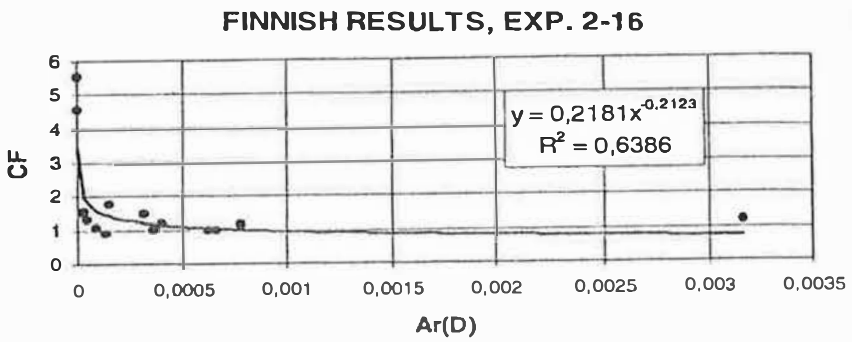

Correction factor CF for measured window opening with awning. Ar is Archimedes number

Task 4 : Development of Smart Solar Control

Preliminary activities were focused on the occupant use of blinds and on simplified modelling. BRE carried out a statistical analysis of venetian blind use in office in order to assess the most frequent actual actions of occupants on the shading and the mean blind position in relation to outdoor daylight level.

TNO developed the model (reference premises) of a single window office room with a solar screen as shading. The tool simulates also an on-off / dimming lighting system and gives luminances and illuminances in different points of the room and the electrical lighting consumptions.

A new concept of simulated users was developed by Somfy and 6 basic users profiles were created and inserted in the modelling of reference occupants.

Somfy finalised the modelling of reference control strategy and the design of the control sensor located on the table and controlling the screen and/or two set of lights. The sensor is characterised by a weighted integrated optical responses in order to avoid a too important sensitivity to the direct illuminance in case of clear sky and to feel the desk luminance. It can be used directly by the users through a keyboard or by PC.

Task 5 : Integration in design tools

The tools selected to incorporate the developed algorithms, were:

- A new version of LAMAS software (product from PASCOOL project)
- The PASSPORT Plus software (product from PASCOOL project)
- The WIS software (product from WIS project)

A GUI (Graphical User Interface) is under development by Universities of Seville and Ljubljana, whereas VTT prepared a preliminary version of a GUI tool for the simplified calculation of the optical properties of curved slats.

Task 6 : Design Guidelines and Shading Component Dictionary

The overall structure for the Handbooks were outlined and the main contents prepared.

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THE APPLICATION OF DYNAMIC INSULATION IN BUILDINGS

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ABSTRACT

Dynamic insulation, a form of 'Breathing Wall' construction which allows the movement of air and moisture through the external walls of a building, was seen as one possible method for reducing building envelope heat losses and achieving high indoor air quality. A research investigation was conducted to provide a firm scientific understanding of dynamic insulation. An important outcome of the work will be the development of building envelope designs which effectively and economically employ dynamic insulation in cold climates. This paper presents some general conclusions, confirming that the energy saving produced by dynamic insulation alone is small relative to that obtained in conjunction with conventional air heat recovery methods.

KEYWORDS

Breathing wall; buildings; dynamic insulation; heat recovery; U-value; ventilation.

PROPERTIES OF DYNAMIC INSULATION

Modern buildings have attempted to reduce their energy requirements by improving the air tightness of the envelope and increasing the thickness of insulation. This trend has developed simultaneously with increased use of synthetic materials in construction, furnishings and decorations, which give off volatile organic compounds. Increasing living standards have also resulted in higher indoor temperature and moisture generation rates within homes. The outcome has been a reduction in indoor air quality which directly affects occupant health, and increasing problems of dampness in homes, particularly for the poor. Dynamic insulation, a form of 'Breathing Wall' construction which allows the movement of air and moisture through the external walls of a building, was seen as one possible method for reducing ventilation and building envelope heat losses and achieving high indoor air quality.

