Assess the Energy Saving Potential of an Air Tightness Device for Hollow Core Concrete Slabs: Heat Loss and Cost Savings.

Client: Atlantic Air Testing

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Abstract

This project investigates a new type of energy saving component to prevent excess air flow from the cores of precast concrete slabs and a ventilated wall cavity. Such air exchange will lead to increased heat loss through the building envelope, increasing both building space heating costs and CO2 emissions. The product is designed by Atlantic Air, 101 Dunamore Road, Cookstown, Co. Tyrone, BT80 9PF. The system consists of an end cap of suitable material, such as plastic, which covers the end of the precast slab. A jointing material, such as airtightness tape, is provided to allow draft proof jointing at both sides of the slab to the interior wall.

1.0 Aim and Objectives

1.1 Project Aim

Assess the energy saving potential of the air tightness device in terms of heat loss and cost savings.

1.2 Research Objectives

1. Define the product construction details, materials and material parameters.

2. Quantify the heat loss performance of a cavity wall under differing environmental conditions using finite element software both before and after the installation of the product.

3. Estimate the cost savings of the product in a standard construction building.

2.0 Theoretical Background

Heat exchange between the inner and outer boundaries of a building occurs via a number of physics mechanisms: radiation, convection and conduction. These transfer mechanisms have been summarised in Figure 1. The mathematical relationship between these elements is generally well understood, although can become very complex in a large 3 dimensional model with multiple interactions on several planes.

To simplify the thermal design of construction elements BS EN 6946: 2007 simplifies the formula involved in calculating the heat loss through a building component, such as a wall assembly, to a 1 dimensional problem. This heat loss is known as the Thermal Transmittance, or U-Value, and is measured in W/(m_2K). For the BS EN 6946 calculation, entry and exit losses due to convection from the inner and outer surfaces are simplified to heat transfer coefficients expressed in m_2K/W. For the main solid elements of the construction such as masonry block, insulation etc. BS EN 6946 calculates heat flow via conduction only as this is the main parameter of heat transfer in solids. Importantly though for cavity boundaries an estimation of thermal resistance or air is given for idealised conditions. This is a simplified thermal resistance value which was calculated by the British Standards Institute for a number of different cavity wall scenarios. The resistance value given takes into account conductive, convective and radiative heat transfer mechanisms but is based on idealised air flow regimes within the cavity. In cases were cavity air flow is increased, the heat loss through the cavity will have a larger effect on heat loss through the wall assembly than is suggested by the British Standard method.

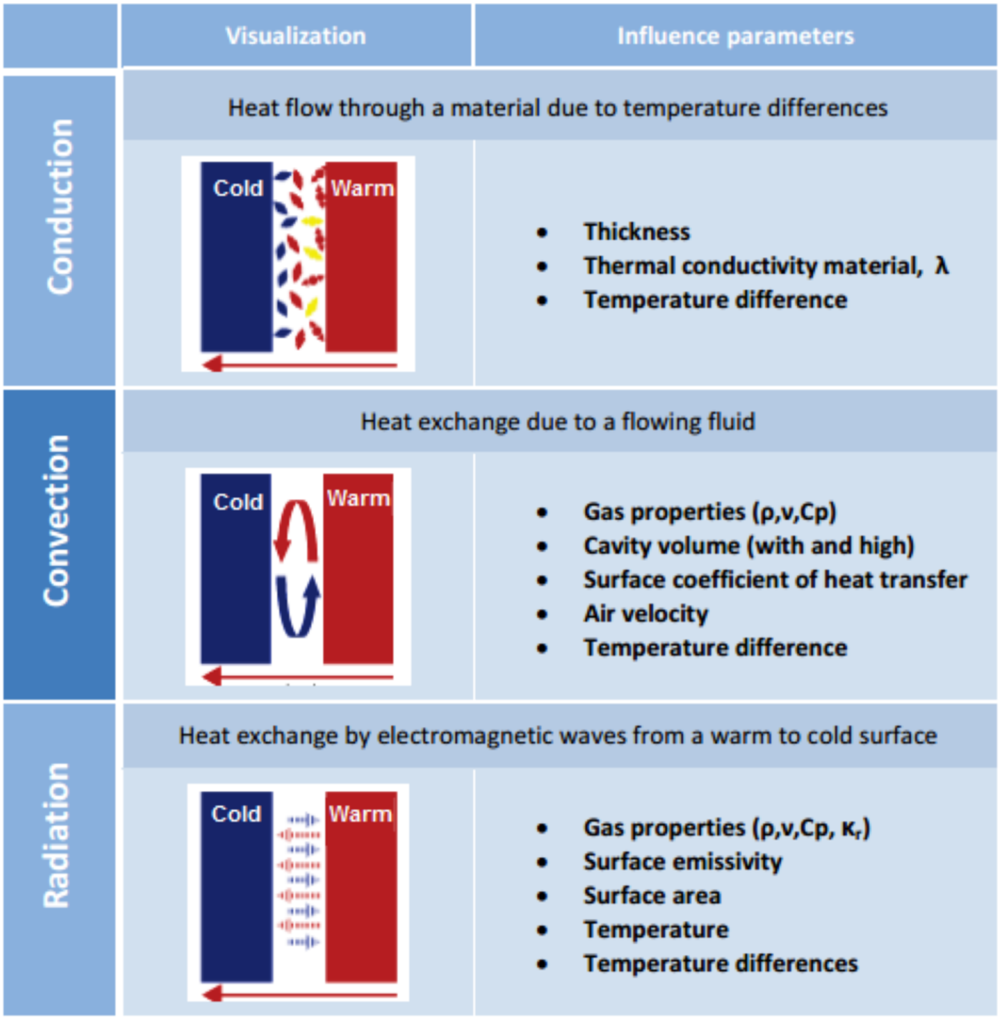


Figure 1: Heat Transfer Mechanisms

3.0 Model Development

The modelled design is based on the performance of a standard precast slab detail recommended by Accredited Construction Details for Building Regulations Part L (Conservation of fuel and power). The approved detail MCI-IF-01 entitled Masonry Cavity Wall Installation Concrete Intermediate Floor has been used throughout this report. The Accredited Construction Details document does not specify exactly how the Air Barrier Continuity should be achieved between the two floors, as can be seen by the dotted blue line in the document extract below. The product under investigation is proposed as a method of completing this junction detail. This document is available at http://www.planningportal.gov.uk/uploads/br/masonry_cavity_wall_insulation_illustrations.pdf

