injected insulation	3	4	2.
	2	5	external insulation (and thermal bridging)	1	5	3.
	3	3	thermal bridging separately	1	3	6.
	4	1	internal insulation	1	1	4.
	5	1	windows replacement	1	1	7.
Steel frame and cavity wall, drylined internally	1	1	thermal bridging	1	1	6.
	2	0	windows replacement	1	0	17.
Solid blockwork, rendered externally, wet plastered internally	1	25	external insulation (and thermal bridging)	5	5	3.
	2	25	insulation on ceiling level	5	5	1.
	3	20	windows replacement	4	5	7.
	4	6	floor insulation	2	3	5.
	5	2	thermal bridging separately	2	1	6.
	6	2	internal insulation	2	1	4.

airtightness

Construction type (ext.wall)		index (25-1)	description	feasibility	suitability	reference
Traditional cavity construction, drylined internally	1	25	check and set (repair) window hinges and lock mechanism	5	5	8.
	2	25	check and repair (install) proper weatherstripping)	5	5	9.
	3	25	seal cracks around windows (inside, outside)	5	5	10.
	4	25	refurbishment of loft hatch (weatherstripping,lock mechanism)	5	5	11.
	5	16	dismantle old vents-check, block them airtightly	4	4	15.
	6	15	check openings for service pipes and wires -seal them	3	5	12.
	7	10	seal space behind plasterboard (at skirting level)	2	5	13.
	8	9	refurbishment of outlets (to passive house standard)	3	3	14.
	9	6	windows replacement	2	3	17.
Timberframe, drylined internally	1	25	check and set (repair) window hinges and lock mechanism	5	5	8.
	2	25	check and repair (install) proper weatherstripping)	5	5	9.
	3	25	seal cracks around windows (inside, outside)	5	5	10.
	4	25	refurbishment of loft hatch (weatherstripping,lock mechanism)	5	5	11.
	5	15	check openings for service pipes and wires -seal them	3	5	12.
	6	10	seal space behind plasterboard (at skirting level)	2	5	13.
	7	9	refurbishment of outlets (to passive house standard)	3	3	14.
	8	1	windows replacement	1	1	17.
	9	0	dismantle old vents-check, block them airtightly	4	0	15.
Refurbished solid wall to cavity construction, drylined internally	1	25	check and set (repair) window hinges and lock mechanism	5	5	8.
	2	25	check and repair (install) proper weatherstripping)	5	5	9.
	3	25	seal cracks around windows (inside, outside)	5	5	10.
	4	25	refurbishment of loft hatch (weatherstripping,lock mechanism)	5	5	11.
	5	15	check openings for service pipes and wires -seal them	3	5	12.
	6	10	seal space behind plasterboard (at skirting level)	2	5	13.
	7	9	refurbishment of outlets (to passive house standard)	3	3	14.
	8	8	dismantle old vents-check, block them airtightly	4	2	15.
	9	5	check and seal joints between new and old structure(if possible)	1	5	16.
	10	1	windows replacement	1	1	17.
Steel frame and cavity wall, drylined internally	1	25	check and set (repair) window hinges and lock mechanism	5	5	8.
	2	25	seal cracks around windows (inside, outside)	5	5	10.
	3	15	check openings for service pipes and wires -seal them	3	5	12.
	4	10	seal space behind plasterboard (at skirting level)	2	5	13.
	5	9	refurbishment of outlets (to passive house standard)	3	3	14.
	6	8	dismantle old vents-check, block them airtightly	4	2	15.
	7	5	check and repair (install) proper weatherstripping)	5	1	9.
	8	0	windows replacement	1	0	17.
Solid blockwork, rendered externally, wet plastered internally	1	25	check openings for service pipes and wires -seal them	5	5	12.
	2	25	seal cracks around windows	5	5	10.
	3	25	refurbishment of loft hatch (weatherstripping,lock mechanism)	5	5	11.
	4	25	dismantle old vents-check, block them airtightly	5	5	15.
	5	20	windows replacement	4	5	17.
	6	10	check and set (repair) window hinges and lock mechanism	5	2	8.
	7	10	check and repair (install) proper weatherstripping)	5	2	9.

ventilation strategy (airtightness standard min4.0 AC/H has to be achieved)

Construction type (ext.wall)		index (25-1)	description	feasibility	suitability	reference
Traditional cavity construction, drylined internally	1	25	installation of extract fans where there are none	5	5	18.
	2	25	refurbishment of open fireplace to stove (with damper)	5	5	19.
	3	20	installation of self-controlled vents (Dwell-Vent)+pass. stacks	4	5	21.
	4	15	installation of passive stacks instead of extracts	3	5	20.
	5	6	upgrading of windows to SAW's (requires passive stacks)	2	3	22.
	6	6	installation of controlled ventilation system (INNOVENTUS etc)	3	2	23.
	7	2	installation of MVHR (different systems)	1	2	24.
Timberframe, drylined internally	1	25	installation of extract fans where there is none	5	5	18.
	2	25	refurbishment of open fireplace to stove (with damper)	5	5	19.
	3	20	installation of self-controlled vents (Dwell-Vent)	4	5	21.
	4	15	installation of passive stacks instead of extracts	3	5	20.
	5	6	upgrading of windows to SAW's (requires passive stacks)	2	3	22.
	6	6	installation of controlled ventilation system (INNOVENTUS etc)	3	2	23.
	7	2	installation of MVHR (different systems)	1	2	24.
Refurbished solid wall to cavity construction, drylined internally	1	25	installation of extract fans where there is none	5	5	18.
	2	25	refurbishment of open fireplace to stove (with damper)	5	5	19.
	3	20	installation of self-controlled vents (Dwell-Vent)+pass. stacks	4	5	21.
	4	10	installation of passive stacks instead of extracts	2	5	20.
	5	6	installation of controlled ventilation system (INNOVENTUS etc)	3	2	23.
	6	4	upgrading of windows to SAW's (requires passive stacks)	2	2	22.
	7	2	installation of MVHR (different systems)	1	2	24.
Steel frame and cavity wall, drylined internally	1	25	installation of extract fans where there is none	5	5	18.
	2	20	installation of self-controlled vents (Dwell-Vent)+pass. stacks	4	5	21.
	3	10	installation of passive stacks instead of extracts	2	5	20.
	4	6	installation of controlled ventilation system (INNOVENTUS etc)	3	2	23.
	5	2	installation of MVHR (different systems)	1	2	24.
	6	1	upgrading of windows to SAW's (requires passive stacks)	1	1	22.
Solid blockwork, rendered externally, wet plastered internally	1	25	installation of extract fans where there is none	5	5	18.
	2	25	refurbishment of open fireplace to stove (with damper)	5	5	19.
	3	20	upgrading of windows to SAW's (requires passive stacks)	4	5	22.
	4	20	installation of self-controlled vents (Dwell-Vent)+pass. stacks	4	5	21.
	5	12	installation of controlled ventilation system (INNOVENTUS etc)	3	4	23.
	6	10	installation of passive stacks instead of extracts	2	5	20.
	7	3	installation of MVHR (different systems)	1	3	24.

DANISH PROPERTIES

The Danish surveyed flats fall into one of five main construction types:

- *Brick Cavity*
- *Insulated Panel*
- *Timber Frame, brick tiles*
- *Concrete, Eternit panels*
- *Timber frame, Eternit panels*

As all properties were constructed to a higher insulation and air-tightness standard than the UK and Irish properties, and so in some cases no feasible insulation or air-tightness upgrade was identified, and more 'high-tech' solutions were considered.

Brick Cavity (Stationsgården & Kildevaenget)

Insulation

In these, the oldest of the buildings measured, some insulation solutions were a viable upgrade. The most cost effective thickness for the insulation was calculated and an extra 100mm of roof insulation for the top most flats at Stationsgården, (costed at 2,851DKK) and 200mm at Kildevaenget (costed 6999DKK). At Stationsgården and 50mm of floor insulation for the ground floor flats (costed at 5,399DKK and 10,883DKK respectively) was considered. Replacement of the existing windows with super low-emissivity units was also considered (costed at 52,718DKK and 60,358DKK).

Air-tightness

The existing average air-tightness level of below 2ACH@50Pa at both sets of properties is more than adequate for the installation of advanced ventilation systems and achievement of energy efficiency and no further air-tightening measures have been considered here.

Ventilation

The airtightness and existing passive ducting servicing the flats makes the installation of a high efficiency MVHR system viable at both Stationsgården and Kildevaenget (costed at 21,442DKK and 18,368DKK respectively).

Further measures

Due to the good air-tightness and insulation standards already existing in the flats, and the clear ventilation upgrade path, other active energy saving measures were considered. These included solar thermal (costed at 14,168DKK and 16,342DKK respectively) and solar photovoltaic installations (costed at 30,000DKK at both sites).

Conclusions

The tables below show the overall results for Stationsgården and Kildevaenget. Costs in these tables are cumulative and the financial consequences of each technology can be seen as the payback period goes up or down. Most of the technologies provide similar payback times with the insulation + MVHR option proving to be the most cost-effective at Stationsgården, and insulation on it's own the best at Kildevaenget. The addition of low-E windows raises the payback times, and are not an optimal investment.

	Total Energy (KWh/(kWh/m²/year))	Energy Cost (DKK)	CO_2 Emissions (kg/year)	Intervention Cost (DKK)	Cost Savings (DKK/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	10066 (121)	6452	1309	N/A	N/A	N/A	N/A
After (Insulation)	9421 (113.5)	6038	1225	8250	414	84	20
After (MVHR)	8272 (99.7)	5312	1075	21442	1140	233	19
After (Solar Thermal)	7474 (90)	4802	972	35610	1650	337	22
After (PV)	5584 (67.3)	3545	726	65610	2907	583	23
After (Low-e)	3973 (48)	2512	516	118328	3940	792	30

	Total Energy (KWh/(kWh/m²/year))	Energy Cost (DKK)	CO_2 Emissions (kg/year)	Intervention Cost (DKK)	Cost Savings (DKK/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	11196 (142)	7436	1455	N/A	N/A	N/A	N/A
After (Insulation)	10249 (130)	6804	1332	10883	632	123	17
After (MVHR)	9096 (115)	6092	1182	29250	1344	273	22
After (Solar Thermal)	7525 (95)	4836	978	59250	2600	477	23
After (PV)	6815 (86)	4373	886	75592	3063	570	25
After (Low-e)	5353 (68)	3400	696	135950	4036	760	34

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Insulated Panel (Mørkhøjvænge)

Insulation

In these, the oldest of the buildings measured, some insulation solutions were a viable upgrade. The most cost effective thickness for the insulation was calculated and an extra 200mm of roof insulation for the top most flats at Mørkhøjvænge, (costed at 9,569DKK) was considered. The same was done for the floor and 50mm of floor insulation for the ground floor flats (costed at 5,230DKK) was considered. Replacement of the existing windows with super low-emissivity units was also considered (costed at 41,257DKK).

Air-tightness

The existing average air-tightness levels were the worst of the Danish sample and remedial sealing work has been considered here. The cost effectiveness of various sealing levels has been analysed and sealing the property to 0.6l/s/m2 was the best option (and has been costed at 8000DKK).

Ventilation

The achievable airtightness and existing passive ducting servicing the flats makes the installation of a high efficiency MVHR system viable (costed at 12,555DKK for a high efficiency system). This higher efficiency system was shown to provide the better cost effectiveness compared to medium or low efficiency systems in a preliminary analysis.

Further measures

Due to the good air-tightness and insulation standards already existing in the flats, and the clear ventilation upgrade path other active energy saving measures were considered. These included solar thermal (costed at 12,626DKK) and solar photovoltaic installations (costed at 30,000DKK).

Conclusions

Conducting purely the roof and floor insulation work results in the best simple payback figure of 12 years but delivers only 16% energy total energy savings. Adding MVHR installation and air-tightening brings the simple payback up to 15 years but now reduces energy consumption by 33%. Additional PV and solar thermal installation deliver overall paybacks of 18 and 20 years respectively and energy savings of 47 and 52% respectively. New low-E windows raises the payback further to 23 years, even though they increase energy savings to 69%, due to their high cost. Although payback times increase with each installation type the energy savings are significant with total energy consumption reduced by two thirds from 203kWh/m²/year to 64kWh/m²/year with a total investment of 119338DKK. The payback times are better than the previous case as the relative lack of air-tightness of these flats generated larger space heating consumption figures for the base case.

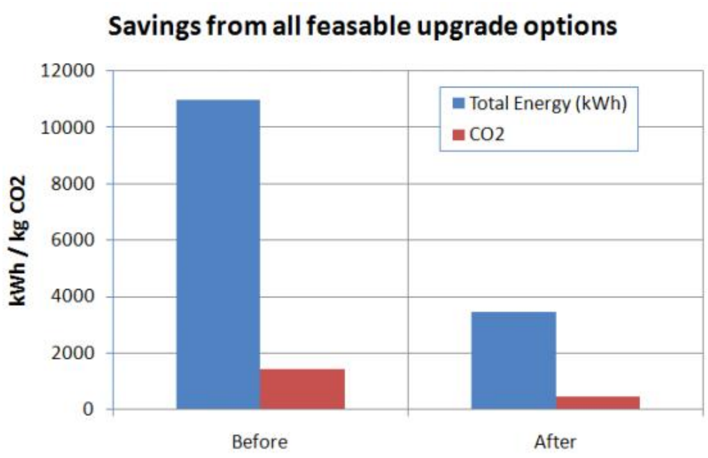

Figure 1. Annual total energy and CO_2 savings.