Heat Transfer

Physical insight into the heat and mass transfer processes in dynamic insulation for any proposed envelope design can be gained from a simple 1-D analytical model. The model can be used to predict the effective or dynamic U-value for the envelope and the mass transport rate for any gas species. The dynamic U-value can be incorporated into an energy and air flow balance for the whole building to estimate the overall energy savings. This simple analysis which can be carried out on a spreadsheet is ideal for the conceptual design of

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buildings. However, for the detailed design of the air permeable envelope, 2-D models of the heat air and moisture transport should be used to assess (i) air bypassing the insulation through defects or construction details, (ii) buoyancy effects in the porous insulation, defects and cavities, and (iii) increased heat losses and vapour transport due to the above. There are a number of such models in existence but they tend to be research tools and not available for use by practitioners. Hens (1996) provides an excellent review of heat air and moisture transport modelling in general and specific computer programs in particular.

This paper will describe the practical results of the 1-D analytical model. It was shown (Taylor et al., 1996) that the dynamic U-value for a multi-layer envelope can readily be calculated from the total thermal resistance of the wall (R_t) and the air flow through the wall (v)

$$U_d = \frac{v \rho_a c_a}{R_t\left(\exp(v \rho_a c_a R_t) - 1\right)} \qquad (1)$$

The dimensionless group of variables that controls the behaviour of dynamic insulation has a formal resemblance to the Péclet number

$$Pe = \frac{v \rho_a c_a L}{k} \qquad (2)$$

Unlike boundary layer analysis where it is the fluid physical properties that are employed, the thermal conductivity, k, in this case refers to the porous material. The density, ρ_a and specific heat, c_a are that of the air. Table 1 illustrates how the material thermal conductivity and the air flow combine to determine the dynamic U-value for two envelopes, one comprising 200 mm of cellulose insulation and the other 200 mm thick porous masonry block such as Pumalite.

Table 1: Dynamic U-Value versus thermal conductivity and air flow rate.

	Cellulose (k = 0.035 W/mK)		Pumalite (k = 0.3 W/mK)	
v (m/hr)	1	10	1	10
Pe	1.91	19.1	0.224	2.24
U_d / U_s	0.33	9.5 E-8	0.89	0.27
U_d (W/m^{2}K)	0.058	1.7 E-8	1.34	0.4

The masonry wall requires an air flow approximately ten times that of cellulose to achieve a comparable improvement (U_d/U_s) in U-value. However, to achieve the same insulation value the air flow through a Pumalite wall would have to be about 100 times that for cellulose. Consideration of the pressure drop across the wall (280 Pa) at a flow rate of 100 m/h leads to the conclusion that this would not be practical.

Thus dynamic insulation works best with materials that are inherently good insulators. However, the thermal capacity of the masonry can be combined with the insulating properties of the cellulose to produce a composite permeable wall with a low U-value and high thermal capacity.

Another reason why this is the case is that the analytical theory assumes that the air and the solid matrix of the porous insulation are in local thermal equilibrium. This assumption is valid for low air flows. Calculating the air flow at which the equilibrium theory is not applicable in terms of the physical properties of the porous medium is one of the useful results to be obtained from a non-equilibrium theory of dynamic insulation which is under development. It is sometimes suggested that with dynamic insulation less insulation material may be used in the wall.

From Table 2 it can be seen that to get a significant reduction in U-value for a wall with only 40 mm of insulation high air flows are again required.

Table 2: Dynamic U-Value versus insulation thickness.

	Cellulose (L= 200 mm)		Cellulose (L= 40 mm)	
v (m/hr)	1	10	1	10
Pe	1.91	19.1	0.382	3.82
U_d / U_s	0.33	9.5 E-8	0.82	0.085
U_d (W/m^{2}K)	0.058	1.7 E-8	1.23	0.13

Another feature of dynamic insulation is that as the air flow increases the inner surface temperature decreases (Taylor and Imbabi, 1997). This is because more heat has to be put into the inner surface of the wall to heat the increasing amount of air which in turn increases the temperature drop across the air film thermal resistance. The temperature drop is about 0.5 °C for a flow of 1 m/h through a wall with 200 mm of cellulose insulation increasing to over 5 °C at 10 m/h. Even at low air flows this temperature depression will significantly alter the radiant heat exchange within a room.