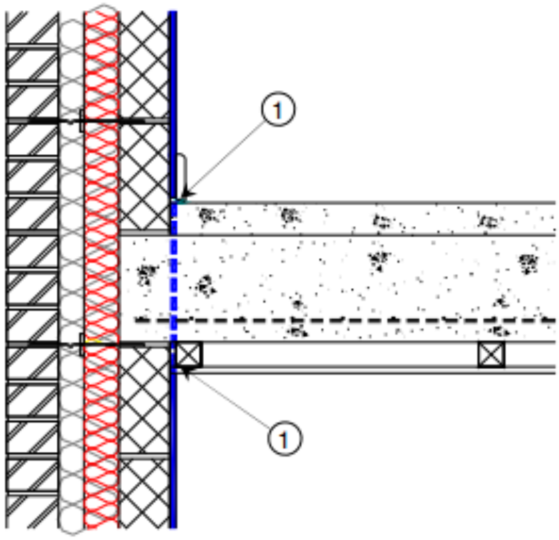


Figure 2: Accredited Construction Detail MCI-IF-01

The model was developed in graphical software using the finite element method to solve partial differential equations for the problem. The model combined the physical interaction of computational fluid dynamics and heat transfer meaning that all problems were solved considering particle air flow movement as well as convective, radiative and conductive heat transport mechanisms. This system allows the heat loss effect of the moving air in the cavity to be analysed.

3.1 Cavity Ventilation

As discussed previously, the air flow in the cavity will have a significant effect on the performance of the wall assembly; therefore the degree of ventilation within the cavity will have a significant effect on the airflow rate in the hollow core concrete slab. To allow accurate modelling of the system performance accurate estimations of cavity air flows are needed.

A number of standards make reference to the cavity ventilation design. British Standard BS 8215: 1991 (Code of practice for design and installation of damp-proof courses in masonry construction) and BS EN ISO 6946:2007 (Building components and building elements- Thermal resistance and thermal transmittance), detail methods for the design of cavity wall ventilation systems. BS 5250:2002 also specifies that the designers should take account of 5 sources of moisture when designing wall details. They are: weather, ground moisture surface condensation, interstitial condensation and construction water. To account for this vented air spacing's in a cavity should have air opens of 500mm2 per meter length of wall.

BS 493:1995+A1:2010 (Airbricks and gratings for ventilation) details the specifications for the inlet design. These design methodologies are based on the principle of mm^2 of unobstructed air space whether the design is a traditional brick hole design (either square or rectangular in Figure 3) or a Louvre design (Figure 3). This allows easy comparison of physical system sizes and their relative performance regardless of architectural detailing. For this reason this study will model the air flow inlets in the cavity as unobstructed free space only as it is assumed that the actual inlet design will have no effect on the air flow through it.

In line with these documents discussed $500mm^2$ of free ventilation space will be modelled at a spacing of 1.0m.

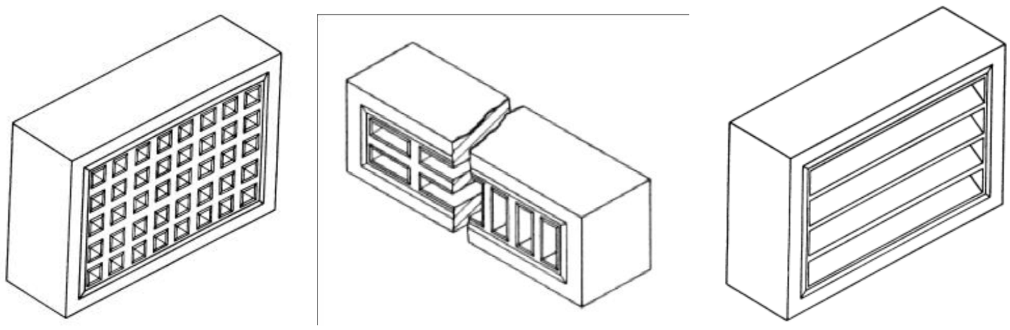
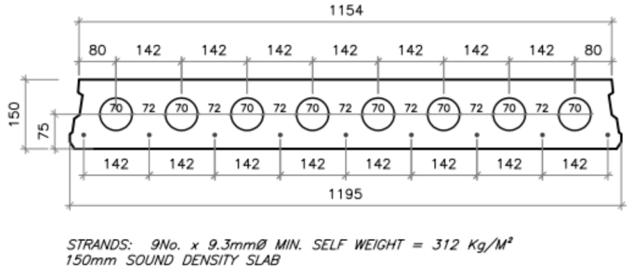


