NOVEL HVAC STRATEGIES FOR WELL-INSULATED AIRTIGHT BUILDINGS

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Summary

The proposed changes to Part L of the Building Regulations will require better-insulated and airtight buildings. Envelopes that are insulated to these new standards, but with high-performance windows and good-practice airtightness specifications provide the opportunity for a new approach to HVAC design. Such systems will be significantly reduced in capacity and hence cheaper to install and operate. They will be simpler to control, will provide excellent year-round thermal comfort, and are environmentally beneficial. The approach to be described here therefore offers a potentially significant contribution to all three areas of the sustainability agenda - economic, respect for people and environmental.

Introduction and Background

An on-going DETR supported Partners in Innovation project involving a group of researchers, designers, manufacturers and CIBSE [‡] has been investigating a radical approach to HVAC design. The paper will demonstrate that this novel approach can provide improved commercial performance relative to more traditional design concepts, but still be of comparable (or lower) cost, have reduced CO_2 emissions and high comfort levels.

The approach explores the potential for high performance building envelopes to simplify the design and operation of HVAC systems. By effectively isolating the occupied space from the external climate, the internal loads become much more constant with time and much more even between core and perimeter and between different orientations of perimeter zone. This isolation of the occupied space is only in terms of thermal interaction, since the provision of substantial areas of untinted glazing is important for good external view and occupant satisfaction. Glass technology is improving at a very fast rate, and high performance window systems are now available at relatively small marginal costs. The specification of such high performance windows can deliver the following commercial benefits–

- High insulation standards eliminate the need for perimeter heating, thereby adding value to the project by freeing up valuable perimeter space, as well as saving distribution space and to some extent plant room space. It will also reduce running costs.
- Effective solar control reduces solar loads, simplifying the problems of maintaining summer comfort in the perimeter zone.
- Simplification of the controls, again reducing costs but also improving manageability and maintainability.
- Enabling HVAC systems to operate at very high efficiencies, often utilising free cooling, thereby resulting in lower operating energy consumption and CO_2 emissions.

[‡] Project partners include Oscar Faber as lead partner, plus BRE, BSRIA, Building Sciences, CIBSE, IPPEC, Flomerics, KlimaTherm, Pilkington, SAS Holdings and Trox (UK) along with the DETR as the major sponsor.

- As the windows have a longer service life than the HVAC plant, the capital investment shifted from savings in plant to additional cost in windows can be amortised over a longer period, generating further direct financial benefit.
- Very good thermal comfort.

This paper provides the evidence for these conclusions, based on a range of detailed computer modelling techniques and measurements carried out in a climate chamber.

Energy balance in buildings with well insulated envelopes

With a well-insulated and airtight building, the balance point is below the usual UK winter design temperature, at least in terms of the majority of the building, which has only one external surface, i.e. the end wall. This means that during the occupied period, most of the building is self-heating, the possible exceptions being corner rooms and those with exposed roof or floor areas. Figure 1 shows the steady state energy balance for a typical office module with wall U-value of 0.35W/m^{2}K, 54% glazed façade with a window U-value of 1.5W/m^{2}K, airtightness of 5m^3/m^2.hr @50Pa, with an inside temperature of 21^{o}C and outside at –3^{o}C. The internal gains represent occupancy at 12m^2/person, equipment gains of 10W/m^2, and lighting loads of 10W/m^2. The lighting gain is substantially less than this, because a proportion of the convective gain is lost to the ceiling void via the air handling luminaire. The assumed internal gains are all relatively modest figures for modern office space, and yet there is a net heat gain of about 5.6W/m^2, even before any allowance is made for possible winter solar gain. The final bar in fig.1 shows the midday diffuse solar gain averaged across a 6m deep perimeter zone. In fact, the balance remains positive for all window U-values below about 2.3W/m^{2}K. The recent consultation paper on Part L of the Building Regulations [1] was proposing that the minimum standard of window U-values should be 2.2W/m^{2}K. This means that apart from pre-heat requirements, many well-insulated and airtight office buildings will be in constant cooling mode year round during the occupied period. This opens up the opportunity for a radical rethink of HVAC strategies for such buildings.