Mass Transfer

Diffusive insulation is a special case of dynamic insulation where the air flow is zero. In other words its thermal behaviour is no different from a conventional wall. Indeed diffusive insulation is merely a wall which does not include a vapour retarder with a high vapour resistance such as polythene or metal foil. Such wall constructions are acceptable in certain circumstances and BS 5250 (BSI, 1989) quotes a useful but not infallible rule of thumb that the vapour resistance on the warm side of the insulation be at least five times greater than that on the cold side. Diffusion can be stopped if the air is flowing in the opposite direction to the diffusion process. The critical air velocity v_c required to do this is dependent only on the ratio of the concentrations of the gas (inner concentration C_i assumed to be greater than the outer concentration C_o) and the total diffusion resistance of the multi-layer wall R_d (Taylor et al., 1996):

$$v_c = \frac{\ln\left(C_i/C_o\right)}{R_d} \qquad (3)$$

This explains how dynamic insulation can act as a vapour barrier. If the air velocity is greater than v_c then water vapour will be carried from outside to inside despite there being a higher water vapour concentration on the inside. For a typical timber frame insulated wall construction with total thermal resistance of 6.434 m^{2}K/W (200 mm cellulose insulation) and the indoor and outdoor temperature and humidity conditions of 15 °C, 85% RH and 5 °C, 95% RH respectively as specified in BS 5250, this critical air velocity is very low at 0.0063 m^3/m^{2}h. This is very much lower than the recommended air flows of 0.5 to 1.5 m^3/m^{2}h (Dalehaug, 1993). The partial vapour pressure difference corresponding to the standard internal and external conditions, stated above, is 621 Pa.

The authors have measured the air permeability of a variety of commonly used insulating materials. The air permeance of 200 mm of cellulose is found to be 1.5 m^3/m^{2}hPa. and that for 12 mm thick fibreboard was 0.116 m^3/m^{2}hPa. The controlling resistance to air flow in a wall construction comprising of wood wool board (air permeance too high to measure), 200 mm cellulose, and 12 mm fibreboard is that of the fibreboard. The pressure drop across this wall at the critical air flow corresponds to a difference in air pressure of only 0.054 Pa Thus water vapour cannot flow from inside to out through a wall operating in contra-flux (heat and mass flow in opposite direction) mode.

There is then a conflict between the air flow requirements to minimise heat losses and that necessary to maximise the removal of water vapour or other indoor pollutants. On the other hand provided one can ensure that air is flowing inwards through the envelope at all time then there should, in general, be no problem of interstitial condensation. However, if the outer wall cladding is saturated by wind-driven rain followed by heating by the sun then the temperature and relative humidity in the cavity could rise very quickly and condensation could occur in the still relatively cool insulation. A useful outcome of the recently completed IEA Annex 24 on Heat Air and Moisture transport in buildings has been the compilation of data on air permeability, vapour permeability and hygroscopicity for many building materials (Kumaran, 1996).

SYSTEMS ANALYSIS

Equation (1) can be readily incorporated into an air flow and energy balance for a whole house to calculate the heat loss through the air permeable parts of the envelope (Taylor and Imbabi, 1996). A fact that is often overlooked by the proponents of dynamic insulation is that whilst the heat loss to the outside is reduced more heat needs to be put into the interior surface of the wall in order to warm the incoming air than would be the case without air flow. Therefore, if the air coming through the wall is merely vented to atmosphere without heat recovery little is gained. With an air-to-air heat recovery scheme as shown in Figure 1 the ventilation requirements are supplied partially through the wall, m_p, and partially through the heat exchanger, m_f. The model also allows for air leakage through doors and windows, m_L. The heat input to the building Q (partly supplied by incidental gains) compensates for the heat lost through the porous envelope Q_p, the non-porous part of the envelope, Q_n and the ventilation loss.

The only way a building can be reliably de-pressurised in the mild and variable UK climate is by using fans. In northern Scandinavia with a 40 °C temperature difference between indoors and out in winter a reliable and significant stack affect may be obtained. The de-pressurisation must be no greater than 5 to 10 Pa otherwise the occupants will have difficulty opening doors and windows (BSI, 1989). This restriction on de-pressurisation could be relaxed if the opening and closing of windows and doors were mechanically assisted. Since the pressure drop through an air-to-air heat exchanger and associated ductwork is in the region of 50 to 100 Pa both a supply and an extract fan are required.