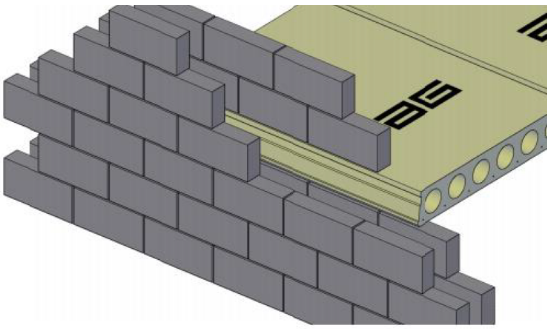
Figure 3: Cavity Ventilation Block Designs allowing 500mm2 of Free Airflow

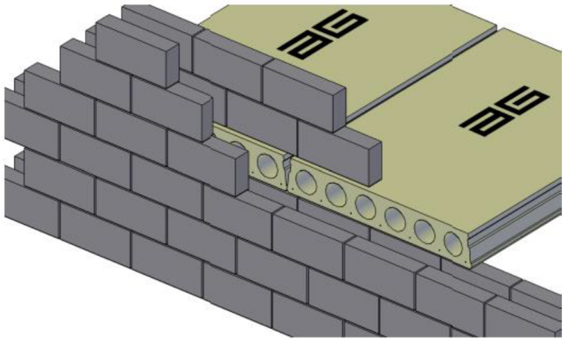
3.2 Sizing of Precast Concrete Slabs

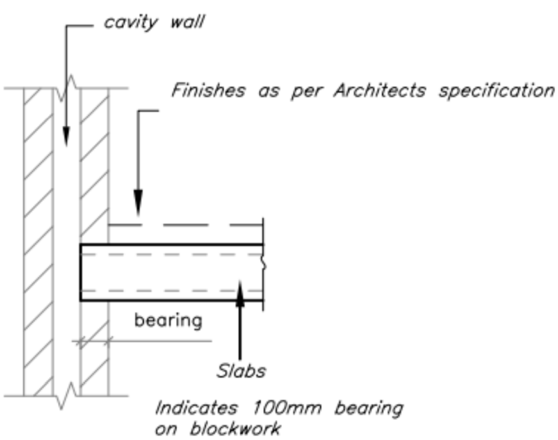
Various manufacturers sell precast concrete slabs for use in the domestic and commercial building sectors. Each manufacturer develops their own optimised design based on concrete specification, reinforcement and cross sectional design. These designs are then validated from testing and load span tables produced for use by specifies such as architects or engineers. A load span table along with dimensional specifications of a common brand of slab is given in Figure 4. For a domestic scenario the allowable live loads and spans which are achievable for the 150mm depth unit are adequate for the majority of domestic applications, therefore it will be used for the purposes of this work. The dimensional cross section in Figure 4 was used to construct the model. The recommended manufacturers loading arrangement was also used as this is in line with the approved construction detail MCI-IF-01 as discussed previously.

Overall structural depth mm	Self wt: kN/m²	Spans indicated below allow for characteristic service load (live load) plus self weight plus 1.5 kN/m² for finishes									
		Characteristic service loads kN/m²									
		0.75	1.5	2.0	2.5	3.0	4.0	5.0	7.5	10.0	15.0
		Effective span in metres									
150*	**2.4**	7.50	7.50	7.50	7.50	7.50	7.14	6.70	5.87	5.28	4.49
200	**3.0**	10.00	10.00	9.86	9.50	9.15	8.55	8.05	7.10	6.42	5.50
250	**3.3**	12.53	11.75	11.31	10.91	10.55	9.93	9.38	8.31	7.53	6.46
300	**4.0**	15.00	14.67	14.16	13.71	13.29	12.56	11.94	10.72	9.80	8.51
350	**4.4**	17.00	16.18	15.65	15.18	14.74	13.97	13.31	11.99	11.00	9.58
400	**4.8**	18.00	17.26	16.73	16.24	15.80	15.01	14.32	12.95	11.91	10.41
450	**5.3**	18.00	18.00	18.00	17.56	17.10	16.28	15.57	14.14	13.04	11.43

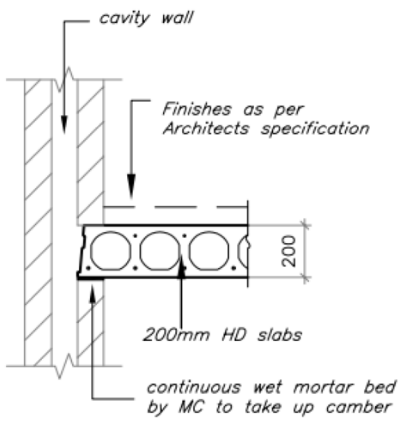








End bearing on block wall



Side bearing on block wall

Figure 4: Precast Concrete Slab Details from Acheson Glover

3.3 Estimating Natural Ventilation Rate within the Cavity

The rate of air flow through the cavity inlet will have a large effect on the model outcome therefore definition of an appropriate value, or range of values is critical to the designed modelling protocol. Due its wide range of engineering applications, such as moisture transport and heat loss, much research has been undertaken in this area. Most of this work has focused on calculating the most efficient aspect ratio (height to width ratio) for wall cavity design with 2 dimensional modelling being verified against laboratory experimentation. *No known work before 2011 studied the 3 dimensional air flow and temperature regime of ventilated cavity walls-* this is due to the large computer processing power needed to solve such complex interactions. In the case of hollow core concrete slabs the 3 dimensional interactions are vital and cannot be simplified to a 2 dimensional case. It must be stressed therefore that the complexity of this modelling work should not be underestimated as no articles on models of this complexity are available currently in the academic realm.