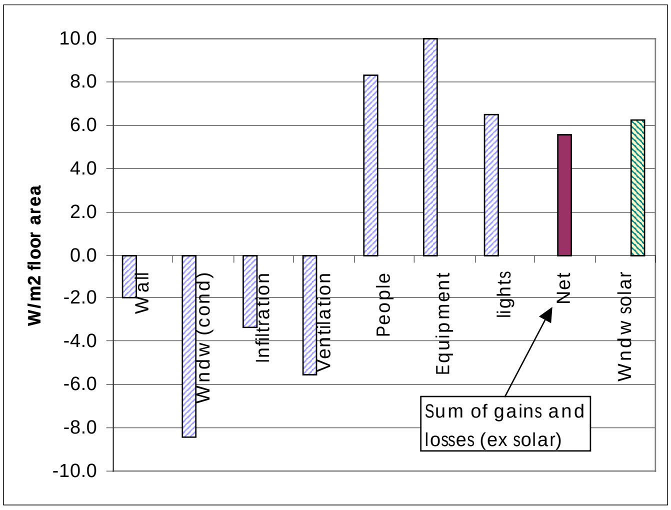

Fig. 1 Winter energy balance for mid-floor office

Winter comfort conditions in spaces with high performance windows.

In conventionally glazed spaces typical of today's norms, where the U-value of the glazing is of the order of 2.8W/m^{2}K and a shading coefficient of 0.6 or more, it is usually necessary to provide special perimeter treatment to offset cold radiation and downdraught in winter, and excessive solar gain in summer. The first element of the work was to investigate perimeter comfort conditions with no additional perimeter treatment when using improved glazing systems, with U-values of between 1.0 and 2.0 W/m^{2}K, and shading coefficients down to 0.15. This meant that there was no perimeter heating, and the cooling was achieved using radiant panels only, without recourse to a perimeter passive chilled beam.

Comfort was assessed using CFD techniques, and also using the climate chamber. There was good correlation between the two assessment methods, but the climate chamber work will be presented here. The tests were carried out by establishing a thermal balance in the test chamber (i.e. the condition where the internal heat gains were exactly balanced by the perimeter losses). This was achieved by lowering the surface temperature of the panel representing the window surface until a steady state condition was achieved. This exercise was carried out for two different mean internal temperatures, 20 and 22°C. Once the thermal balance was achieved, detailed traverses were made of air speed and turbulence, air and globe temperatures. These were used to determine the predicted comfort in the perimeter zone using the relationships in ISO7730 [2].

These tests were carried out for a range of window heights (from 1.2m to a full height 2.8m), for two levels of internal gain (15 and 30W/m^2 total occupancy and small power) and for two displacement ventilation supply rates (3 and 6 ach^{-1}), with the supply temperature fixed at 19°C. The results shown in figure 2 indicate the predicted mean vote (PMV) at a seated head height of 1.1m and at a point only 300mm from the window. The calculations were based on normal winter clothing (clo=1.0) and normal sedentary activity (met=1.2). The results clearly show that perception of comfort is totally dominated by the average dry resultant temperature of the enclosure, and so local effects near the window are largely irrelevant. A PMV of ∀ 0.85 corresponds to the ASHRAE comfort zone (less than 15% people dissatisfied) and so it can be seen that all test conditions are well within what might reasonably be desired. Indeed, thermal neutrality could be achieved for all conditions simply by adjusting the mean room temperature to around 21°C.

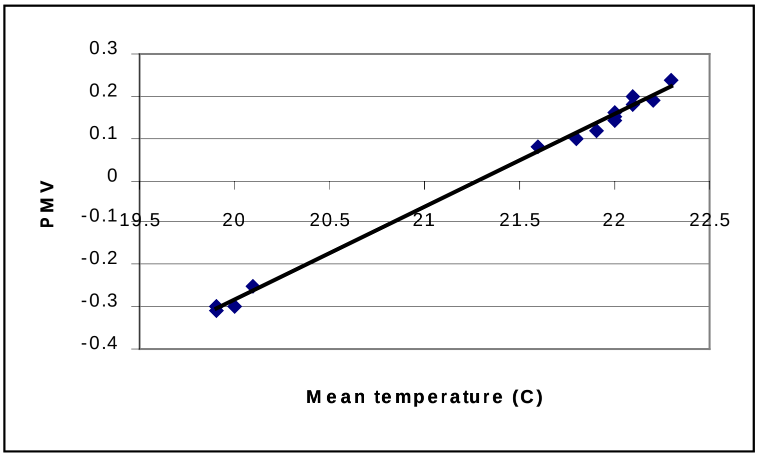

Fig. 2 Thermal comfort close to the window

The temperature of the surface representing the glazing was measured at each of the thermal balance points, and this can be used to determine the maximum U-value of the glazing that can be accepted at any given outdoor design temperature. For an outside temperature of –3°C, glazing U-values of between 1.5 and 2.0W/m^{2}K would be sufficient to ensure thermal comfort, even at the lower level of internal gains, and for all but the full height glazing. It should also be noted that in this analysis, we are primarily concerned with the average glass temperature, which is mainly controlled by the glazing U-value, not the whole window U-value. With most windows, the glass performs better than the frame, and so a glazing U-value of 1.5W/m^{2}K is much easier to achieve than the same standard for the whole window. A substantial amount of window modelling was done using finite element techniques. Figure 3 shows the overall U-value for three different units

- An aluminium framed double glazed units with an ultra low emissivity (e) pane (e=0.026).
- A pvc-U framed double glazed unit with a very low-e pane (e=0.06).

