SECOND INTERNATIONAL
CIB SYMPOSIUM ON
ENERGY CONSERVATION IN THE BUILT ENVIRONMENT

PREPRINTS—SESSION 2

Methods to improve the building envelope

Sponsored by
CIB Working Commission W67
SOFUS - BYG
Danish Building Research Institute

May 28 - June
Copenhagen
Conclusion

Based on the measurements and calculations undertaken, it is almost certain that injection of insulation in crawl space basements is suitable in some form or other, like for instance:

a. Simple injection
b. Injection with external foundation wall insulation, possibly combined with drain pipes.

c. Like a. or b. with some kind of advance control of the boundary conditions as regards moisture.

d. Like a., b. and c. but with a fungicide mixed into the injected insulation.

When the project has been completed in 1 to 2 years, the empirical material is expected to be comprehensive enough for us to have found a method for the determination of the moisture and constructive boundary conditions which are clearly decisive of the choice of the method of insulation for a crawl space basement.

For the time being, we are of the opinion that closing the ventilation and measuring temperatures and moisture content in the soil below the crawl space basement after 1 to 3 months will result in the necessary boundary conditions for choosing the insulation procedure as insulation compared with this experiment will be an obvious improvement of the hygrothermal conditions in the floor construction.

The effect of insulation, mode of operation and air leakage on the energy demand of dwellings in the U.K.

D. J. Nevala, Head of Buildings and Environment Group, Heating Division, British Gas Corporation, U.K.

Summary

The paper describes the results of a computer study of the behaviour of two better insulated houses, one of rationalised traditional and one of timber frame construction. Their performance is compared with a contemporary house.

The conclusions of the study are that better insulation is an effective energy conservation measure, but the heavyweight characteristic of insulated structures results in intermittent heating being a less attractive means of reducing the heat demand. Air leakage, if not controlled, becomes an important component of the total heat loss and the consequences of its underestimation are explored.

Résumé

Cette étude décrit les résultats d'une étude par ordinateur du comportement de deux maisons avec une isolation meilleure, une a construction traditionnelle rationalisée et l'autre a charpente en bois. Leur performance est comparée avec une maison moderne.

On a conclu par l'étude qu'une isolation meilleure est une mesure effective en ce qui concerne les économies d'énergie mais la nature lourde des constructions isolées a pour conséquence que le chauffage intermittent est une méthode moins satisfaisante pour réduire les besoins en chauffage.

La fuite d'air, si elle n'est pas réglée, fait une partie importante des pertes du chaleur et les conséquences de sa sous-évaluation sont étudiées.
The effect of insulation, mode of operation and air leakage on the energy demand of dwellings in the U.K.

D. J. Nevola, Head of Buildings and Environment Group, Heating Division, British Gas Corporation, U.K.

The most widespread and effective measure taken to conserve energy in dwellings has been the application of better insulation. What may not be appreciated in the first instance is that a better insulated dwelling may not behave as expected for a number of reasons. The factors considered most important are discussed in this paper.

The consequence of better insulation levels and therefore low fabric heat losses, is the emergence of the ventilation heat loss as an important factor which has to be explored.

Better insulation - background to research programme

The British Gas Corporation, as the dominant supplier of fuel for domestic heating, has an interest in the implication of future trends in building design and of the likely patterns of energy demand. An analysis of past trends and likely future developments in the provision of housing by traditional and non-traditional methods in the U.K. has shown that it is the rationalised traditional and the timber-framed methods of construction which are likely to dominate the market. The study has also shown that because of changes in the structure of the population and other socio-economic factors, it is likely that the typical dwelling will have a floor area of around 80 m².

For this reason, the British Gas Corporation initiated a computer based study of the performance of these two types of better insulated semi-detached houses, one of rationalised traditional and the other of timber framed construction. In our view, the two types represent the practical limits of "heavyweight" and "lightweight" construction likely to appear in the mass housing market in the near future. The performance of these two types of better insulated houses was compared with a contemporary house, the insulation levels of which were based on current practice and conform to the requirements of the U.K. Building Regulations. The size, plan and glazing areas of all three structures are identical and the total design heat loss as calculated according to the CIBS Guide, of the two better insulated houses are identical. Details of house construction, fabric and ventilation heat losses and of useful fortuitous heat gains are given in Table 1.