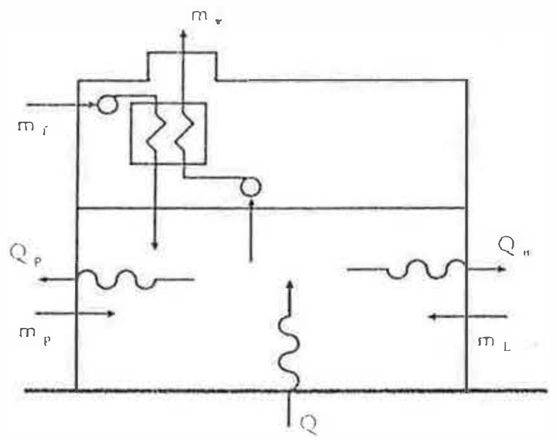

Fig. 1: Model of a dynamically insulated house with air to air heat recovery

The results of analysis of such a scheme are shown in Figure 2. The ordinate plots the reduction in energy consumption over a conventional envelope construction of the same static U-value for the same air change rate to maintain an indoor temperature of 20 °C when it is 0 °C outside. The curves show how a dynamically insulated building and conventional envelope compare when both use air-to-air heat recovery. At low air change rates the conventional building performs better than the dynamically insulated building. The bigger and better the heat exchanger the higher is the air change rate before it becomes worth while to think about dynamic insulation. Both schemes show a maximum saving at around 1.5 to 2 ach. This level of ventilation in a conventional house could be achieved merely by opening the windows.

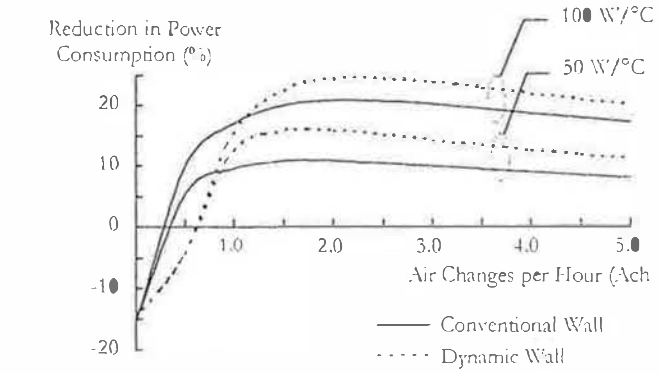

Fig. 2: Variation in power consumption with conventional and dynamic envelopes.

An air-to-water heat exchanger operating at 2.0 ach would require a continuous steady flow of water of the order of 1550 kg/day in a home. This flow rate is much larger than the domestic requirements for bathing, showering and laundering. Also, the temperature constraints imposed by the exhaust air flow and the heat exchanger mean the water temperature will rise only from about 5 °C to 15 °C. If the warm air were used instead to melt snow the water it would provide at, say, 10 °C is a more manageable 170 kg/day. However, snow is not a reliable heat sink in most areas of the UK.

With the simple tools developed so far the designer can explore, for example, how the proportion of non-permeable surfaces (such as glazing) to permeable surfaces and how the size of the building affect thermal performance. The results are much as one might expect. To make the most effective use of dynamic insulation as great a proportion of the external envelope as is practical should be air permeable. This has obvious implications for the use of incident solar radiation for lighting and heating. It also means that a detached house is a more suitable candidate for dynamic insulation than a small apartment with only one or at most two external surfaces. As the volume of the building increases, the ratio of volume to surface area increases and so the relative importance of the ventilation heat loss to envelope loss increases. In general, where energy conservation is the main objective, dynamic insulation would appear to be appropriate only for small detached buildings.

FURTHER ASPECTS OF DYNAMIC INSULATION

It has been theoretically established that a dynamically insulated wall will inherently act as a filter (Taylor et al., 1997). Studies of porous ceilings in barns where the ventilation rate can be as high as 80 m^3/m^2h have shown that over a span of 20 years the pressure increase due to dust accumulating in mineral wool insulation is insignificant (Sällvik, 1989). In homes, the ventilation rate will be an order of magnitude smaller and the rate of dust accumulation in the walls will be correspondingly slower. However, insulation materials such as cellulose and mineral wool will not remove chemical pollutants in the way that activated charcoal filters would.

Cellulose insulation fibre is treated with borax to prevent fungal growth and infestation by insects and rodents. Bacteria cannot survive in the air on their own: they require dust particles to sustain small colonies. When such dust (and other) particles are trapped in the insulation, bacteria living on them may multiply unaffected by the borax in the cellulose. The microbes and or toxins they produce could then subsequently be disseminated into the living space. It is also known that certain types of bacteria provide the nutrients required by moulds and fungi to grow (Singh, 1994). This potential health hazard requires investigation in order to identify the circumstances under which dynamic insulation may act as an amplifier and disseminator for bacteria, fungal spores and viruses.
In view of the risks attached to mechanical ventilation systems, which may be overcome by proper maintenance, the hybrid scheme (Fig 2) offers no health advantages over a purely mechanical ventilation