Akindeji (2011) presented the first work in this area of 3 dimensional cavity wall interaction (https://www.escholar.manchester.ac.uk/uk-ac-man-scw:131830) analysing the velocity field of a thin, slot ventilated wall cavity. The overarching aim of the study was to calculate cavity air flow rates in partial fil cavity walls. The figure below shows the 3 dimensional model which was calibrated against site data and solved under varying parameters. The work used in all cases a 50mm cavity, in line with current UK building regulations. [Tricker, R. and Algar, R. (2007). Building Regulations in Brief. Elsevier Butterworth and Heinemann, ISBN-13: 978-0-7506-8444-6, Oxford, UK.] As all air movement is driven by pressure gradients, pressure coefficient data from buildings is needed for the model input which is technically difficult to ascertain. By gathering this data on site and calibrating the pressure coefficient based model against that data, Akindeji was able to define a range of cavity velocities predicted for different pressure gradients. The pressure gradients achieved on real walls depend on structure orientation, temperature, wind speed and water vapour concentrations. The results of Akindeji's work is therefore be correct for any combination of these mentioned parameters which cause the pressure differential modelled.

In the case of this research project the model must be simplified to allow it to solve in a reasonable time frame as its geometric complexity is much larger. For all cases investigated it is assumed that wind speed is the greatest influence on pressure differential and therefore air movement into the cavity via other means can be ignored (e.g. via pressure differentials caused by temperature gradients). The second assumption is that wind hits the inlet vent at 90 degrees and its path is not affected by the grating design. In this scenario average wind speeds can be used to assess the performance of the system.

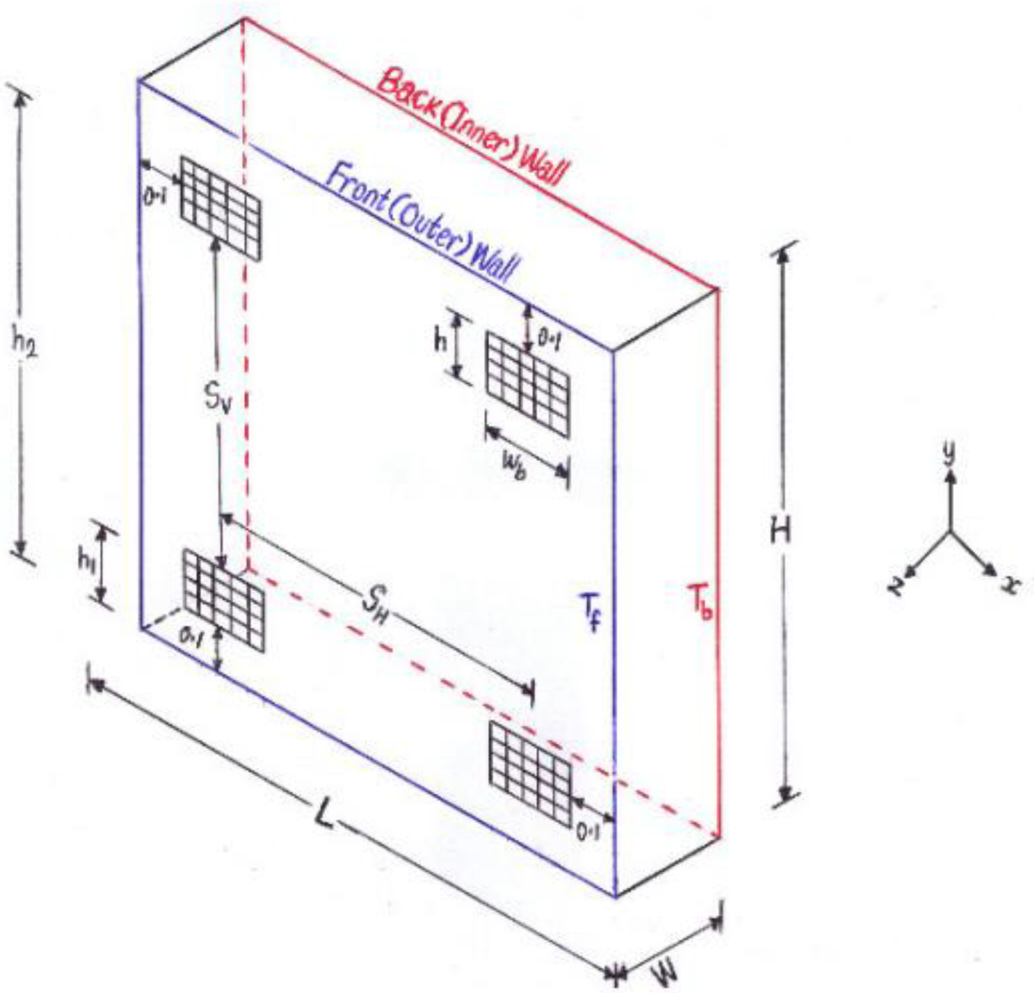


Figure 5: 3 Dimensional Air Flow Scenario Investigated by Akindeji (2011)

3.6 Mean Wind Speeds in Northern Ireland

To assess the heat loss through the slab an average wind speed hitting perpendicular to the wall will be modelled. For the vast majority of the UK average wind speeds lie between 3 and 8m/s with some exposed areas falling into the 8 to 10m/s bracket. In some very extreme environments this rises to 10m/s or more although these areas tend to see very limited levels of housing constructed due to the conditions. For this reason the model will assessed for wind speeds between 1 and 10m/s and the difference in heat loss examined. Figure 6 shows the average wind speeds recorded in the UK over a 30 year period by the UK Met Office.