	Total Energy (KWh/(kWh/m²/year))	Energy Cost (DKK)	CO_2 Emissions (kg/year)	Intervention Cost (DKK)	Cost Savings (DKK/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	10986 (203)	7311	1428	N/A	N/A	N/A	N/A
After (Insulation)	9234 (171)	6120	1200	14799	1191	2629	12
After (MVHR)	7344 (136)	4901	955	35454	2410	473	15
After (PV)	5778 (107)	3644	751	65454	3667	677	18
After (Solar Thermal)	5238 (97)	3307	681	78080	4004	747	20
After (Low-e)	3456 (64)	2133	449	119338	5178	979	23

Timber frame with brick tile cladding (Egebjergvang)

Insulation

As the built construction becomes more modern the existing level of insulation in the properties becomes better (see page 16). The existing U-values of 0.3W/m2K in this case makes the upgrade of external wall insulation uneconomic. A preliminary analysis of different insulation types and levels did however indicate that the upgrade of the roof insulation with 100mm of extra insulation for the upper level flats would be the best insulation upgrade option. This has therefore been considered here at a cost of 6450DKK. Replacement of the existing windows with super low-emissivity double glazed units was also considered (costed at 53,482DKK) as it offered better financial returns than triple glazed windows.

Air-tightness

The existing average air-tightness levels were very good with an average level across the three properties of 2.0ACH@50Pa. No further air-tightening procedures were therefore considered in this case.

Ventilation

The good existing air-tightness and exisiting passive ducting servicing the flats makes the installation of a high efficiency MVHR system viable (costed at 11,375DKK for a high efficiency system). This was shown in a preliminary analysis to offer better financial returns than low or medium efficiency systems.

Further measures

Due to the good air-tightness and insulation standards already existing in the flats, and the clear ventilation upgrade path other active energy saving measures were considered. These included solar thermal (costed at 11,366DKK) and solar photovoltaic installations (costed at 30,000DKK).

Conclusions

Of all the considered upgrades MVHR provided the single most cost-effective measure, largely due to the pre-existing levels of good air-tightness and relative ease of install which reduces the cost of this particular intervention in this case. The installation of MVHR reduces total energy consumption by 1600kWh or 17% and saves over 1100DKK per year, delivering a simple payback of 10 years. Cumulative installation of extra roof insulation raises the overall payback slightly to 12 years and further increasing energy savings to 20%, an additional solar thermal installation brings the simple payback to 15 years and increases energy savings to 28%. An additional PV installation brings the simple payback up to 19 years and energy savings to 46%. Efficient low-E windows raises the final payback figure to 24 years and represents the least cost-effective single upgrade due to their cost as they are effective at reducing energy consumption further by 68%. All interventions reduce the total energy consumption of the flats by more than two thirds, saving 6762kWh/year, for a total expenditure of 112007DKK.

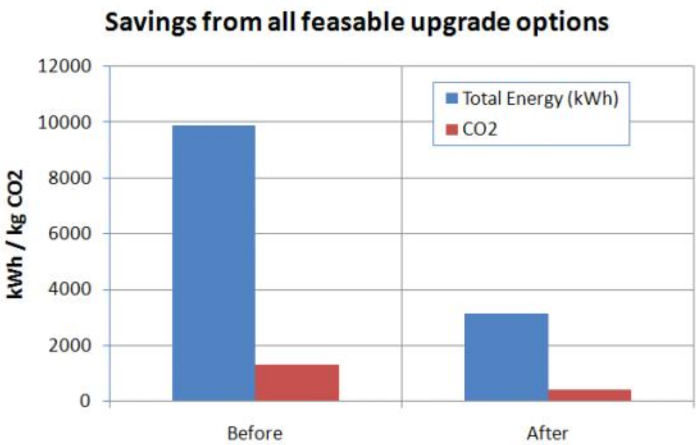

Figure 1. Annual total energy and CO_2 savings.

	Total Energy (KWh/(kWh/m²/year))	Energy Cost (DKK)	CO_2 Emissions (kg/year)	Intervention Cost (DKK)	Cost Savings (DKK/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	9894 (125)	6775	1286	N/A	N/A	N/A	N/A
After (MVHR)	8220 (104)	5627	1069	11375	1148	218	10
After (Insulation)	7890 (100)	5401	1026	17159	1374	261	12
After (Solar Thermal)	7132 (90)	4885	927	28525	1890	359	15
After (PV)	5360 (68)	3629	697	58525	3146	589	19
After (Low-e)	3132 (40)	2107	407	112007	4668	879	24

Concrete frame with Eternit cladding (Bøgehegnet)

Insulation

The existing insulation levels of these flats is slightly poorer than the previous sample, going against the general trend of lowering U-values with newer constructions, but the rise is slight and is only 0.33W/m2K. This is still a very good insulation standard and extra wall insulation were calculated as being uneconomic in this case. Floor insulation was also shown to not offer good returns on investment but an extra 100mm of roof insulation was however considered to be potentially cost-effective in this case and has been considered here at a cost of 4462DKK. Double and triple glazed low-E windows were also considered for upgrade with double glazing the most cost-effective and costed at 61886DKK.

Air-tightness

The existing average air-tightness levels were amongst the best of the Danish sample (average value of 1.2ACH@50Pa) and remedial sealing work not has been considered here.

Ventilation

The very good existing airtightness and existing passive ducting servicing the flats makes the installation of a high efficiency MVHR system viable (costed at 13,163DKK for a high efficiency system), which proved more cost-effective than medium or low efficiency systems.

Further measures

Due to the good air-tightness and insulation standards already existing in the flats, and the clear ventilation upgrade path, other active energy saving measures were considered. These included solar thermal (costed at 11,366DKK) and solar photovoltaic installations (costed at 30,000DKK).

Conclusions

Again the very good air-tightness levels already exhibited by the properties made MVHR the single most cost-effective upgrade technology delivering a simple payback period of 10 years and reducing energy demand by 23%. The addition of a solar thermal installation broiught the payback period up to a still reasonable 13 years and increases energy savings to 30%. Addition of a PV installation brings the payback time up to 19 years and could be considered marginal in terms of cost-effectiveness but does increases energy savings further to 47%. Low-E windows brings the payback period up to 27 years, due to their large cost, but do increase energy savings to 70%. Improved roof insulation is the least cost-effective, due to its relatively low energy saving potential (147kWh/year) and brings overall payback to 28 years and increases energy savings slightly to 71%. The first three interventions, that deliver the most cost-effective upgrades, reduce total energy consumption by 45%, with the last two interventions total energy is reduced by 71%. Investment to achieve these two energy savings are 54529 and 120877DKK respectively.

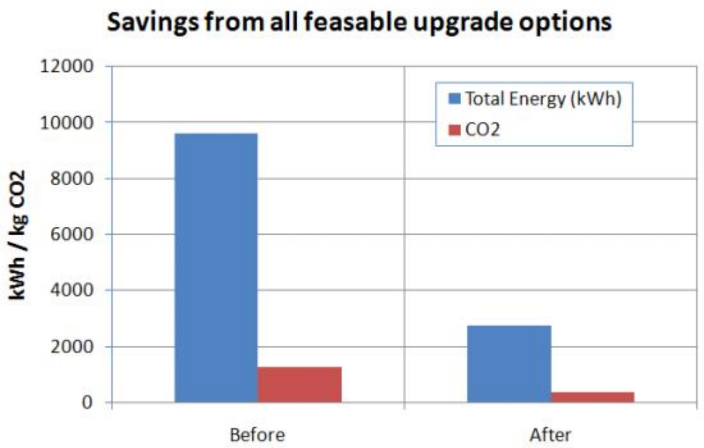

Figure 1. Annual total energy and CO_2 savings.

	Total Energy (KWh/(kWh/m²/year))	Energy Cost (DKK)	CO_2 Emissions (kg/year)	Intervention Cost (DKK)	Cost Savings (DKK/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	9599 (114)	6127	1248	N/A	N/A	N/A	N/A
After (MVHR)	7432 (88)	4743	966	13163	1384	282	10
After (Solar Thermal)	6675 (79)	4262	868	24529	1865	380	13
After (PV)	5046 (60)	3194	656	54529	2933	592	19
After (Low-e)	2899 (35)	1825	377	116415	4302	871	27
After (Insulation)	2752 (33)	1732	358	120877	4395	890	28

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Timber frame with Eternit cladding (Skotteparken)

Insulation

In these, the newest of the buildings sampled, wall insulation was again shown to be not cost effective but 100mm of roof insulation and 50mm of floor insulation did provide a potentially cost-effective upgrade and have been analysed in detail here. The cost of these interventions was 5949 and 5048DKK respectively. Low-E insulative double glazed windows were also shown to be potentially cost-effective, albeit marginally, and have been analysed here at a cost of 55010DKK.

Air-tightness

Despite being the newest flats in the sample the air-tightness was the second highest for the Danish housing at an average of 3.8ACH@50Pa. As this is slightly too high for the optimal performance of mechanical heat reclaim systems air-tightening measures were included at a cost of 8100DKK.

Ventilation

The achievable airtightness and existing passive ducting servicing the flats makes the installation of a high efficiency MVHR system viable (costed at 3,600DKK for a high efficiency system). A high efficiency system provided again better cost-effectiveness than medium or low efficiency systems.

Further measures

Due to the good air-tightness and insulation standards already existing in the flats, and the clear ventilation upgrade path other active energy saving measures were considered. These included a solar photovoltaic installation (costed at 30,000DKK).

Conclusions

The MVHR and air-tightening measure provided the most cost effective upgrade in this case with a simple payback of 9 years being delivered. The relative compactness of the flat, and hence relative cheapness of the MVHR, was a large factor in this. Energy savings from this measure amount to 29% of the base line total which is the highest saving from MVHR amongst all sample types. Further upgrade strategies provide far less cost effectiveness with the simple payback period rising to 17 years for additional floor and roof insulation which deliver only a slight increase in energy savings (52kWh/year) to achieve a an overall reduction of 30%. PV installation has a simple payback of 22 years but increases energy savings to 55%. Low-E windows further increase the simple payback time to 31 years but further reduce energy consumption by 69%. The low base line of energy usage, again largely due to the compactness of the flat, accounts for these large payback times even though the percentage reduction in total energy expenditure is on a par with the other properties, with a reduction of 70% achieved overall at a total intervention cost of 107708DKK. Also, as the intervention cost is not proportional to it's size, but also has an independent installation cost, the cost is higher relative to absolute energy savings than in the other property types.

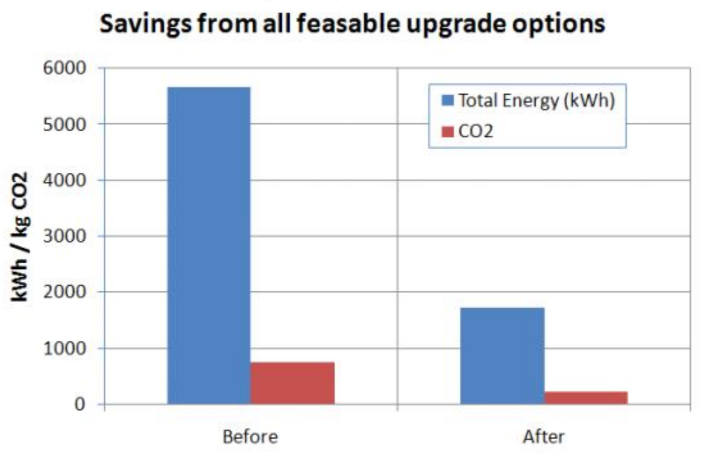


Figure 1. Annual total energy and CO_2 savings.

	Total Energy (KWh/(kWh/m²/year))	Energy Cost (DKK)	CO_2 Emissions (kg/year)	Intervention Cost (DKK)	Cost Savings (DKK/year)	CO_2 Savings (kg/year)	Simple Payback (years)
Before	5673 (93)	4441	737	N/A	N/A	N/A	N/A
After (MVHR)	4039 (66)	3200	525	11700	1241	212	9
After (Insulation)	3983 (79)	3114	518	22698	1327	220	17
After (PV)	2563 (43)	2046	333	52698	2395	404	22
After (Low-e)	1711 (28)	1311	222	107708	3130	515	34

Danish Matrix

On this page is the Danish housing Matrix which has broken down the six sampled sets of housing into three main construction types. The Matrix can be used in a similar way to the Irish and UK Matrices.