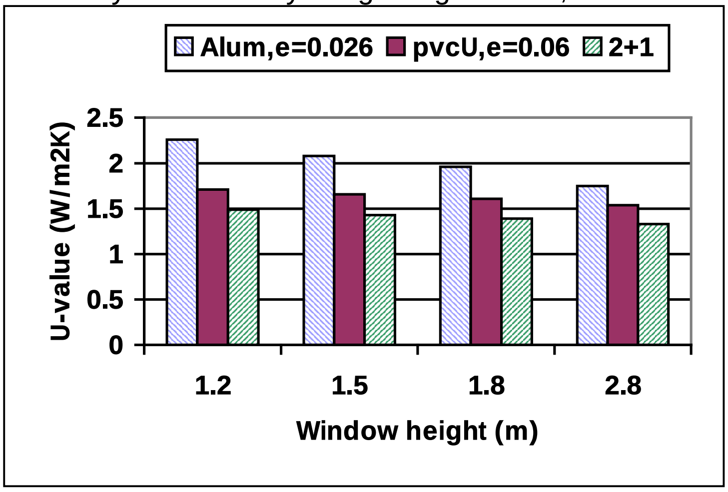

Fig. 3 U-values of various window units

- A 2+1 window (inner double pane unit with outer single pane), with a low-e pane (e=0.16) on the double-glazed unit.

Summer comfort conditions in spaces with high performance windows.

In a similar way, climate chamber tests were carried out for the summer condition. The solar heat gain was determined by detailed modelling of the window unit, and this was used to define the heat output from the heated mats [§] in the climate chamber. Again, detailed traverses were taken in the situation with a good solar control window (shading coefficient 0.16), but with the cooling only being provided by radiant panels and the displacement ventilation supply. Space does not permit a detailed consideration of these tests, but suffice it to say that at the level of internal gains suggested by the BCO specification [3], good comfort could be achieved at all glazing heights. At higher internal loads, (7m^2/person and 25W/m^2 equipment load, good comfort could still be achieved for all window heights below about 2.0m, provided the ventilation supply rate was increased to 6ach^{-1}. ***It must be stressed that both winter and summer tests are for an office module with only an exposed end-wall. More care needs to be taken for corner modules, or those with exposed roofs or floors.***

Alternative HVAC strategies

Because no perimeter space conditioning system is needed in winter or summer, and the heating is only needed in pre-heat mode, the option of using the chilled ceiling panels to distribute warm water during the pre-heat period was assessed. This has the benefit of eliminating one complete distribution system, and also reducing problems of interaction between heating and cooling systems. The concept is that the single system works in changeover mode – all in pre-heat, then all in cooling. The viability of this was tested using dynamic thermal modelling. The approach was to pre-heat the whole building to 21.5^{o}C prior

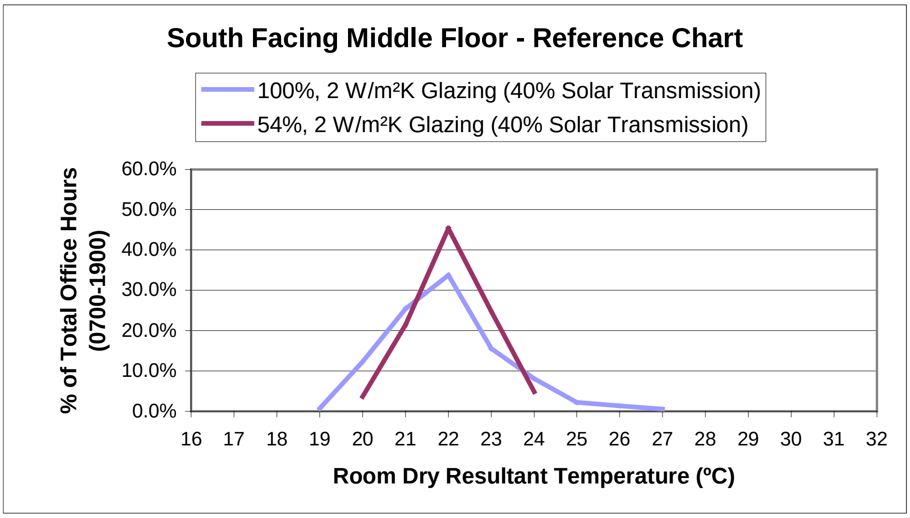

Fig. 4 Temperature distribution over winter months

to occupancy, and then to switch the ceiling panel system over to cooling availability throughout the building. Figure 4 shows the predicted frequency distribution for a reference case with 54% of the internal area of the perimeter wall glazed, and the extreme case with full height glazing. Even in the extreme situation, comfort temperatures are well within

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[§] Electrically heated mats are used to simulate the effect of solar heat gains in terms of both the re-transmitted heat and the location of the solar “patch”.

reasonable limits, but with more sensible glazing ratios, temperatures are under excellent control.