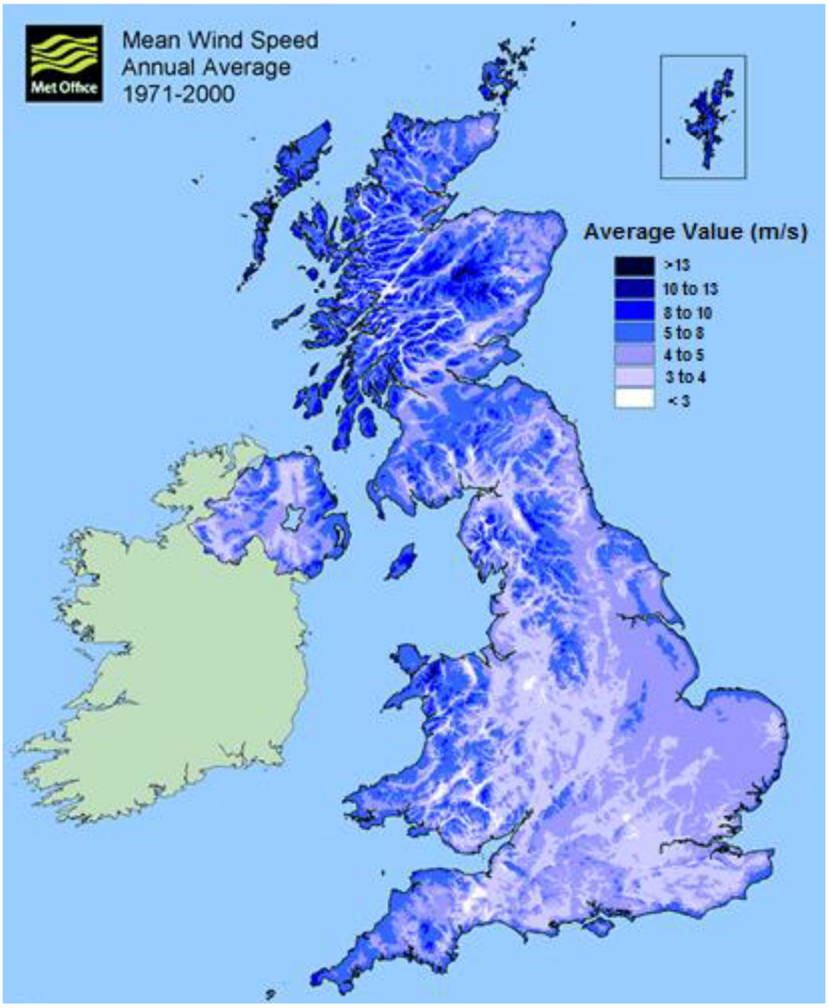


Figure 6: Met Office Average Wind Speeds for the UK

3.6 Model Global and Material Parameters

Table 1 outlines the global parameters used within the model. These are variables which can be investigated in time but given the scope of this investigation only wind speed (noted as inlet speed below) was analysed due to the large computational time taken to solve the model. The material parameters used for the investigation are given in Table 2. Figure 3 shows the system which was modelled based on the manufacturers fitting details (Figure 4) and approved detail MCI-IF-01 (Figure 1). Figure 8 details the simulated penetrations into the concrete cores to allow access for cables and services. These penetrations are 30mm by 30mm in size. This equates to a penetration size of 2700mm_2 per m_2 of floor space in the building, or 27cm_2 per m_2 of floor space. Similarly this can be thought of as a 5.2cm by 5.2cm penetration in every square meter.

Table 1: Global Model Parameters

Name	Expression	Description
Wall_gf_h	2400[mm]	Ground floor interior wall height
Wall_gf_w	100[mm]	Ground floor interior wall width
Wall_ff_h	2400[mm]	First floor interior wall height
Wall_ff_w	100[mm]	First floor interior wall width
Slab_h	150[mm]	Slab (precast concrete) height
Slab_w	1250[mm]	Slab (precast concrete) width
Cavity_h	4950[mm]	Cavity height
Cavity_w	150[mm]	Cavity width
Wall_ext_h	4950[mm]	Exterior wall height
Wall_ext_w	200[mm]	Exterior wall width
Vin	Variable[m/s]	Velocity of air inflow to cavity
Tin	10[degC]	Temperature of air inflow to cavity
Tamb_i	20[degC]	Temperature of internal ambient air
Tamb_ext	10[degC]	Temperature of external ambient air
Rsi	0.13[m^2*K/W]	Heat Transfer Coefficient
Rse	0.04[m^2*K/W]	Heat Transfer Coefficient
E	0.85	Emissivity
Ins_w	100[mm]	Insulation Thickness
Ins_gap	150[mm]	Insulation Gap at Slab
SS_h	50[mm]	Suspended ceiling height

Table 2: Material Parameters

Name	Unit	Clay Brick	Block	Phenolic Insulation	Plasterboard	Interior Plaster
Density	kg/m^3	1600	2000	40	850	750
Thermal conductivity	W/(m*K)	0.6	0.6	0.025	0.2	0.17
Heat capacity at constant pressure	J/(kg*K)	850	850	1500	850	800