Proposals for improvements of KAB Social Housing, AVASH project

Insulation U-value

Construction type (exc.wall)		index	description	feasibility	sustainability	reference
Block of flats, Brick cavity 1930 - 1960	1	25	Window replacement	5	5	7
	2	25	Ceiling (loft) insulation	5	5	1
	3	20	Cavity wall insulation	5	4	2
	4	16	Secondary window	4	4	7
	5	15	External insulation	3	5	3
	6	15	Thermal bridging/wall	3	5	6
	7	9	Floor insulation	3	3	5
	8	9	Thermal bridging/windows	3	3	6
	9	8	Internal insulation	4	2	4
Block of flats, Concrete cavity, 1960 - 1970	1	25	Window replacement	5	5	7
	2	20	External insulation	4	5	3
	3	20	Ceiling (loft) insulation	5	4	1
	4	15	Insulation of wall socket	5	3	6
	5	12	Floor insulation	3	4	5
Timber frame construction, 1970 -	1	25	Window replacement	5	5	7
	2	20	External insulation	4	5	3
	3	12	Ceiling (loft) insulation	3	4	1
	4	15	Insulation of wall socket	5	3	6
	5	12	Floor insulation	3	4	5
	6	12	Internal insulation	4	3	4

airtightness

Construction type (exc.wall)		index	description	feasibility	sustainability	reference
Block of flats, Brick cavity 1930 - 1960	1	25	Weather stripping	5	5	9
	2	25	Sealing around windows	5	5	10
	3	25	Sealing around installations	5	5	12
	4	20	Sealing of external surfaces	5	4	10
	5	20	Windows hinges and locks	5	4	8
Block of flats, Concrete cavity, 1960 - 1970	1	25	Weather stripping	5	5	9
	2	25	Sealing around windows	5	5	10
	3	25	Sealing around installations	5	5	12
	4	20	Sealing of external surfaces	5	4	10
	5	16	Sealing of building elements	4	4	10
Timber frame construction, 1970 -	1	25	Weather stripping	5	5	9
	2	25	Sealing around windows	5	5	10
	3	25	Sealing around installations	5	5	12
	4	20	Sealing of external surfaces	5	4	10
	5	16	Sealing of building elements	4	4	10

ventilation strategy

Construction type (exc.wall)		index	description	feasibility	sustainability	reference
Block of flats, Brick cavity 1930 - 1960	1	25	User behaviour	5	5	28
	2	20	SAW	5	4	22
	3	16	Extract air fan with HP	4	4	27
	4	10	MVHR	2	5	24
	5	8	Extract air fan	4	2	18
	6	8	Automatic tricklevent	4	2	21
Block of flats, Concrete cavity, 1960 - 1970	1	25	User behaviour	5	5	28
	2	16	Extract air fan with HP	4	4	27
	3	15	MVHR	3	5	24
	4	15	Installation of PSV	5	3	20
	5	12	SAW + passive stack	3	4	22
	6	8	Automatic tricklevent	4	2	21
Timber frame construction, 1970 -	1	25	User behaviour	5	5	28
	2	16	Extract air fan with HP	4	4	27
	3	15	Installation of PSV	5	3	20
	4	12	MVHR	3	4	24
	5	12	SAW + passive stack	3	4	22
	6	8	Automatic tricklevent	4	2	21

Summary & Conclusions

UK

The nature of the predominant housing type in Camden's stock, namely flats, raises a number of issues regarding the appropriate upgrade strategies for the properties. Not only does the preponderance of flats have an influence on this but also the type of flat construction.

For example, purpose built blocks all owned by the same housing provider have the potential for the whole block to be externally insulated relatively cost-effectively. This not only dramatically improves the insulation of the block but can rejuvenate its visual appearance as well. Converted Victorian town houses represent the other end of the spectrum however because their listed status and presence of privately owned properties on either side make this strategy unfeasible.

Many of the concrete constructions either have, or could have, good levels of air-tightness, but the concrete construction makes the installation of ducted ventilation systems unfeasible. Even advanced heat recovery applied on a per room basis has no energy benefit for this sample because the flats are small, occupancy is low, and it is difficult in these cases to justify a constantly running fan as opposed to intermittent.

Although many advanced types of ventilation have been looked at during the course of this project the available technologies seem geared towards bespoke construction and not refurbishment. They rely on good levels of air-tightness to maximise heat recovery strategies, or to be necessary to guarantee required flow rates. They also rely on the ventilation system to be designed in, rather than applied to, a design. This has made some of the simpler and traditional modes of ventilation the most appropriate in most cases, with added benefits in terms of low maintenance and capital cost.

Despite this, the energy savings were significant and achieved with a level of investment levels that is realistic for a refurbishment program. Energy savings of between 30 and 50% were achieved, bringing all the properties to below current requirements and some to below best practice standards. Further incremental improvements are likely as window and insulation technologies advance. There is currently however no advanced ventilation strategy particularly suitable to this context, which there will need to be if many existing properties are to be brought up to very good energy efficient standards. A ventilation strategy that is automatic and demand controlled, or constant whilst flexible (with very good heat recovery) would be of huge benefit in this refurbishment context.

This is why intermittent extract fans are often the best solution. They are flexible as they can be installed in windows or walls on a per room basis, with no requirement for further building works. They are demand controlled via light fittings or cooker hob meaning that they do not ventilate when not required.

In terms of the energy savings achieved in the properties the graph below summarises the energy consumption in kWh/m²/year both before and after the chosen interventions.

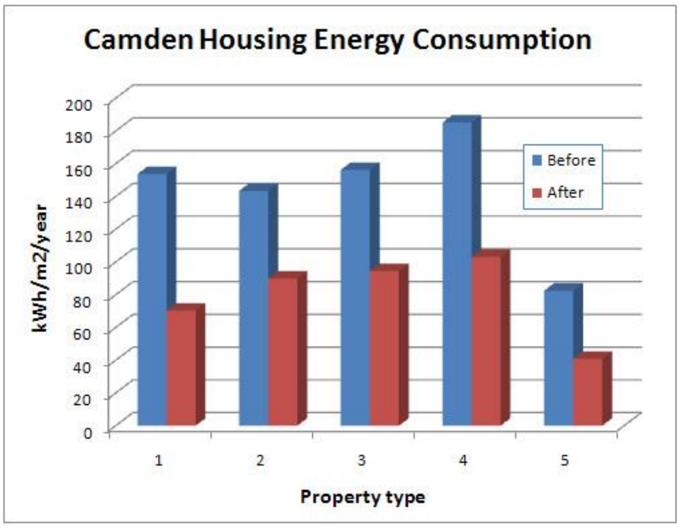


Figure 1. Camden property space heating consumption

All properties could be brought below the current energy efficiency standard of 125kWh/m²/year as results ranged from around 40 to 100kWh/m²/year. Some will therefore conform to a very high standard and others will only be acceptable up to the next revision of the building regulations.

The cost of the interventions for each housing type are shown in the next graph.

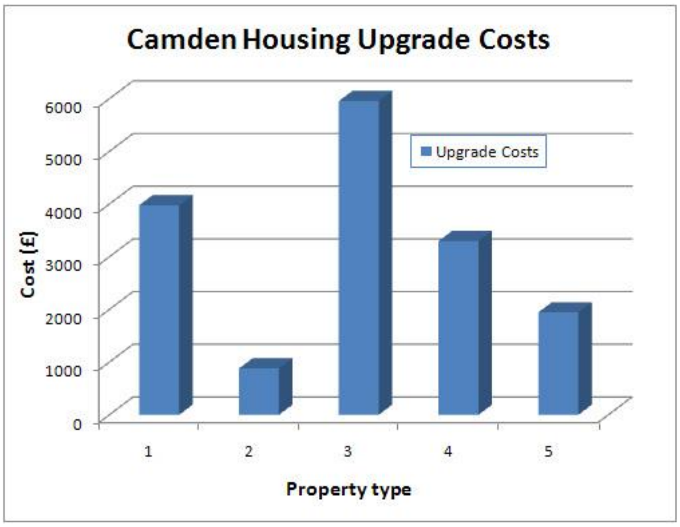


Figure 2. Upgrade costings

Very high cost improvements were not considered as it is unrealistic to expect larger housing authorities to upgrade their housing unless it is cost-effective. The range in costs is high and depends on which type of insulation method is considered, whether windows need replacing and whether more complex interventions are considered. Some properties can be upgraded effectively quite cheaply, especially property type two which still managed to achieve a 37% reduction in space heating consumption.

Levels of CO_2 emissions savings are shown in the graph below.

Figure 3. CO_2 emissions savings

In pure economic terms it is difficult to justify most of the upgrades with gas heating, even with the current high price of fuel. If electric is the heating source for the property however then most types have simple paybacks below 10 years. Property type 2 (brick and block) offers the most cost-effective upgrade possibility, largely due to the cheapness with which cavity wall insulation can be applied. Type 3 (Solid brick, wooden floor), mainly consisting of Victorian town houses, are the least cost-effective to upgrade, largely due to the extra expense in air-tightness measures required.

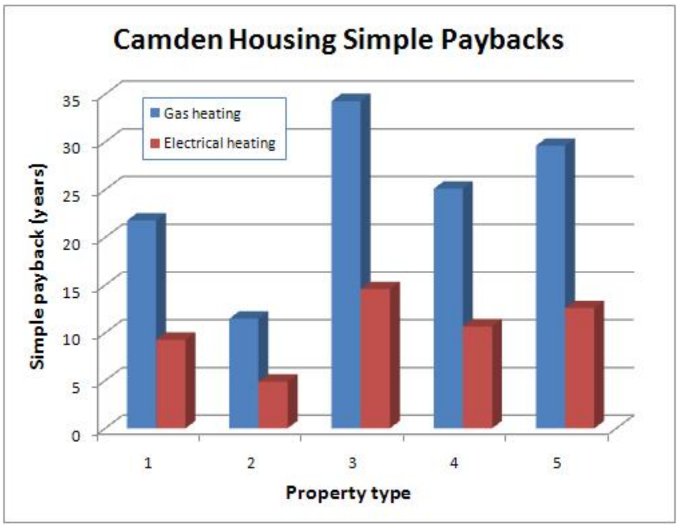


Figure 4. Simple paybacks

It is fortunate that type 2 is a prevalent type in Camden's whole housing stock, and indeed throughout the wider UK social housing market. The number of each of the assessed housing types within Camden's housing stock is shown below.

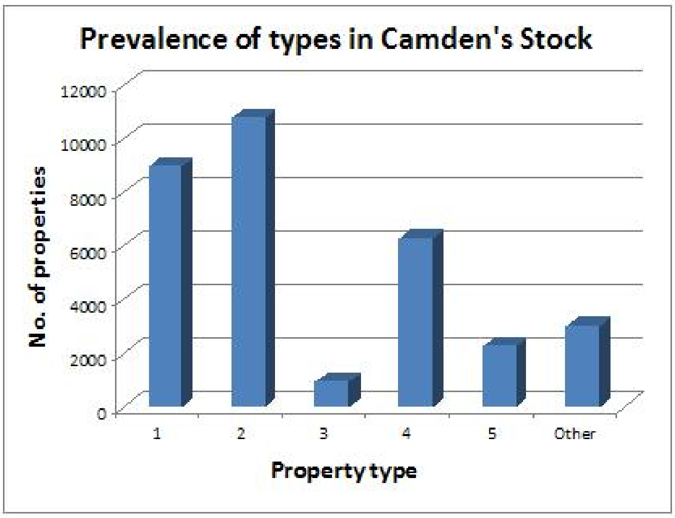


Figure 5. Breakdown of Camden's housing stock

Not only is the most cost-effectively upgradable property type the most prevalent, but type three, the least cost-effective, is also the least common, comprising only 3% of the total. This makes an interesting addition to the debate about the eco-refurbishment of historical houses in the UK, which do make up only a small percentage of the total housing stock, and it seems that resources would be currently better spent on newer properties.

The graphs below shows the overall benefits if the savings in CO_2 and kWh for each house type are applied across Camden's whole housing stock. Across all housing types this would amount to annual savings of 92GWh, 20,219 tonnes of CO_2 and fuel cost savings of over £2,800,000 for the residents.

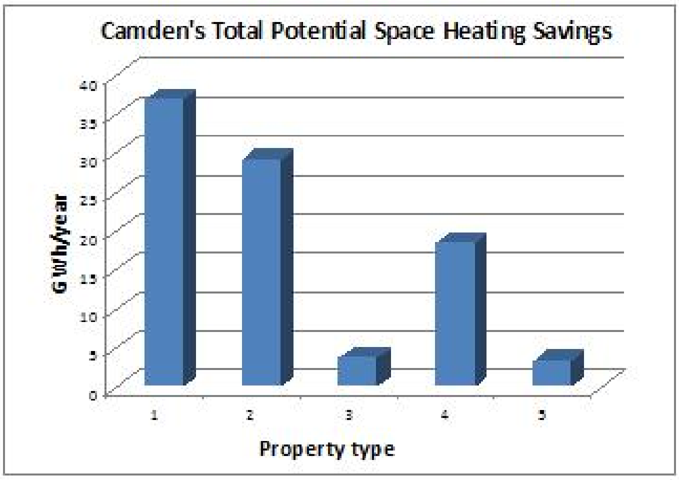


Figure 6. Total potential space heating savings.