The computer program which was used in the analysis of the thermal performance of the structures had been developed on the basis of the work of Rouvel.

<table>
<thead>
<tr>
<th>TABLE 1 DETAILS OF HOUSE CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTEMPORARY</td>
</tr>
<tr>
<td>Ground Floor</td>
</tr>
<tr>
<td>First Floor</td>
</tr>
<tr>
<td>Ceilings</td>
</tr>
<tr>
<td>Roof</td>
</tr>
<tr>
<td>Internal Walls</td>
</tr>
<tr>
<td>External Walls</td>
</tr>
<tr>
<td>Glazing</td>
</tr>
<tr>
<td>Fabric heat loss (W)</td>
</tr>
<tr>
<td>Ventilation heat loss (W)</td>
</tr>
<tr>
<td>Total design heat loss (W)</td>
</tr>
<tr>
<td>Total diurnal useful heat gain (MJ/day)</td>
</tr>
</tbody>
</table>

The current U.K. practice of sizing space heating systems, as recommended in the CIBS Guide (i), is to calculate the heat loss based on an external design temperature of -8°C and then to add an extra 20% to the total. The additional 20% is basically in recognition of the fact that the external design temperature should be several degrees lower. The accepted sizing procedure therefore implicitly assumes continuous heating in cold weather.
However, a study of the way central heating systems are used in the U.K. has shown that even in cold weather conditions the majority of householders (70%) operate their systems intermittently. (The reasons are - it is thought that intermittent operation results in a substantial reduction in fuel costs, house is occupied in the morning and evening only, heating system is grossly oversized thus permitting intermittent operation, lower comfort standards are accepted etc.). Although, strictly speaking, heating systems are sized to operate continuously at design conditions, it is just as important to examine the performance of structures at design conditions when heated intermittently as there is a high probability that in practice they may be heated in this manner.

Effects of better insulation
A structure will be subjected over the heating season to a wide range of climatic conditions, cloud cover being one important variable. In cloudy conditions the heat requirement, for continuous heating, will not vary significantly over a 24 hour period and its magnitude will depend on the level of insulation. The more complex phenomena associated with thermal storage in multi-layer walls affect the energy demand only to a limited degree. The difference in the thermal performance of structures is more accentuated on clear sunny days. For this reason, it will be the energy requirements and temperature variations of structures on clear days that will be used to illustrate the main point in the following discussion, although the original research investigated the performance of structures under a whole range of climatic conditions.

The energy requirement and the internal temperatures of practical intermittently heated better insulated houses on a clear day having a mean external temperature of -1°C are shown in Fig. 1. The limits of a band, within which the majority of better insulated houses would lie, are given by the performance of the "heavyweight", H, (rationalised traditional) and "lightweight", L, (timber-framed) houses. Also shown in Fig. 1 are the values for the contemporary house, C. For comparison, the energy requirements of continuously heated structures are shown in Fig. 2.

From Fig. 1 and Fig. 2 it can be seen that the diurnal energy requirement on a clear design day has been more than halved by a reduction of the design heat loss from 3.9 kW to 3.4 kW, i.e. 177 MJ instead of 394 MJ for continuous heating, and 149 MJ instead of 326 MJ when heating is intermittent. The reduction in heat requirement is not proportional to the reduction in design heat loss because of the way the structure can make use of incidental heat gains. The results of the study tend to show that there is little
difference between the energy requirements of the two better insulated houses although their method of construction is significantly different and, as mentioned before, in our view, they represent the two practical extremes of heavyweight and lightweight construction that will be adopted in the mass housing market. For the above example, a more general statement can therefore be made – a 42% reduction in design heat loss results in a 55% reduction in energy requirement on a cold clear day. Surprisingly, the percentage is only slightly reduced on a cold cloudy day to 50%. On a "typical" winter day, in U.K. climatic conditions, one having a mean diurnal temperature of +6.5°C, the percentage reduction rises to 63% on a clear day and 56% on a cloudy day. The above results, showing that proportionally more energy is saved than the increase in insulation levels would suggest, indicate that a realistic better insulated structure can make good use of the internal heat gain, relatively independent of the time of their occurrence and of the mode of operation of the heating system. The ability to utilize internal heat gains can only be explained by a heavyweight characteristic of the structure.