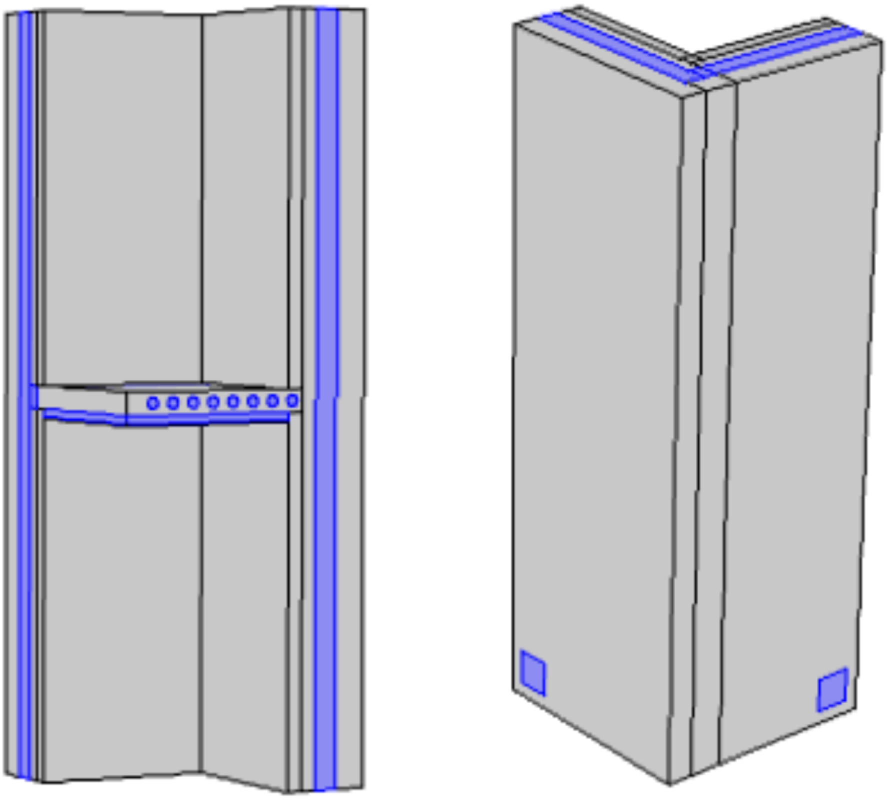


Figure 7: Outline of the Modelled System from the Interior and Exterior

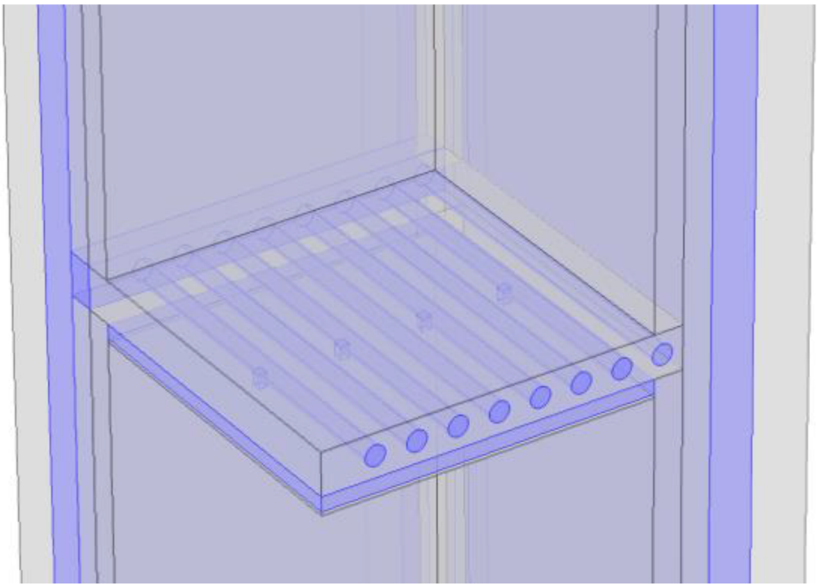


Figure 8: Penetrations from Slab Hollow Cores into Suspended Ceiling Void

3.7 Mesh Construction and Solver

Accurate and repeatable mesh construction is vital for the scientific validity of the simulation as these are the points at which temperatures, heat fluxes and air velocities are calculated by the partial differential equations within the software. The more calculation points there are in a model the longer it takes to solve but the accuracy is increased. There is an optimum point were increasing the mesh density no longer yields real benefits as the accuracy increases are beyond that of the accuracy of the input parameters. The mesh statistics are presented in Table 3. The system was solved using a Fully Coupled Non Linear Method using a Direct PARDISO solver and Pseudo time-stepping.

Table 3: Mesh Statistics

Property	Value
Minimum element quality	3.334E-4
Average element quality	0.5963
Tetrahedral elements	580142
Pyramid elements	3040
Prism elements	93462
Triangular elements	66519
Quadrilateral elements	1692
Edge elements	5548
Vertex elements	210

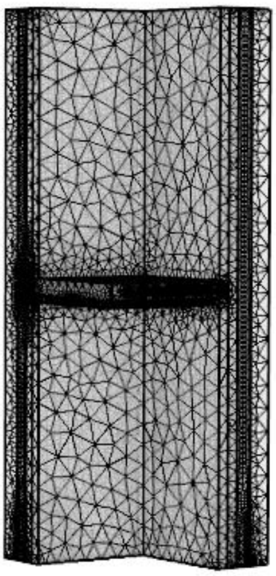


Figure 9: Mesh Construction for Solving

4.0 Results

4.1 System with no air barrier

The system was modelled under the average wind speed parameters to assess the heat loss through the building fabric without the addition of the designed product. Table 4 presents the average heat losses through the building fabric under these conditions in W/m^2. Using the surface areas derived from the model geometry in Table 5 the total heat loss per element is shown in Table 6. This is then converted to a percentage increase in heat loss through the building fabric for each average wind speed. In a highly exposed site heat losses could be increased by as much as 170% of the design value based on an average wind speed of 10m/s. In an average exposed site in Northern Ireland the increase in losses are calculated at 136% for a 3m/s average wind speed.

Figure 10 details the internal temperatures that have been modelled under the various wind speed conditions. It can be seen that at higher wind speeds the internal temperatures increase due to the increased heat loss through the fabric.