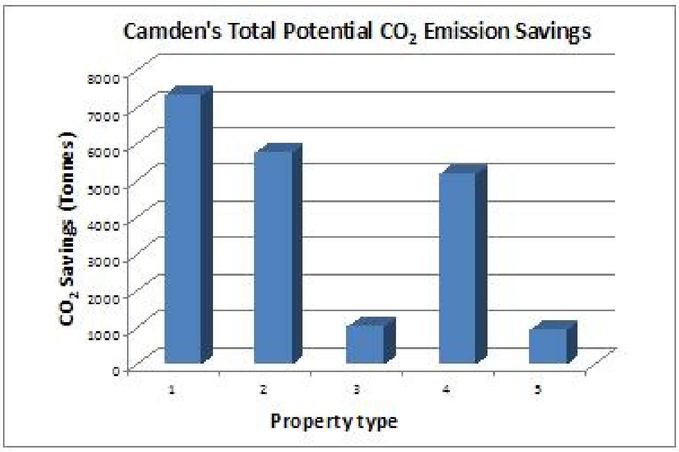
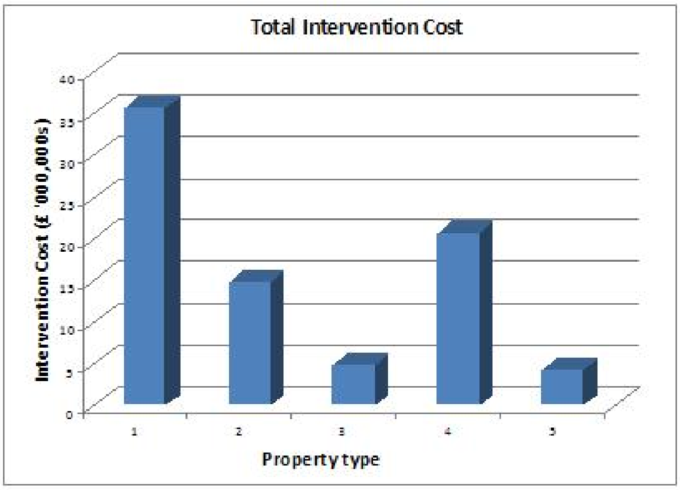


Figure 7. Total potential CO_2 emission savings.

The cost of these interventions broken down by house type, if applied over Camden's complete housing stock, are shown below in figure 8. Across all house types the total cost of these interventions would be £80,656,000.



Ireland

Ireland presents its own issues regarding the implementation of advanced ventilation strategies. Although the construction of the houses with their wooden floors and sometimes good levels of achievable air-tightness do lend themselves to the installation of more complex systems, the prevalent wind speeds and exposed nature of many of the properties in Ireland causes infiltration to be higher than optimal for many systems. In this context it is difficult for systems that attempt to provide all the required ventilation to a building to dominate the ventilation regime as they should, and to provide the energy savings they can.

This situation does however throw up some interesting and encouraging results. The simple blocking of chimney flues can have a very significant influence on the heat consumption of the relevant properties for example as the generally high wind speeds causes significant excess ventilation out of the chimneys, especially as the fabric of the building is not air-tight and is even likely to have bespoke ventilation apertures to feed the fireplace.

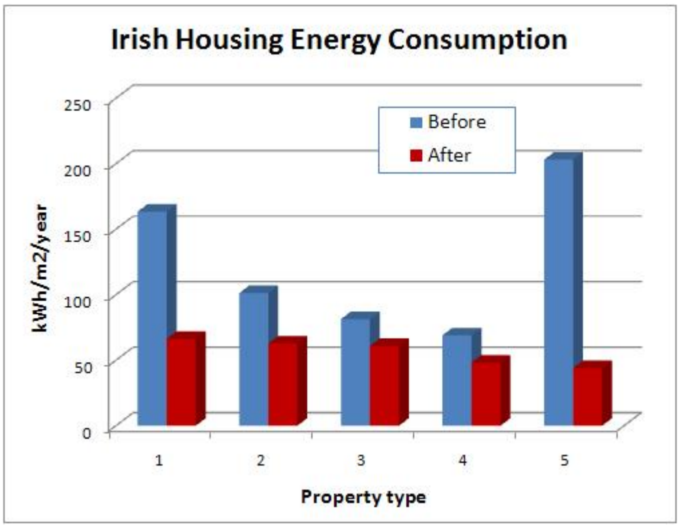


Figure 1. Irish space heating consumption figures

This can be seen in the amount of energy saved in both properties with chimneys (1 & 5), which is far higher then the others. Not only are the energy savings significant but the cost of this particular intervention is small as well.
The efficacy of this intervention can also be seen in the percentage reductions in space heating and CO_2 below.

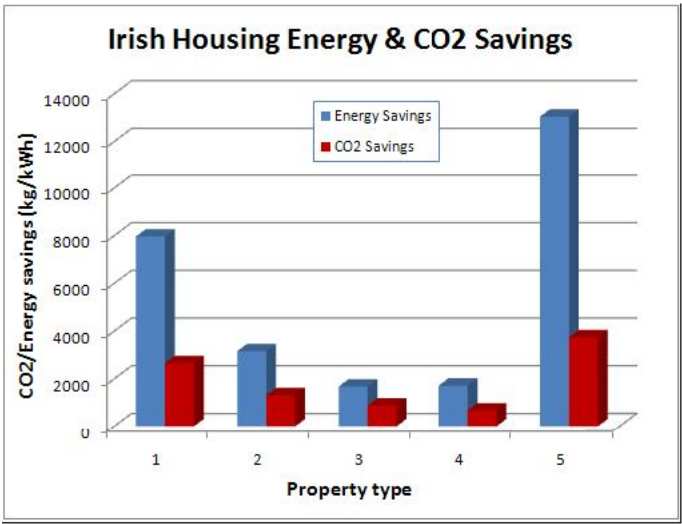


Figure 2. Percentage reduction in Irish property CO_2 and space heating consumption

As in the UK, in terms of pure energy efficiency, maintenance and running costs, simple intermittent extracts are almost universally the most appropriate system. In a current context where constant mechanical forms of ventilation are sold as the only way to achieve the sustainable housing of the future, it is surprising that this should be the case. It may well be the case that these systems are optimal for air-tight new build properties where the system is designed in to reduce installation costs, but in a retrofit scenario, with housing not built to modern standards of air-tightness or insulation then it is hard to make a case for them. Even in the more airtight properties the best performing systems only achieved parity with this simple and traditional method of ventilation, and care should be taken before applying what are ostensibly new build technologies in a very different retro-fit context.
However, in general savings above 30% are achieved, except where the properties already had a good level of insulation and air-tightness. Payback periods for the base cases again show the influence of the cost-effective chimney intervention with good paybacks on properties types 1 and 5. Even with gas heating the paybacks are around 10 years in these cases. Intervention costs are again reasonable in all cases except property 5, which also however saw the largest drop in energy consumption (from the largest to the smallest) leading to a reasonable payback time.

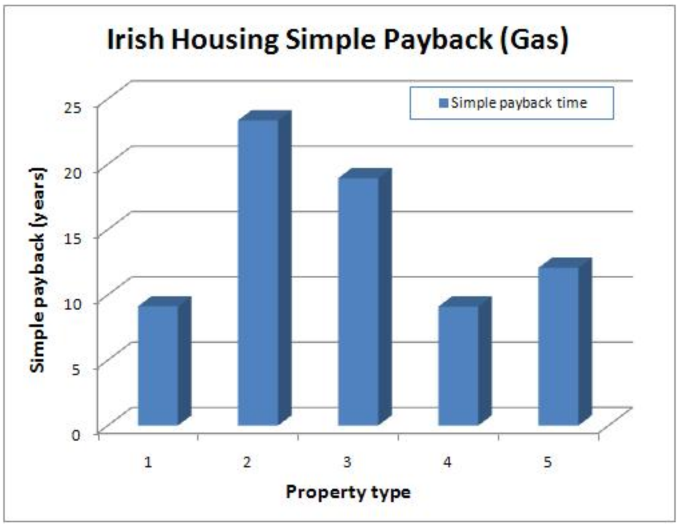


Figure 3. Simple paybacks (gas)

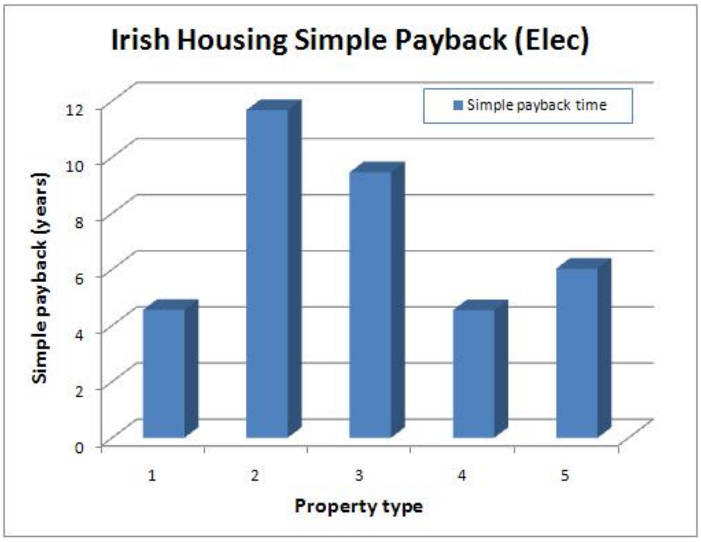


Figure 4. Simple paybacks (electricity)

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In the wider context of Cluid's housing stock the traditional cavity construction type (1) is by far the most common, which reflects the recent Irish housing boom, and as no property built by Cluid is older than 1990. The savings that can therefore be achieved with their, and the wider Irish social housing stock, is typified by the savings achieved with property type 1, especially as the other types are largely the very newly built.

Applying these savings across Cluid's 2780 properties results in the total energy and CO_2 savings shown below.

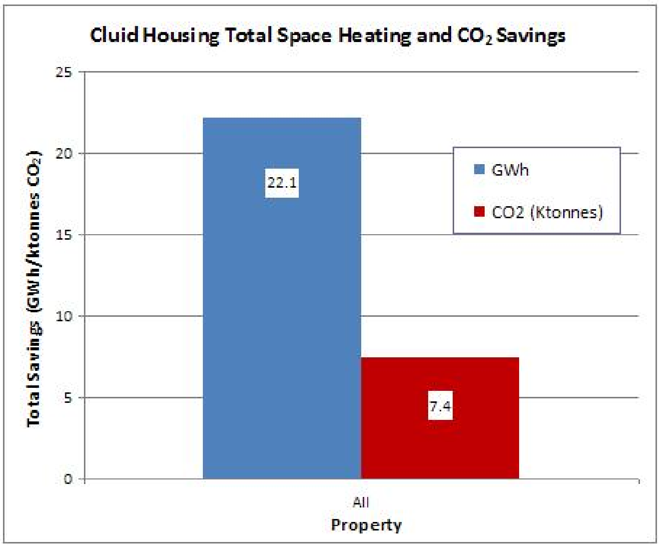


Figure 5. Overall space heating and CO_2 emissions savings.

To achieve these savings a total capitol expenditure of €23,000,000 is required, saving the residents €1,770,000 in gas fuel costs annually. This represents a simple rate of return on investment of 7.7%, far higher than current national bank interest rates, and lends some credence to the policy of investing in energy efficiency in housing and recouping the investment with a levy on fuel bills.

Denmark

The nature of the predominant housing stock in KAB's stock, namely post-war purpose-built flats, has a significant impact on the type of upgrades that should be considered. For example, the already good levels of fabric insulaltion and air-tightness makes many of the upgrades considered for the UK and Irish houisng either obselete or not cost-effective. For example extra wall insulation whether it be internal, external or intistitial provide too little extra benefit when U-values are, even for the least insulated properties less than 0.6W/m²K. Extra roof or floor insulation can be more cost-effective but only in the older properties as the extra energy savings are too little in the better insulated newer properties. More insulative windows have been considered for each housing sample, and low-E double glazed units were shown to offer the most cost-effective window upgrade solution, but were still often the least cost-effective measure overall due to their high cost. They do hoewever achieve quite high absolute energy savings and are required to achieve the 60-70% energy savings overall.

In addition, very little air-tightnening is required as most of the properties have existing air-tightness metrics far below the Uk and Irish properties. One exception to this are the flats sampled in the middle of the overall age range, where insulated panels were first used, and the new combination of these with air-tightness membranes led to some errors in installation.

As the flats are all currently passively ventilated, of have existing older MVHR systems then the installation or upgrade with newer MVHR systems was not only feasible but shown to be the most effective solution. In cold climates, where MVHR is installable, it would appear that this is generally the case. Actual energy savings in reality, given that MVHR systems require a level of maintenance and user-interaction to operate effectively, is hard to quantify but it is safe to assume that the greater familiarity with such systems in Denmark makes it more likely that they will be used and maintained effectively and user behaviour is specifically included in the Danish matrix to reflect this.

As the choice of upgrade technologies for the Danish flats was either limited or much clearer some additional, active upgrade strategies have been considered to achieve substantial energy reductions. In the main solar thermal and photovoltaic have been considered to be the most cost-effective options but are not in general as cost-effective as insulation or ventilation measures. To achieve energy savings of over 50% these systems are however required.

The graph below shows the before and after energy consumption for each flat type in kWh/m²/year.