Energy / CO_2 considerations

In addition to the comfort assessments, estimates of energy consumption have been made. This was based on a comparison between a current typical fan-coil design and the same building with a high performance envelope and the combined heating and cooling system. Fig 5 shows the results for 3 cases – the current typical reference, and light and heavyweight versions of the high performance building with the integrated system. It should be stressed that the results show system loads, and represent heating and cooling demands, NOT the energy used by plant to satisfy those loads. It is interesting to note that in the lightweight case, although heating demand is reduced, plant cooling demand is increased. This is principally due to the reduction in "free cooling" provided by infiltration in the winter [**]. The improved glazing has reduced summer cooling demand, but this is more than compensated by the higher winter cooling demand. The heavyweight equivalent shows a further reduction in heating and the lowest cooling demand of all.

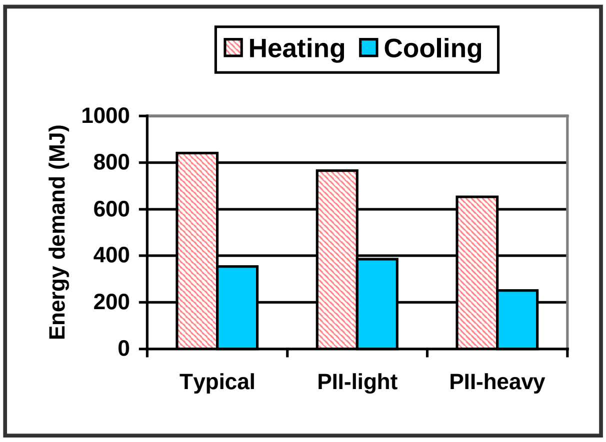

Fig. 5 Heating and cooling

What is even more significant is that the loads can be met with very high system efficiencies in the high performance building case. The heating is provided by water at 28°C flow temperatures to the radiant panels. This means that boilers could operate in full condensing mode year round, or heat pumps could be considered, with the low condensing temperature giving very good CoP. As far as cooling is considered, much of this can be provided through free cooling using dry coolers. This can be seen from figure 6, which shows the energy efficiency ratio (kW of fan power per kW of cooling effect) for a dry air cooler producing an-off cooler water temperature of 16°C. This shows "coolth" can be generated very efficiently at average winter outside air conditions. This means that the cooling between October and April can be provided at very high efficiency, and at a cost and carbon intensity lower than providing heating to a less well-insulated building.

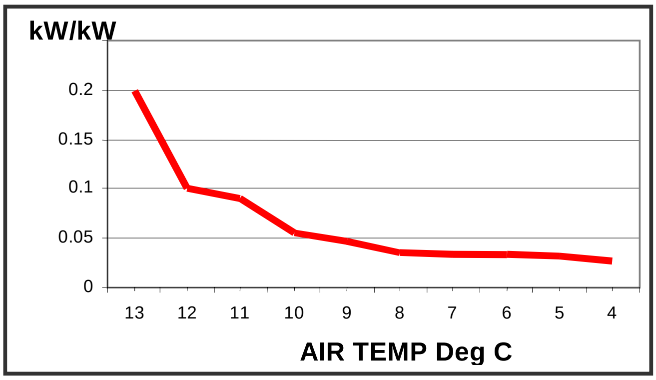

Fig. 6 Efficiency of "free" cooling

Conclusions

This paper has demonstrated a small sample of the evidence that has been developed to show that novel HVAC strategies can deliver significant benefits in well-insulated airtight buildings. This approach can deliver excellent thermal comfort, low initial cost, low operating cost, simple operating procedures and increased space flexibility. This gives all the

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[**] This is not an argument in favour of leaky buildings, since the infiltration will create unwanted draughts, and may reduce the effectiveness of insulation and the balance of ventilation systems.

commercial benefits required in the commercial property market – it also happens to be a more sustainable approach as a major added benefit.

Acknowledgements

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[1] DETR, ***Proposals for amending the energy efficiency provisions***, DETR Consultation paper, DETR, 2000

[2] ISO 7730, ***Moderate thermal environments: determination of the PMV and PPD indices and specification of the conditions for thermal comfort***, International Standards Organisation, 1994

[3] BCO, ***Best practice in the specification for offices***, British Council for Offices, 2000.