Table 4: Heat Loss through Building Fabric

Wind Velocity (m/s)	First Floor Wall Heat Flux (W/m^2)	Ground Floor Wall Heat Flux (W/m^2)	Average Wall Heat Flux (W/m^2)	First Floor Floor Heat Flux (W/m^2)	Ground Floor Ceiling Heat Flux (W/m^2)	Average First Floor and Ground Floor Heat Flux (W/m^2)	Average Internal Heat Flux (W/m^2)
0.00	2.14	2.33	2.24	1.01	1.49	1.25	2.04
1.00	2.21	2.40	2.31	1.04	1.54	1.29	2.11
2.00	2.47	2.68	2.58	2.03	3.14	2.59	2.58
3.00	2.58	2.79	2.69	2.42	4.00	3.21	2.79
4.00	2.69	2.90	2.79	2.81	4.85	3.83	3.00
5.00	2.75	2.95	2.85	2.98	5.39	4.19	3.11
6.00	2.81	3.00	2.90	3.15	5.93	4.54	3.22
7.00	2.85	3.03	2.94	3.25	6.37	4.81	3.31
8.00	2.88	3.06	2.97	3.35	6.80	5.07	3.39
9.00	2.91	3.08	3.00	3.42	7.17	5.30	3.45
10.00	2.94	3.10	3.02	3.49	7.54	5.52	3.51

Table 5: Model Geometries

First Floor Wall Area (m^2)	Ground Floor Wall Area (m^2)	Total Wall Area (m^2)	First Floor Floor Area (m^2)	Ground Floor Ceiling Area (m^2)	First Floor and Ground Floor Ceiling Area (m^2)	Total Internal Surface Area (m^2)
5.520	5.377	10.897	1.323	1.323	2.645	13.542

Table 6: Total Heat Loss through Building Fabric Elements

Wind Velocity (m/s)	First Floor Wall Total Heat Flux (W)	Ground Floor Wall Total Heat Flux (W)	Total Wall Heat Flux (W)	First Floor Floor Total Heat Flux (W)	Ground Floor Ceiling Total Heat Flux (W)	First Floor and Ground Floor Total Heat Flux (W)	Total Internal Heat Flux (W)
0.00	11.84	12.53	24.38	1.34	1.97	3.30	27.66
1.00	12.20	12.92	25.13	1.38	2.03	3.41	28.52
2.00	13.64	14.44	28.09	2.69	4.16	6.84	34.93
3.00	14.25	15.01	29.26	3.20	5.29	8.49	37.76
4.00	14.85	15.58	30.44	3.72	6.41	10.13	40.59
5.00	15.18	15.84	31.03	3.94	7.13	11.07	42.13
6.00	15.50	16.11	31.62	4.16	7.85	12.01	43.67
7.00	15.71	16.28	32.00	4.30	8.42	12.72	44.76
8.00	15.92	16.45	32.38	4.43	8.99	13.42	45.85
9.00	16.07	16.57	32.65	4.52	9.48	14.01	46.71
10.00	16.22	16.69	32.92	4.62	9.97	14.59	47.57

Table 7: Percentage increase in total heat loss

Wind Velocity (m/s)	Increase in Total Heat Loss (% of design value)
0.0	0.0
1.0	103.1
2.0	126.3
3.0	136.5
4.0	146.7
5.0	152.3
6.0	157.9
7.0	161.8
8.0	165.7
9.0	168.8
10.0	171.9

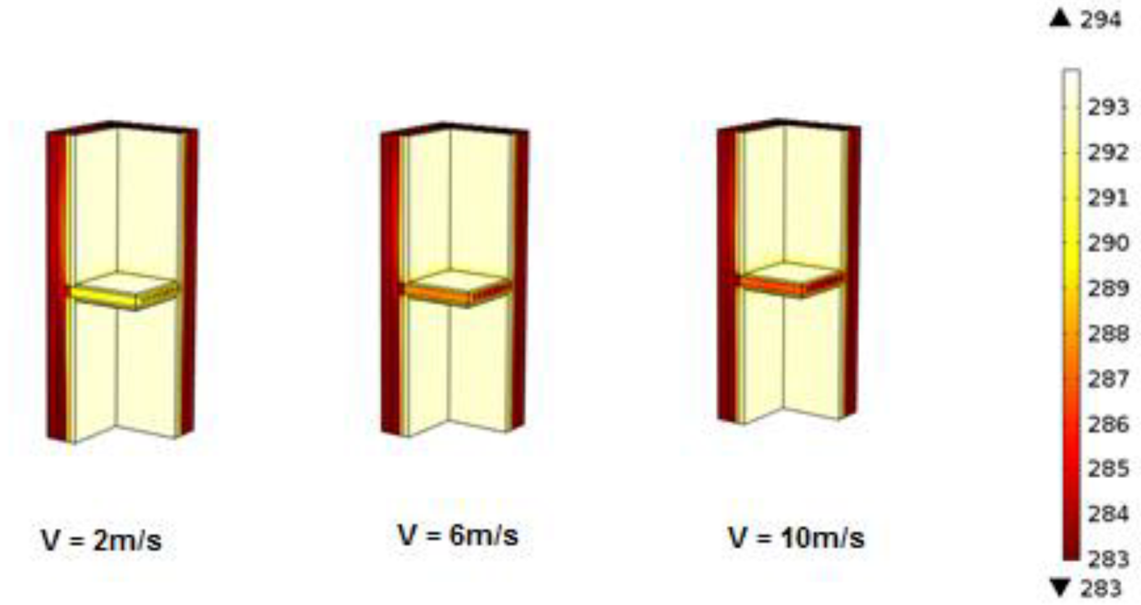


Figure 10: Temperature Profiles of the Wall Assembly Showing Increased Heat Loss at Increase Wind Velocities.