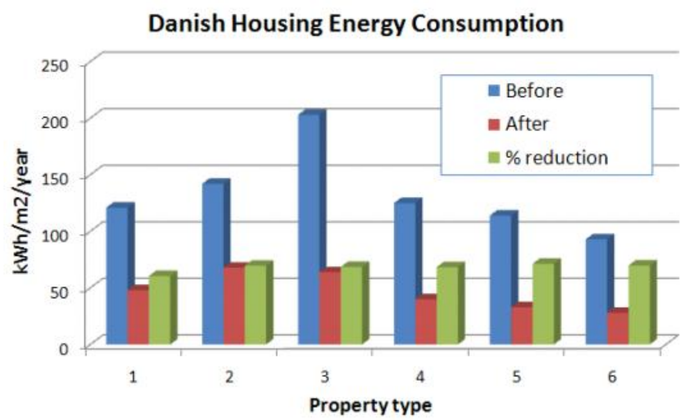


Figure 1. Overall Danish energy consumption.

A feature of these figures is the consistency with which energy demand is reduced varying only between 60 and 71%. This is partly due to the fact that the variance in the base line characteristics and performance of the buildings is much less and the variance in the existing fabric performance is also much less. Also, the good level of air-tightness and insulation means that some upgrade strategies like wall insulation, which has varying final performance depending on whether it is internal, external or cavity, have not been considered.

In general it is possible to reduce energy consumption to below 70kWh/m²/year, which considering the colder Danish climate is a considerable achievement. The use of the more active energy reducing technologies is key to this but does have an impact on the overall cost on the interventions which are shown below.

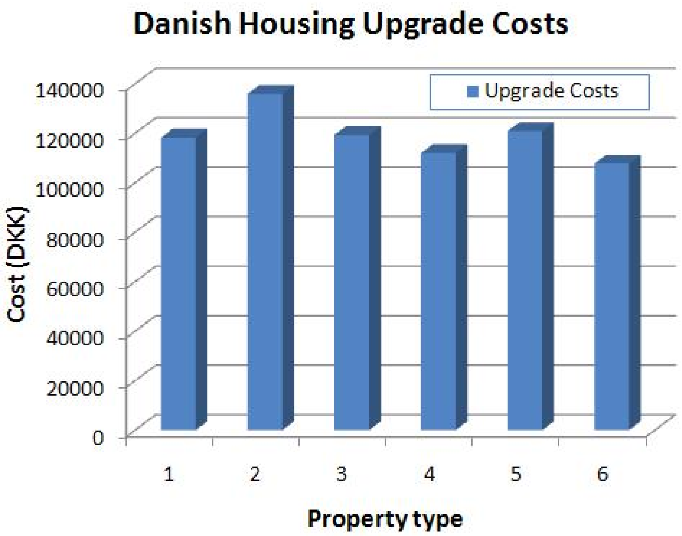
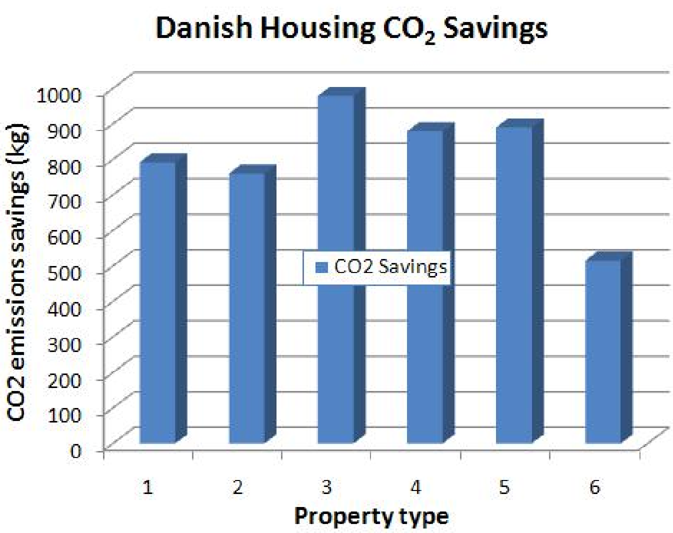


Figure 2. Upgrade costings.

The upgrade costs are also much more consistent for the Danish housing, largely for the same reasons for the consistency in energy savings. The type of wall insulation considered can have a massive influence over costs for example, but as wall insulation is not considered for the Danish housing, that variability is removed. The cost of the installations is higher than in the UK or Ireland due to a higher threshold for building investment in Denmark, and the colder climatic temperatures which delivers greater cost and energy savings from energy saving measures like MVHR or extra insulation, allowing greater investment for a particular payback figure.

The CO_2 emissions savings resulting from the suggested upgrades are shown in the graph below.



The higher variability in the CO_2 savings figures result from the fact that differences in flat floor area express themselves in terms of CO_2 emission and reduction. In almost all cases, with the exception of the smaller last set of flats, over 700kg of CO_2 is saved every year with these measures.

In economic terms less variety is seen in simple payback times than in the other countries with all showing final paybacks on all upgrade measures of over 20 years. Simple payback figures are shown in the graph below.

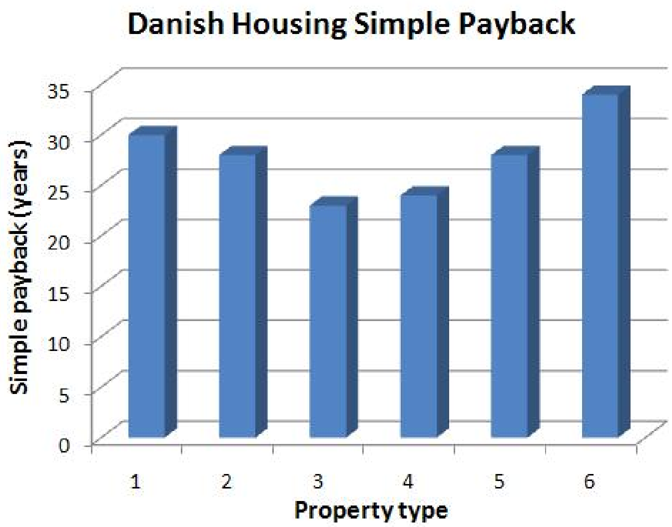


Figure 3. Danish simple payback figures

With these overall payback figures the upgrades considered here are not easily justified on a purely economic basis. Certain upgrades do however provide better paybacks than others, and an organisation may chose to implement certain more cost-effective upgrades in stages and not others.

In terms of KAB's whole housing stock the consistent energy savings achieved with the chosen upgrades can be applied across all their properties which are largely post-war purpose built flats. Assuming that a base line 60% reduction in energy consumption can be achieved then across KAB's 23,860 properties, which currently use 221,543MWh of energy, a total saving of 132,926MWh can be achieved. This would save the emission 17,700 tons of CO_2/year at a cost of 137,432DKK/ton CO_2.

At a total cost of 2,433 Million DKK. If this is extrapolated to the whole of the Danish housing stock of 513,745 properties with a total annual energy consumption of 4,770,185MWh this results in energy savings 2,862,111MWh/year. Yearly savings of CO_2 emissions are 381,110 tons at a total investment cost of 52,377 million DKK.

Overall

The AVASH project has sampled the disparate social housing types of the three partner countries, and shown the highly variant levels of performance, in terms of sir-tightness and thermal insulation, between them. Detailed research into the possible upgrades that can be applied to these buildings has been undertaken, and the buildings modelled with a variety of these options with advanced computational tools. From the results from these software tools we have arrived at conclusions regarding the best upgrade strategy for different housing types from the point of view of energy efficiency, occupant comfort and economy. The checklists that have been created as a result provide a valuable resource to social, and other, housing providers when considering the eco-refurbishment of their existing stock.

In particular the conclusions of this project help housing providers make better judgements regarding the implementation of complex and technological solutions, which currently dominate the eco-refurb market. There is a place for such solutions, and Denmark is a good example of a context in which these solutions can work well, but often the simplest existing technologies constitute not only the cheapest, but also the best performing option in this context.

It is the particular nature of existing housing that makes the implementation of highly technological solutions problematic. These solutions rely on a consistent framework within which to operate, and as the project has shown, this consistent framework does not exist, especially in the UK and Ireland, where properties perform very variably. Even with remedial work creating a consistent enough context so that specific technological implementations can function is extremely difficult.

To compound this problem is that fact that neither the UK or Ireland are leaders in the ventilation technology field, and even if they were it is unlikely that they would have developed MVHR as a solution, as it does not suit the way properties are built in those countries. There are therefore few advanced ventilation technologies that are built with these properties in mind.

In Denmark however the context is very different. Not only are the properties built more consistently (at least for the majority post-war housing stock) they are also built to a high standard. This creates a framework within which research and development of ventilation technologies that require certain performance benchmarks can flourish.

This highlights the dangers in looking to other countries for fixes to problems whose characteristics are localised in nature, as the UK currently looks to MVHR as a ventilation solution. As Denmark is ahead of the UK and Ireland in many areas related to the construction industry, especially the environmental aspects, it is tempting to look to them to provide solutions to common environmental problems. But the technologies developed in, say, Denmark are a response to their own context, and not the UK's. The UK has a different climate, different air-tightness levels, different constructions and, most importantly perhaps, different occupants. The latter is so important because when technologies are developed for a local context than that local context is much better at dealing, maintaining and operating those technologies. For example, MVHR requires user operation on a daily basis to operate efficiently, and regular maintenance to sustain performance and healthy operation. In the UK there is little precedence or culture for interaction with ventilation systems, and there is no appreciation of the maintenance required by these systems as typically simple intermittent fans of passive stack have been used. The lack of awareness needs to be addressed as well as any technological shortfall in a property.

To address these AVASH has generated a new project IFoRe, a collaborative project between Pas-de-Calais Habitat in France and Amicus Horizon in the UK which intends to retro-fit 100 social houses in each country and to investigate aspects of occupant interaction, education and training that can result from the integration of eco-technologies into buildings.

Appendix

The following appendix details the different insulation, air-tightness and ventilation upgrade options that have been investigated for the AVASH project. Each upgrade strategy is given a brief description, where it utilisation is appropriate and pros and cons of its use. Each upgrade strategy is designated a reference number as given in the solution matrix tables at the end of each country's assessment section. A table of costs for these different strategies is also provided at the end.

Insulation

1. Ceiling level (loft) insulation

This is a relatively easy way to improve insulation above a heated space, as the attic space, if present, is usually accessible. The final thickness of the insulation should be at least 200mm to give a U-value 0.19 W/m²K. Ideally, a thickness 400mm should be achieved, to reach Passivhaus standard.
Usually mineral or glass fibre insulation is used, either in rolls or blown form. It is appropriate and sometimes necessary to install a wind barrier (breathable membrane) on the top of the insulation, to avoid possible thermal looping and removal of heat by moving air. OSB or chipboards can be used alternatively.
Additional counter battens should be used to eliminate thermal bridging, and to achieve required thickness of insulation.

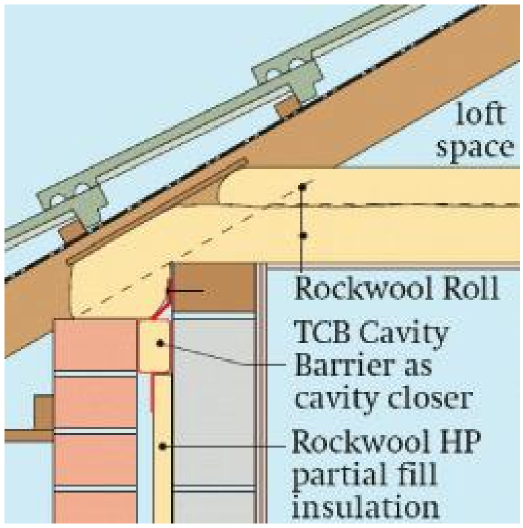
Cost: £300 (€400). Payback: 2-3 years

Advantages: accessible space, relatively easy installation, solving thermal bridging as well.

Disadvantages: difficult to deal with attic perimeter detail. It could be necessary to dismantle piece of roof to bring the insulation inside and provide sufficient ventilation during works. Requires a loft space to be implementable.

Suitability: for all dwellings with a loft space that has low or poorly installed insulation.

Manufacturers/Certified systems: Moy-Plus Isover –ISOVER ST GOBAIN, Rockwool ROCKPRIME (blown loft insulation), and other soft roll insulation, products from Rockwool, Isover etc.



2. Cavity wall insulation

This is suitable only for structures with cavities (especially for traditional UK and Irish brick and block cavity wall construction). The insulation material is injected into the cavity under pressure and fills the entire cavity. Different materials can be used e.g. EPS beads, mineral fibre, cellulose fibres made from recycled paper etc. The mass may contain glues to allow the insulation to become rigid in the cavity and to render the insulation resistant to moisture.
This technique requires drilling holes in the wall in order to blow the insulation into the space.

Cost: £50 + £3.50*m² (€12*m²). Payback: 2 - 4 years

Advantages: There is no need to alter or refurbish the internal or external façade and thermal bridging at partition walls junctions is solved. Fully filled cavities also help to greatly improve the air-tightness of a dwelling. Relatively clean installation, with no need for inside works.