The temperature profiles in Fig. 1 show that better insulated houses of both conventional and timber-framed construction do not cool down overnight as much as the conventional house. Subsequently, with conventionally sized heating systems, all three structures require approximately six hours to reach design temperature. In this respect, the better insulated house behaves as if instead of extra insulation more thermal mass had been added to the contemporary structure. This heavyweight characteristic of insulated houses will affect the energy saving potential of intermittent modes of operation of the heating system.

Although the heating plant has to be designed to perform adequately under specified extreme conditions, i.e. peak design requirements, for most of the time it will operate in much milder climatic conditions. It is therefore in these milder climatic conditions that the thermal properties of a structure are most important. It is when the heating system has to respond to a rapidly changing situation and usually has to operate at both its maximum and minimum output levels. In Fig. 3 the variation of percentage heat output of a heat source sized according to current U.K. practice (1.2 x design heat loss) with external temperature over a 24 hour period is given. The percentage heat demand curve of better insulated structures is always more extreme (i.e. the ratio of maximum to minimum demand are greater) than that of the uninsulated structure for the same external conditions. It can be seen that the percentage demand curve of insulated houses at -1°C is more akin to the uninsulated structure at +6.5°C. Better insulated structures may therefore impose more stringent requirements on the operation of heating systems.

**Mode of operation**

When operated intermittently at design conditions, see Fig. 1, the timber-framed house, as expected, cools down overnight more than the insulated house of traditional construction. Both insulated houses and the contemporary house, require a long time (approximately 6 hours) to reach design temperatures. It is a question whether some of the lower temperature would be acceptable and whether a night set-back to, say, 16°C would be desirable. It could be argued that because of higher activity levels of the occupants (housewives) lower morning temperatures would be tolerated or even considered desirable.

To achieve design temperatures in the morning, say, at 7 o'clock, it is evident that a heat source sized in the usual manner (design heat loss x 1.2) would permit only nominal intermittent operation, the plant being only a few hours "off". With low plant size ratios (plant capacity over design heat loss p = 1.2) the bulk of the energy saved due to intermittent operation (14-17°C) can only be at the expense of lower environmental standards during hours of occupancy.

Fig. 4, where the variation of warm up time with plant size ratio is plotted, shows that to achieve short warm up times at external design conditions plant size ratio of 2 or even 3 would be required. Such excess capacity would undoubtedly raise the initial cost, which would have to be...
Figure 4. Variation of warm-up time with plant size ratio on a clear design day ($T_{\text{mean}} = 15^\circ C$).

taken into account when savings due to intermittent operation are calculated.

To establish the extreme practical annual energy savings due to intermittent operation, a minimum pre-heat time of one hour at design conditions was specified for a series of computer simulations. A house nearly identical to the better insulated house of traditional construction, as described in Table 1, was used. The principal difference was a reduction of the cavity insulation to 25 mm and the retention of single glazing, the changes resulting in a higher design heat loss of 4.5 kW. For these simulations a BGC computer program THERM, enabling multicell operation, was used. The relative annual energy saving for various modes of operation are given in Table 2.

TABLE 2 RELATIVE ENERGY REQUIREMENTS OF A HOUSE FOR VARIOUS MODES OF SYSTEM OPERATION

<table>
<thead>
<tr>
<th>Mode of Operation</th>
<th>Relative Energy Requirement (%)</th>
<th>System &quot;on&quot; Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td>100</td>
<td>All day</td>
</tr>
<tr>
<td>Set-back to 15°C</td>
<td>90</td>
<td>0600-2300</td>
</tr>
<tr>
<td>$= 10^\circ C$</td>
<td>87</td>
<td>0600-2300</td>
</tr>
<tr>
<td>$= 5^\circ C$</td>
<td>87</td>
<td>0600-2300</td>
</tr>
<tr>
<td>Intermittent</td>
<td>87</td>
<td>0600-2300</td>
</tr>
<tr>
<td>Zone Control</td>
<td>81</td>
<td>GF 0600-2300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1st F 0600-0900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and 2000-2300</td>
</tr>
</tbody>
</table>

GF = Ground floor; 1st F = First floor.

The results show that the potential savings are of the order of 40%, except for zone control. Intermittent and set-back to $10^\circ C$ and $5^\circ C$ give the same answer because the internal temperature does not drop below the trigger value. For practical purposes, it can be assumed that savings due to any intermittent mode of control will probably not exceed 20%.