4.2 System with Air Barrier

The system has now been remodelled with the air barrier included in the design. The results are shown in the tables below. Table 8 details the heat loss through the building elements with the air barrier in place. Table 9 then shows the calculated total heat losses through the system taking into consideration the building fabric surface areas from Table 5. Table 10 then shows the percentage increase in total heat loss throught the system based on the Total Internal Heat Flux from Table 9.

Table 8: Heat Loss through Building Fabric (with air barrier)

Wind Velocity (m/s)	First Floor Wall Heat Flux (W/m^2)	Ground Floor Wall Heat Flux (W/m^2)	Average Wall Heat Flux (W/m^2)	First Floor Heat Flux (W/m^2)	Ground Floor Ceiling Heat Flux (W/m^2)	First Floor and Ground Floor Heat Flux (W/m^2)	Average Internal Heat Flux (W/m^2)
0.0	2.15	2.33	2.24	1.01	1.55	1.31	1.43
1.0	2.20	2.37	2.30	1.09	1.60	1.35	1.47
2.0	2.54	2.76	2.65	1.02	1.75	1.38	1.57
3.0	2.65	2.86	2.75	1.23	1.84	1.54	1.69
4.0	2.76	2.97	2.86	1.27	1.90	1.59	1.74
5.0	2.82	3.02	2.92	1.30	1.95	1.62	1.79
6.0	2.87	3.07	2.97	1.32	1.99	1.66	1.82
7.0	2.91	3.10	3.01	1.34	2.02	1.68	1.85
8.0	2.95	3.13	3.04	1.36	2.05	1.71	1.88
9.0	2.98	3.15	3.07	1.38	2.08	1.73	1.90
10.0	3.00	3.18	3.09	1.39	2.10	1.74	1.92

Table 9: Total Heat Loss through Building Fabric Elements (with air barrier)

Wind Velocity (m/s)	First Floor Wall Total Heat Flux (W)	Ground Floor Wall Total Heat Flux (W)	Total Wall Heat Flux (W)	First Floor Floor Total Heat Flux (W)	Ground Floor Ceiling Total Heat Flux (W)	First Floor and Ground Floor Total Heat Flux (W)	Total Internal Heat Flux (W)
0.00	11.87	12.53	24.40	1.34	2.05	3.46	27.85
1.00	12.14	12.74	24.89	1.45	2.11	3.56	28.45
2.00	14.01	14.82	28.83	1.35	2.31	3.66	32.49
3.00	14.61	15.39	30.01	1.63	2.43	4.06	34.07
4.00	15.22	15.96	31.18	1.68	2.51	4.19	35.38
5.00	15.54	16.23	31.77	1.72	2.58	4.30	36.07
6.00	15.87	16.50	32.37	1.75	2.63	4.38	36.75
7.00	16.08	16.67	32.74	1.78	2.67	4.45	37.19
8.00	16.28	16.84	33.12	1.80	2.71	4.51	37.63
9.00	16.43	16.96	33.39	1.82	2.75	4.57	37.96
10.00	16.58	17.08	33.66	1.84	2.78	4.61	38.28

Table 10: Percentage Increase in heat loss (with air barrier)

Wind Velocity (m/s)	Increase in Total Heat Loss
0.0	0.0
1.0	103.1
2.0	112.5
3.0	118.1
4.0	122.0
5.0	125.0
6.0	127.5
7.0	129.6
8.0	131.5
9.0	133.1
10.0	134.5

4.3 Comparison of Total Heat Loss for Each Scenario

To effectively see the increase in performance caused by the new product we must compare the differences in heat loss found for the same wind speed for the situations with and without the air barrier added. Table 11 shows this comparison in the form of total heat flux and percentage improvement in each scenario. The results show that for 0m/s it is calculated that there is a small decrease in performance with the barrier. This may be down to a number of factors - the simplest being rounding errors within the calculation software. The second reason is that there is increased smoothness of the airflow in the cavity at very low air speeds because of no mixing with the slab hollows. This reduction in turbulent behaviour may be increasing heat loss slightly from the surface due to the increase in cavity air speed. The performance decrease is extremely small, only 0.69% therefore can be considered acceptable. For the percentage performance increases for other wind speed scenarios can also be seen in Table 11. In certain environments where the average wind speed is 10m/s the increase in performance can be as much as 19.5%.

Table 11: Improvement in System Performance

Wind Velocity (m/s)	Total Heat Flux with No Barrier (W)	Total Heat Flux with Barrier (W)	Effective U Value of Wall with No Barrier (W/m^2K)	Effective U Value of Wall with Barrier (W/m^2K)	% Improvement in Performance
0.00	27.66	27.85	0.20	0.21	-0.69
1.00	28.52	28.45	0.21	0.21	0.23
2.00	34.93	32.49	0.26	0.24	6.99
3.00	37.76	34.07	0.28	0.25	9.78
4.00	40.59	35.38	0.30	0.26	12.85
5.00	42.13	36.07	0.31	0.27	14.39
6.00	43.67	36.75	0.32	0.27	15.86
7.00	44.76	37.19	0.33	0.27	16.90
8.00	45.85	37.63	0.34	0.28	17.91
9.00	46.71	37.96	0.34	0.28	18.73
10.00	47.57	38.28	0.35	0.28	19.53

5.0 Conclusions

A barrier system to prevent mixing of air flow from a hollow core concrete slab and a partial fill cavity wall has been assessed. It has been shown that the savings per year are dependent on the average wind speed at the location of construction. The system was modelled under each wind speed scenario with and without the air barrier to calculate the effective U-Value of the wall taking into account losses causes by cavity ventilation rates. These values were then put into standard SAP calculation software to estimate the energy demand for each.