Disadvantages: U-value achieved is limited by the thickness of cavity, typically at 100mm cavity (minimum u-value is in the order of 0.35W/m²K). Thermal bridging around openings is not resolved. The holes for injection are visible and need to be made good. This requires special equipment and skills.

Suitability: For all cavity walls including those with partial fill insulation

Manufacturers/Certified systems: Rockwool Energy Saver (blow-in granulate insulation).

Glued EPS beads

Insulation injection

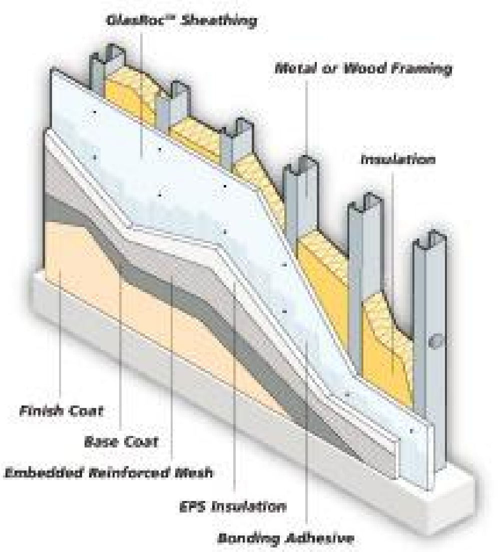
3. External insulation and thermal bridging

This is the most common technique used in central Europe and probably the most effective. A rigid insulation is glued and/or mechanically fixed to the exterior of the wall.
The most common materials are boards of EPS or hardened mineral / glass fibreboards. Protective plaster is applied to the exterior of the insulation; this consists of a reinforcing mesh and plaster. Depending on the type of insulation used the plaster may need to be breathable. The insulation used depends on the wall construction and is subject to specialist's assessment of coupled heat and moisture transition and any requirements for fire resistance.
Very low U-values can be achieved, depending on the thickness of the applied boards. Thermal bridging at wall junctions and around openings is effectively solved.
In some cases soft glass or mineral fibreboards are installed between battens/rails and rainscreen is mounted to the exterior, providing a ventilated cavity for moisture removal. The U-value achievable is affected by battens, though moisture transition can be much improved.

Advantages: Very low U-values can be achieved, thermal mass of interior is not reduced, thermal bridging effectively eliminated – along with the risk of condensation and mould growth.
Airtightness is usually increased.
Internal living space is not affected.

Disadvantages: Changes the facade and overall look of the building. For multiple properties with the same facade all owners would have to agree to the upgrade. Relatively expensive.

Suitability: For most dwellings, especially for those with solid wall construction unless conservation factors prevents the changing of the external facade.



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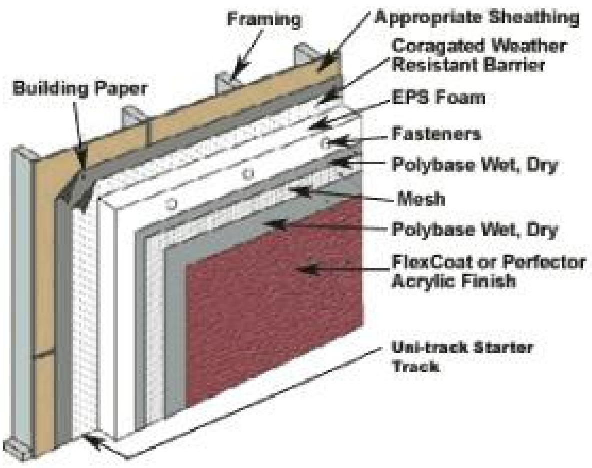
Exterior Insulation and Finish Systems (EIFS) Applications



Manufacturers/Certified systems: Rockwool RAINSCREEN DUO-SLAB, Rockwool ROCKSHIELD (triple function – weather protection, insulation, aesthetic). UK based suppliers can be found at: http://www.ribaproductselector.com/DirectoryBrowseSubjectBuilding.aspx?ac=&sid=000%20410%20007

4. Internal insulation

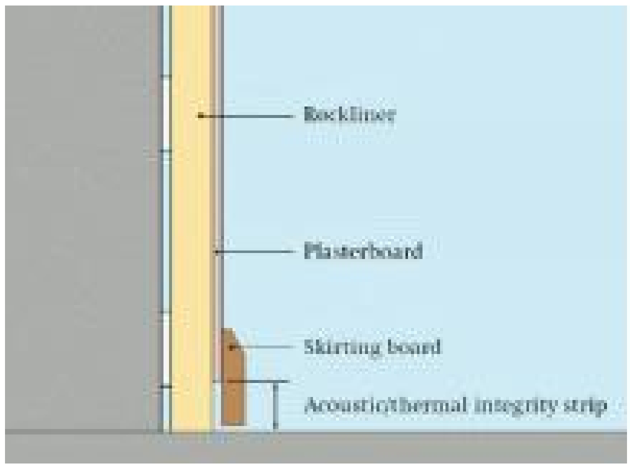
This method uses a variety of available materials, depending on client's or contractors preference. Usually insulation is installed between battens and screwed to the interior of a wall and internal plasterboard is fixed to the battens. Counter battens can be used, to lower thermal bridging.
Other systems use rigid insulation attached to plasterboard; units are fixed directly to the wall. Joints are taped and skimmed.
Cost: £42/m2 (€50/m2). Payback: 6-12 years

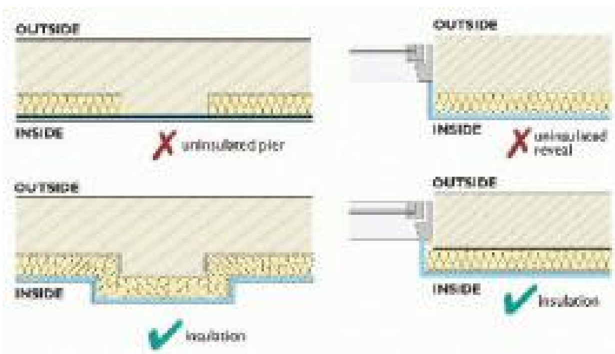
Advantages: Simple installation in most cases, and can be applied to individual apartments. Can be applied in conservation areas and to some listed buildings.

Disadvantages: Internal and disruptive installation. The U-value improvement is limited due to the relatively small thickness of insulation. The system reduces room areas, which could be significant in small dwellings. Thermal bridging remains a problem and the risk of condensation and mould growth is not significantly improved. Wall fittings may have to be changed.

Suitability: For individual apartments, where other systems could not be applied.

Manufacturers/Certified systems:Rockwool ROCKLINER (acoustic and thermal composite dry lining system), Spacetherm F - K10 NBS, Spacetherm P - K10 NBS





5. Floor insulation

If the floor is poorly insulated then additional insulation can be installed. As there are limitations to thickness that can be applied, the most common solution consist of layer of a rigid insulation and a hard top flooring layer.
Occasionally, if there is enough space, the insulation is laid down between the battens and flooring is fixed to the battens.
Other solution comprises of tongue-and-groove chipboard with ridgid insulation attached. It is laid down and glued together. Reguires flooring or carpet installation.

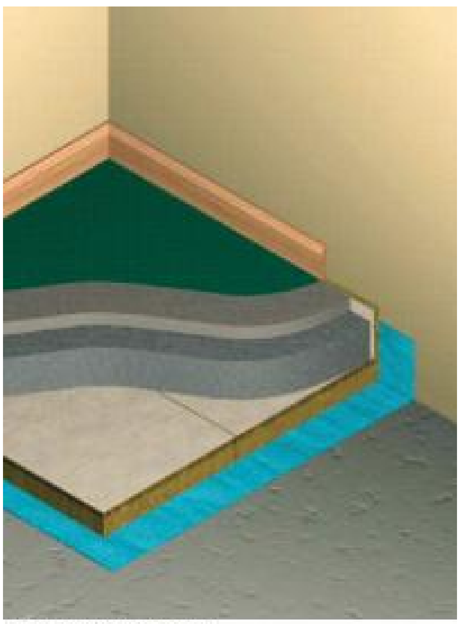
Cost: £12/m2 (€22/m2). Payback: 15 - 20 years

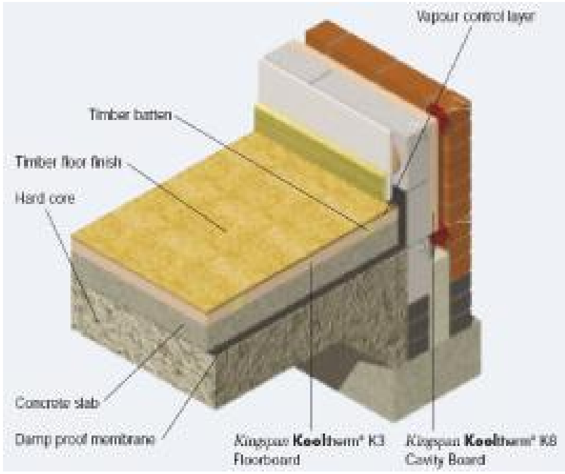
Advantages: There is no need to remove old layers unless otherwise required.

Disadvantages: The U-value improvement is limited, thermal bridging at junction of the floor and external wall is not solved – so the risk of condensation and mould growth remains. The finished floor level is raised, and the effect this has on doorways, skirting boards and stairwells has to be considered.

Suitability: For dwellings with flat and poorly insulated floors.

Manufacturers/Certified systems: Rockwool ROCKFLOOR, Kingspan Kooltherm K3 floorboard





6. Eliminating thermal bridging

Can be done to avoid condensation (mould growth) and reduce thermal bridging. Most appropriate when replacing existing windows and doors. Additional insulation and plasterboard is mounted on the side of openings (jambs and head) to eliminate thermal bridges. The "moulding" shape is created around the opening. The old plasterboard (or other layers) can be removed for better performance and possible improvement in the sealing of the window frame. Wall sockets can also be removed and extra insulation installed.

Cost: £100/(window/door) when done during replacement work.

Advantages: Simple installation, targeted locally at the relevant windows

Disadvantages: Overall thermal performance of the dwelling is not greatly improved.

Suitability: For dwellings with significant mould growth around openings.

Manufacturers/Certified systems: N/A

7. Window replacement

Old windows are replaced and usually the jamb and sill are upgraded to eliminate thermal bridging and the risk of condensation at the same time.

New units should be certified for the thermal bridging of the frame and for overall U-value. Double glazing with a low E coating should be a minimum requirement. Triple glazed units with thermally broken frame are available to comply with the passivhouse standard (U-value=0.8-0.9 W/m²K). Alternatively, cheaper supply air windows can be used having a dynamic U-value as low as 0.7 W/m²K (an air-tight property and an air extract system, e.g. passive stacks, is required to be installed/present for these to be effective). In listed buildings secondary glazing may be the only option for improved ait-tightness and insulation.

Certified windows are airtight compared to old ones, having more efficient and multi weather-stripping and all-perimeter locking mechanisms. Materials used during installation provide airtight solutions as well, therefore infiltration is significantly reduced.

Installation is done from the interior and takes approximately 1-2 days for an average apartment.

Cost: £300/€400 (standard) - £400/€500 (Dwell-vent window)

Advantages: Eliminates a large portion of the thermal loss through transparent elements. Minimises air leakage and therefore eliminates infiltration loss. Solves thermal bridging and reduces or possibly avoids condensation at and around window.
Improved security and fire protection.
Reduction in noise from outside.

Disadvantages: Installation work is done from the inside and can be disruptive in cases of refurbishment. Initial costs. May not be possible if the building is in a conservation area or is listed.

Suitability: For dwellings with old, single glazed, metal or very leaky windows, that can have their external appearance changed.

Manufacturers/Certified systems: Dwell-Vent (supply air windows), NorDan Vinduer, DANSK Window system, Carlson and Howarths Windows & Doors.new ones. Usually the jamb and sill are upgraded to eliminate thermal bridging and the risk of condensation at the same time.

Air-tightness

8. Check and set (repair) window hinges and lock mechanism

Relatively simple technique to reduce air leakage through window. In majority of the cases certain distance between window frame and the sash could be noticed. It is required to adjust the hinges and probably the lock mechanism as well – this could be quite individual and depends on type of hardware used. Usually simple tools are satisfactory (Phillips screw driver, hexagonal keys, wrench). Some of the parts might require to be changed.

Cost: £20/€25 per window.

Advantages: Simple, no cost measure if done by occupants, very effective

Disadvantages: Can become complicated when special tools are needed

Suitability: Potentially for all dwellings with some level of window air-leakage.

Manufacturers/Certified systems: N/A

9. Check and repair (install) proper weather-stripping

A frequent problem with older windows is little or no weather-stripping, which results in excessive air leakage.
After the hinges and lock mechanism are adjusted, the remaining space between sash and frame has to be assessed and appropriate weather-stripping should be selected. Existing strips (if any) do not usually have to be removed. The area where the new weather-stripping is to be applied has to be cleaned of dust and dirt.
New self adhesive strips are applied, to the sash typically.
The function of the lock mechanism has to be verified and sometimes adjusted to compress the strips.
There is wide range of weather-stripping available (in hardware stores). The most appropriate are silicone based “D” shaped self-adhesive tubes, which could be easily compressed from 6mm to 0.7mm. Others could be made of softened rubber of different shapes (hollow shaped are the best option) and function.