Effect of air leakage

As a result of higher insulation levels the fabric heat loss diminishes and, if no special precautions are taken, the relative importance of the ventilation heat loss will be greater. In the contemporary house, ventilation accounts for a quarter of the total design heat loss in the former, whereas in the better insulated house it is 40%. Air leakage is therefore an obvious target of further energy conservation measures. The ideal solution, which may not be cost effective, would be to seal the house and introduce mechanical ventilation and heat recovery. A less costly alternative would be to install tight windows and external doors. Unfortunately, as a result of measurements made by British Gas and other institutions, there is reason to believe that the fitting of tight windows may not have the desired effect in houses built in the U.K.

Fig. 5 shows the results of air leakage tests of three houses in the U.K. and, for comparison, of a test house in Belgium. Although measurements 2 and 3 were made in houses where precautions were taken to minimize air leakage around windows, these houses do not show a vast improvement over house 1, where no precautions were taken. (House 2 is also somewhat larger, detached and older than house 1). The method of construction and the average quality of workmanship in the U.K. are evidently a factor, as a comparison with the Belgian house 4 would suggest.

The consequences of a failure to appreciate the inherent leakiness of U.K. houses is illustrated in Fig. 6, where the results of a computer analysis are plotted. The better insulated house of rationalised traditional construction, as described in Table 1, was "fitted" with tight windows which resulted in an average air change rate of 0.4 per hour.

It is recommended practice (CIBS Guide) that the sum of calculated individual room air change rates of a house is halved when the central plant is sized. (Outside air enters on one side of the house and leaves the other and it is solely the outside air which is the cause of the ventilation heat loss). In Fig. 6 the consequences of the above described house, having the central plant sized according to the recommended procedure (50% of 0.4 air changes per hour), being exposed to 1 air change per hour are
A computer study has shown that there is no significant difference in the thermal behaviour of realistic lightweight (timber-framed) and heavyweight (rationalized traditional) better insulated houses. Better insulation is an effective measure of reducing energy requirements. A 42% reduction in design heat loss could result in a 50-60% saving in energy demand depending on mode of operation and external climatic conditions.

Compared with contemporary structures, the better insulated house behaves in a heavyweight manner, with the consequences that annual energy savings due to intermittent operation are limited. Even with high plant size ratios (plant capacity over design heat loss) of \( p = 2-3 \) and preheat times of one hour, the maximum energy saving using zone control is less than 20%. To avoid high plant size ratios continuous heating would have to be used in cold weather conditions, the penalty of higher annual energy demand being only slight.

Better insulated dwellings will impose more stringent requirements on the operation of heating systems because the relative heat demand (heat demand over plant capacity) will fluctuate more than in uninsulated dwellings. The fluctuation in heat demand of better insulated dwellings will be accentuated by the now relatively large variable ventilation heat loss. The specification of tight windows and external doors may not be sufficient to control air leakage. In the U.K., a significant proportion of air leakage is directly attributable to the method of construction and standard of workmanship.

In the future, if the present house construction method and its usage pattern (intermittent heating) are not changed, large plant size ratios and individual room temperature control may be necessary.

References
Summary

A model is presented whose input is two sets of measurements: 1. air leakage under fan pressurization, and 2. natural pressure differences between indoors and outdoors. The output is the home's natural infiltration rate. The model was tested on six United States houses, three conventional houses located in a region of mild climate and three energy-efficient houses located in a cold winter region of the country. Good agreement was obtained between infiltration rates measured using a tracer gas and rates calculated from the model.

Résumé

Nous présentons un modèle nécessitant deux ensembles de mesures: 1. fuites d'air sous pression par un ventilateur et 2. différences de pression naturelles entre l'intérieur et l'extérieur d'une maison. Le résultat du modèle est le renouvellement naturel d'air. Ce modèle a été vérifié sur six maisons aux États-Unis, dont trois maisons conventionnelles situées dans une région de climat tempéré et trois maisons d'efficacité énergétique situées dans une région froide du pays et visitées en hiver. Nous avons obtenu un bon accord entre les prédictions du modèle et les taux de renouvellement d'air mesurés avec un gaz traceur.