Hard rubber or flat strips are not suitable as they can not be compressed.
If improvement to a door with no threshold is required, special profiles, screwed into the door, can be used (rubber + metal)

Cost: £20/€25 per window.

Advantages: Easy to install, low cost, very effective.

Disadvantages: Difficult to deploy effectively with sash windows.

Suitability: For all older windows and doors.

Manufacturers/Certified systems: Multiple.

10. Seal cracks around windows and other facade components (inside, outside)

In many cases cracks were observed around windows, at joints between the window frame and plasterboard (plaster) and between sill board and plasterboard, causing additional air leakage. A common way to seal these and other cracks is by the use of Acrylic sealant, which remains plastic after hardening, and is possible to be painted over. It is applied by caulk gun into the crack directly with the method recommended by the manufacturer.
In some cases Silicone (elastic after hardening) or Silicone-Acrylic (solid hard after hardening) sealants are used, when required.
Aimilar procedure can be applied to external cracks as well. The selected material has to be weather resistant. Silicone is mostly used in these cases.

Cost: £10/€25 per window.

Advantages: Simple, low cost, effective. Improving the internal space visually as well.

Disadvantages: None

Suitability: For all older windows and doors.

Manufacturers/Certified systems: Multiple. Sealants a commodity product.

11. Refurbishment of loft hatch (weatherstripping, lock mechanism, additional insulation)

If a loft is freely ventilated then a loft hatch effectively separates the interior environment from the external in a similar way to a window or door, and insulation should therefore be considered here as well. Often though the loft hatch is not insulated and has no weather-stripping either.
Any improvement delivered varies, and is highly dependent on the individual situation.
However, in most cases boards of EPS cut to appropriate size could be glued to the loft hatch to provide thermal insulation. Highly compressive weather-stripping (silicone rubber based, or soft rubber) should be applied to the hatch.

In order to keep the strips compressed the lock

mechanism should be adjusted, or installed if not present.
Hatch opening can be completely refurbished using manufactured folding loft ladders (insulated) as well. These systems are usually provided by roof window manufacturers, and their procedure should be followed during installation.

Cost: £50/€80 for hatch insulation and weather stripping.

Advantages: Simple and effective measure, only simple tools are needed.

Disadvantages: Initial costs and fitting into opening if using manufactured replacement.

Suitability: For all loft hatches with poor insulation.

Manufacturers/Certified systems: LTK Thermo (Fakro), LWS Smart (Fakro), Dolle Extra (Dachstar), Dolle Termo+ (Dachstar)

12. Check and seal openings around service pipes and wires.

All openings around service pipes should be sealed, especially those that link the internal space to the external environment.
The most common technique is to use silicone, if the space is small. Expandable Polyurethane foam is more appropriate for bigger spaces.
Sometimes the openings are not easily accessible, the main part of work is gain access to perform sealing.

Cost: £50/€50

Advantages: Simple effective option

Disadvantages: Might become too complicated if the pipes run in unaccessible service space
Suitability: Any property without well sealed service entries/exits.

Manufacturers/Certified systems: N/A

13. Seal space behind plasterboard (at skirting level)

Usually internal plasterboard is not touching the concrete ground floor or wooden flooring on higher floors (1st, 2nd…) and a 2-5 cm gap can occur behind the skirting board.
This can have a neagitive influence on air-tightness because it creates a connection between the space behind the plasterboard, ceiling space and other service spaces (at ground floor and other higher floors).
The stack effect multiplies the potential infiltration, which can be ulitimately observed through all openings in the plasterboard (outlets, lights, etc)
It is appropriate to dismantle the skirting board and seal the space between the wall and plasterboard, via the gap, – this will break the connection between the spaces.
Alternative solution is to drill frequent appropriate holes into plasterboard, just above the skirting board. The foam is then applied through the holes into the space behind plasterboard, to form continuous barrier on skirting board level. This requires experience how much foam should be applied, as expanding foam is fairly strong and can damage the plasterboard by pushing it inwards.
Expandable polyurethane foam is usually used.

Cost: £200/€300 per house.

Advantages: Greatly lowered infiltration at this point.

Disadvantages: The skirting board can not be dismantled in many cases, as it was installed prior to the final layers of the floor. Cost of the material.

Suitability: For leaky houses with evident leakage from behind plasterboard.

Manufacturers/Certified systems: Multiple. Sealants a commodity product.

14. Refurbishment of electrical outlets (to passivhouse standard)

Existing outlets are replaced by those complying with the passivhouse standard (the outlets are airtight, with having rubber seal around wires).

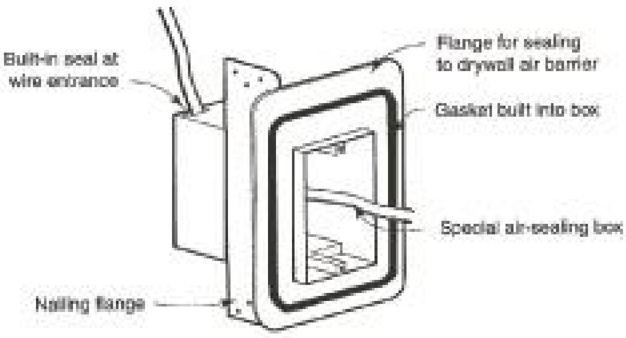
Cost: £10/€15 per socket.

Advantages: Lowered air infiltration at these points.

Disadvantages: Initial cost, work must be performed by a specialist electrician. Change in overall building air-tightness unlikely to be large.

Suitability: For properties where infiltration through outlets is noticeable.

Manufacturers/Certified systems: LESSCO® Low Energy Systems Supply Company, Inc.; AIRFOIL, INC; KAISER 9263-21 ECON 63 and other Kaiser products; Legrang; Honeywell;



15. Dismantle old permanent vents-check; block them to be airtight (rigid insulation+PU foam)

Note: only applies to vents not required for desired ventilation strategy.

Vents should be blocked properly, not simply covered on the outside and inside.
The technique depends on the construction of the wall, but generally the best results are achieved when using pieces of rigid insulation filled around with expandable polyurethane foam.
Cavity walls with partial fill insulation can be more difficult if the openings in each layer are not in the same position or of the same size. In this case blocking the inner leaf and insulation layer is the most important. If there is plastic pipe through entire construction, block the pipe and make sure the opening around pipe is sealed, especially at insulation and inner leaf layer (alternatively remove the pipe and use method described above).
Grilles can be remounted to avoid painting the patched holes.

Cost: £30/€40 per vent.

Advantages: Simple technique for eliminating air infiltration.

Disadvantages: If the ventilation scheme for the property is changed vents may need to be re-opened.

Suitability: For all obseleted permanent vents

Manufacturers/Certified systems: -

16. Check and seal joints between new and old structure (if possible)

If the dwelling contains any additions (extensions) or has been refurbished, there is a risk of cracks between the old and newer structures.
If the cracks are visible or accessible, it is appropriate to seal them to limit air leakage.
The most common sealant used in this case is acrylic, which remains plastic after hardening and can be painted over and is appropriate interior use. It is applied by caulk gun directly into the crack according to the manufacturers instructions.
For the exterior silicone (elastic after hardening) sealants are used as they are weather resistant.
If the cracks are bigger, it is suitable to fill them with expandable polyurethane foam and cover with mortar/plaster

Cost: Highly variable. £150/€200 may be typical.

Advantages: Simple, effective

Disadvantages: Difficult to investigate possible cracks if dry-lining is installed

Suitability: For all structures with cracks

Manufacturers/Certified systems: -

17. Windows replacement

- described in the section "Insulation " above as option 7.

Ventilation

18. Installation of extract fans where there are none and only a permanent or trickle vent is present in wet rooms

Note: this is irrelevant if passive stacks or MVHR is installed

Unless there is engineered ventilation installed (MVHR, SAWs + passive stacks, controlled ventilation) in the dwelling, it is appropriate to have extract fans in order to remove moisture from the dwelling from the point where it is generated (wet rooms, kitchen)
This is especially important if there is problem with water condensation on poorly insulated thermal bridges and windows, as there is increased risk of mould growth in such places – often causing occupants to over-ventilate the space to remove the mould.
Having only permanent or trickle vents in these rooms is unsatisfactory, as there is no control over the air flow, being dependent mostly on wind speed and direction. As a result the air can often flow into the wet room, picking up moisture and redistributing it into the dwelling, causing dampness.
The extract fan can be installed into the window, refurbished opening for previous permanent vent, or into the wall. Ducting is sometimes necessary.
It is important the extract fan has damper and at least a 5 min. "overrun" time.
Some may be set to maintain certain levels of humidity (with humidistat)

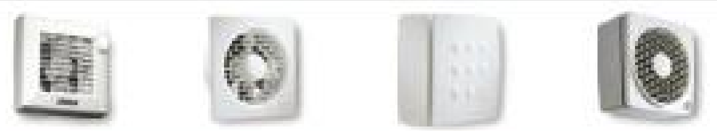
Cost: £700/€1000. Cheaper if existing wiring can be utilised.

Advantages: Removes dampness and odours from the dwelling, lowers possible condensation and risk of mould growth. Stops the air flowing in the opposite direction (damper needs to be installed). Can be retro-fitted to most properties.

Disadvantages: Extracts and ducting needs to be installed, cost of installation.

Suitability: For all wet rooms with no bespoke extraction system.

Manufacturers/Certified systems: Vortice, Xpelair, Multiwing SA.



19. Sealing of chimney flues

The idea behind this is to eliminate excessive infiltration caused by the stack effect of the open fireplace's flue. This also increases the efficiency of combustion from as low as 25% to 95%, because sealed-combustion direct vent stoves/fireplaces are by far the most energy efficient option. (Note: sufficient ventilation strategy has to be provided in order to satisfy occupant's fresh air needs). The replacement is connected to the existing flue and sealed.
There is wide range of products for replacing open fireplaces: - fireplace inserts, stoves, Russian stoves.
They can be divided into categories, depending on fuel:
- combi fuel (wood, coal, peat), wood burning, natural gas.
There are also more options regarding how to supply the air for combustion. It can use internal air (the most frequent option), or air can be brought from outside by separate duct in floor or around existing flue (balanced flue fires)

Some of the stoves/fireplaces can be connected to ducting for hot air distribution, some are designed to accumulate heat and release it overnight.

A cheap option fills the flue end with an inflatable bag (known as a chimney baloon or pillow) to stop infiltration. The insert is made of flexi tri-laminate special hi-tech material and can be easily removed and reinstalled. In case of accidental heat in the flue it shrivels and deflates.

Another option is the retrofitting of a chimney damper installed on the top of the chimney. The damper (works as cap as well) is controlled manually by chain from the inside. Easily installed, the cap protects the chimney from rain etc.

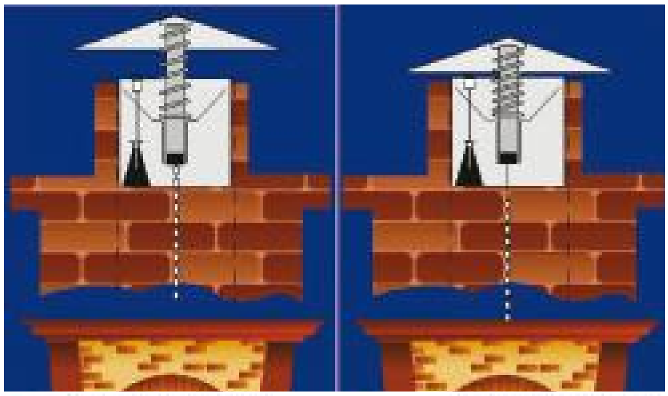
Cost: £25/€35 for inflatable bag, £1000/€1400 for damper installation.

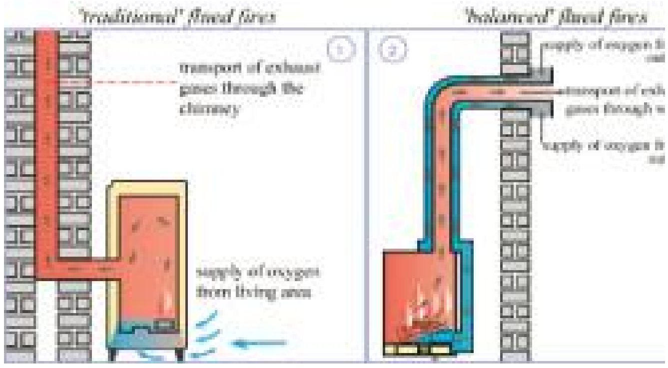
Advantages: increased combustion efficiency from 25% to 95%. Avoiding cold draughts caused by flue's stack effect. Reducing unnecessary thermal loss by infiltration. The replacement can be installed in an existing open fireplace and can use the existing flue – no additional space needed.
Easy installation of chimney balloon.

Disadvantages: If the open fireplace was necessary for ventilation, other strategy has to be proved to satisfy building regulations.

Suitability: For all dwellings having open fireplaces or open flues.

Manufacturers/Certified systems: Retrofitting stoves: The Stove People, Murphy Heating, Fenton Fires, Scandinavian Homes, Heatmaster, Murphy Heating, Ideal Standards Ireland, Midwest FSG, Hearth & Home, TheGasCompany
Chimney balloon: Chimney Balloon ltd.,
The upper damper: Chimney Closure Ltd, Ireland





20. Installation of passive stacks instead of mechanical extracts

Note: only if the ventilation strategy is designed as a whole house extract ventilation.

The concept is to replace existing extract fans by passive stacks which use stack effect and wind pressures to ventilate the house, therefore saving electricity.
There have to be designed openings for air intake into the habitable rooms (permanent or trickle vents).
The installation involves running plastic pipes 100-150mm in diameter from wet rooms to above the roof, where an optional wind cowl is attached to exterior side of the pipe to maximise the flows. A grill is usually at the inlet to the passive stack.
The use can be limited for apartment blocks, as service space in above apartments might be not as big to accommodate the stacks and the apartments on the highest floor might not provide sufficient the height of stack required.

Cost: £1000/€1400 depending on floor structure.

Advantages: Saving electric energy otherwise

needed for running the extract fans, no other work on vents or interior. No maintenance Silent operation.

Disadvantages: Initial costs, work done from interior, generally long payback period. No boost option for wet rooms. Varaible performance.

Suitability: For dwellings with whole house extract ventilation strategy, mainly houses

Manufacturers/Certified systems: Ubbink, Passivent.

21. Installation of self-controlled vents (Dwell-Vent, Lunos) + passive stacks

Note: this is irrelevant if MVHR or SAWs are installed,

This option is a simplified version of following option “upgrading of windows to SAW's”, but windows are not replaced, and the dwelling is required to have at least double glazed low-E units already installed.
Air is supplied through self controlled vents and exhausted above the roof to the exterior. Requires an undercut on internal doors of app. 2cm.
The most appropriate situation to apply this method is when there are permanent vents with no flow regulation and the property has the potential to have a whole house extraction system installed.
The vents may be glazed in or mounted in the frame of the window - requires to have enough space to mortise appropriate hole and to mount the vent (Dwell-Vent system).
Other systems (LUNOS) requires a hole/refurbished existing vent, or vent to be installed while building a wall. These vents are bigger and usually include different filters to improve quality of incoming air. These units can be mounted on side of window with inlet in jamb to visually hide the grilles; there is usually 4-way diffuser from interior side. This (LUNOS) system requires using mechanical extract fans to guarantee the ventilation.

Cost: £1500/€1750 depending on floor construction

Advantages: Engineered balanced ventilation. Low cost of passive stacks (plastic pipes), no additional energy (electricity) needed during entire operation, no maintenance. Silent during operation. Usually simple installation of vents.

Disadvantages: Necessity to install passive stacks, possible problems to accommodate vertical ducting. System has to be specified by specialist. Some systems might require extract fans and electricity used may outweigh the benefits provided.

Suitability: For dwellings with recently replaced windows, but delivering variable ventilation based on permanent vents and open fireplaces (fireplace can be replaced by stove – see the “refurbishment of open fireplace to stove” option)
Manufacturers/Certified systems: Dwell Vent system, Lunos ALD series (Lunos GmbH)

22. Upgrading of windows to SAW's (requires passive stacks and special vents installation)

Ideally Supply Air Windows should be installed only together with special self-regulating ventilators and passive stacks, to maximise the system’s benefits. Building air-tightness should also be very good.

The system is engineered and provides windows with U-values as low as 0.7 W/m²K.

The Supply Air Windows are double glazed windows pre-heated. The self controlled vents are mounted on the window. Air slowly passes through the habitable room and then collected in the wet rooms by the passive stack inlets and exhausted via the cowl on the roof.

The measure requires old windows to be replaced by SAWs, all interior doors to be undercut at app.20mm for free air flow and installation of passive stacks. (Refer to "windows replacement" and "installation of passive stacks" options). It also requires designing by specialist, so sufficient amount of fresh air is guaranteed in all rooms.

Cost: £4000/€6300

Advantages: significantly reduced heat loss through windows. Engineered balanced ventilation. Thermal bridging at openings usually solved during refurbishment.
Low cost of windows (only app. 15% more than similar apecification double glazed units); low cost of passive stacks (plastic pipes).
No additional energy (electricity) needed during entire operation, no maintenance. Silent during operation.
System will last the life of building.
Low initial costs when considered at design stage.

Disadvantages: Installation work is done from the inside and can be disruptive (during refurbishment).
Possible problems to accommodate vertical ducting, and applicability limited to buildings where PSV installation and good air-tightness can be achieved.
System has to be designed by a specialist.

Suitability: Almost for all dwellings where windows are poor, PSV can be installed and good fabric airtightness is achievable.

Manufacturers/Certified systems: Dwell Vent system.

23. Installation of controlled ventilation system (INNOVENTUS etc)

Controlled ventilation systems utilize small units installed in rooms, which are pushing fresh air into the internal space. The exhaust air is then collected at extract/passive stacks inlets, commonly in wet rooms, and then blown into the exterior.
The actuating units can be mounted behind radiators so the incoming air is heated and cold draughts are avoided.
Units can be operated by independent control, based on temperature, occupancy, humidity, CO_2 etc, depending on specific system. They would include low-speed and low-noise fan with optional filters for cleaner air (against pollen, dust etc)
The system requires exhaust, usually satisfied by extract fans or passive stacks.
Extract fans can provide additional boost in case of using the wet room, they can not have dampers. The fans have to run all the time, or their control has to be connected to the actuating units – this is fairly sensitive and requires special design skills. In addition, the extract fans use electricity.
Passive stacks do not have boost option, but are much simpler. In addition they create stack effect, therefore helping actuating units to run on lower speeds and consuming less electricity, while maintaining sufficient air flow.
The installation on system varies and depends on particular manufacturer. Generally, new inlet opening are created, radiators might be refurbished, actuating units are installed, doors undercut. Existing extract system can be utilised and upgraded, or passive stacks could be applied (see previous chapters).

Design and installation has to be done by specialists, actuating units have to be wired to power and control.

Costs: £2000/€2500

Advantages: installed in individual rooms, therefore individual independent control is provided (based on humidity, CO_2 level, etc). Cold draughts avoided. Low electricity consumption when combined with passive stacks. Silent fans, noise barrier between the interior and exterior. Relatively simple installation of actuating units (no ductwork needed). Possibility of using existing extract system.

Disadvantages: High electricity consumption when combined with extract fans. Initial costs of advanced sophisticated systems. Problems to accommodate vertical ducting for passive stacks, if applied

Suitability: for all dwellings where SAWs+passive stacks, or MVHR is not suitable.

24. Installation of MVHR (different systems).

A properly specified, designed and installed system contributes to a higher overall energy efficiency of the dwelling. Permanent vents in walls and trickle vents in windows are not required and must be blocked.

Installation includes mounting duct work, control panel/panels, the MVHR unit and inlet and extract grilles. The work is done from the inside and it may be difficult to accommodate the ducts. The system is ideally suited to single story bungalows, where the unit and ducting can be run directly into the attic, not affecting the upstairs living space.

Operation can be set depending on time, humidity, temperature etc, advanced control panels are common accessories to the system, as well as selective filters for different types of dust or allergen.

Design and installation has to be done by specialists.

Costs: Upto £3500/€4500 for complete system and retro-fit installation.

Advantages: Effectiveness of heat recovery up to 95%, eliminating most of the buildings heat loss associated with ventilation.

Disadvantages: Electricity required for running the fans with associated costs and carbon emissions can outweigh the benefits, espeically in relatively mild weather. The initial cost of installation, running costs, ongoing maintenance liability (changing filters every 6 months, cleaning heat exchanger every 12 months). Danger of bacteria growth in poorly designed and installed systems, potential noise issues.

Suitability: For dwellings where Supply Air Windows and Passive Stacks would not work, or would be too difficult to install.

25. Room based heat recovery fans.

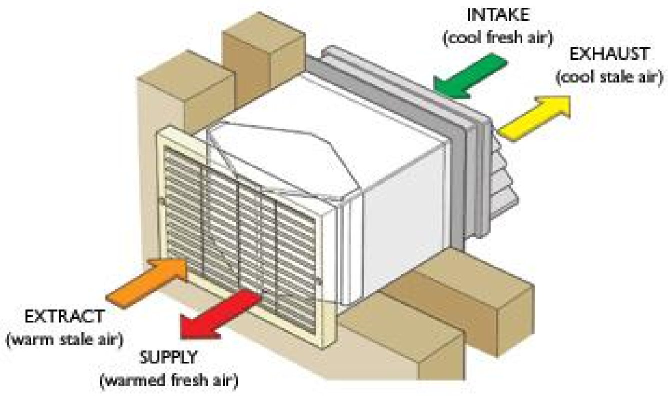
Similar to extract fans but act as supply as well pre-heating the incoming air with the outgoing.As they are balanced they only effectively ventilate the room in which they are housed and are not in general considered as part of a whole house ventilations system.
The fans usually run constantly and should ideally be designed to deliver the correct ventilation rate for the context in which they are placed to achieve the requisite building ventilation rate.

Costs: £250/€400 plus installation (cheaper if replacing existing mechaised vent)

Advantages: Easy to retrofit, heat recovery up to 70%, humidity sensing.

Disadvantages: Electrical power required, constantly running even when not required, consultant needed for correct specification, existing or new hole required in wall.

Manufacturers: Vent-axia



26. Continous central mechanical extract

Continous central mechanical extract removes air from wet rooms and lets the facade (trickle ventilators, walled in vents, leakage) supply the incoming fresh air. Central plant is usually installed in the loft or possibly storagr space of a property. Ducting normally therefore has to run through rooms to reach a downstairs kitchen, and this can make them difficult to retrofit.
Although it is a system more commonly seen in blocks of flats, they are now sometimes installed in individual houses.

Costs: £300/€400 for the unit. Installation depends on floor construction.

Advantages: Can have very low energy consuming fans, controllable, no supply side ducting and extracts reliable rates of air.

Disadvantages: Electricity required for running the fans with associated costs and carbon emissions, the initial cost of installation especially in a retro-fit scenario, ongoing maintenance liability, potential noise issues, no heat recovery, potentially unevenly distributed air supply.

Suitability: New build flats are the most suitable premise for this type of system.

Manufacturers: Hardware, Vent-Axia.

27. Exhaust Ventilation with Heat Recovery.

The ventilation heat loss in a mechanical exhaust air system can be recovered by installing a heat pump (see figure). The system is applicable for existing blocks of flats with exhaust air ventilation as the system doesn't require big changes in the building construction for additional air ducts.
The system consists of a heat pump that transfers heat from the exhaust air to a domestic hot water storage tank in the basement. If the heat pump is installed in the basement close to the storage tank the heat loss from piping is negligible. The energy needs for domestic hot water can be covered by the system and a traditional domestic hot water supply is not needed. The system can be combined with a solar heating system as the circulation pipes and the storage tank will be the same. If the system produces more energy that is needed for hot water the additional heat can be transferred to the space heating network. The system will reduce the heat losses from the internal distribution network and these losses comprise up to 30 % of the total heat demand of a typical properties with central heating plant.

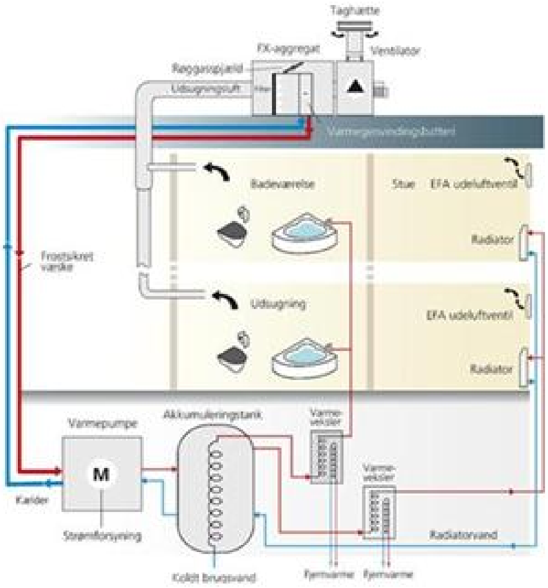
Costs: £8000/€1000 for unit. Installation will vary.

Advantages: Can be retro-fitted where there is existing mechanical air extract, does not require good air-tightness, heat recovery.

Disadvantages: Electricity required for running the heat pump with associated costs and carbon emissions, the initial cost of installation especially in a retro-fit scenario, ongoing maintenance liability, specialist installation.

Suitability: New build or existing blocks of flats could be suitable where consistent mechanical air extract is installed or being considered.

Manufacturers: Exhausto.



Principle diagram of exhaust air ventilation with heat pump.

28. User behaviour

For the succesful implemetation of active ventilation systems it is vital that occupants are aware of the system's operation and function.This is especially the case with mechanical systems with discrete user settings. Detailed instructions and explanations should therefore be provided to occupants on installation of the system, with follow up engagement, possibly corresponding to an existing maintenance programme.

Costs: Mainly personnel and creation of information resources.

Advantages: No material cost. Has benefits beyond the life of the system.

Disadvantages: Requires personnel time above and beyond installation contractors.

Suitability: Where active, user controlled ventilation systems are installed.