Factors affecting energy consumption of buildings

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ABSTRACT

The thermal insulation requirements of the Building Code of Finland have been tightened several times since the first energy crisis in the 1970s. The latest revisions have been justified by the international goal of reducing carbon dioxide emissions. This paper discusses some of the factors affecting the energy consumption of buildings based on studies conducted at Tampere University of Technology during the past 15 years. Measurements covering several years show that the heating energy needed to offset the heat loss through exterior walls is, on average, about 50 % of the calculated value. The calculated value is based on thermal transmittance values (U-values) of walls and the method of calculating their areas. The heat storage capacity of exterior walls reduces the energy needed for heating because solar radiation energy can be stored during the daytime. Electricity consumption has grown due to the increased standard of living. Much of the electricity consumed internally converts into heat and offsets some of the supply needed from the normal heating system. Nowadays houses are also better insulated and built. The end result is that the heating season is becoming shorter and the need for cooling is increasing.

INTRODUCTION

Tampere University of Technology has during the past 15 years carried out several studies on the energy consumption of buildings. Many results show that calculational analysis of energy consumption does not in all cases give a sufficiently reliable overall picture. Several other factors also have an essential impact on the total energy consumption of a building.

Apparently, the measures now taken to slow climate change aim at limiting or even reducing the growth of actual energy consumption. The issue is also political, but the development of energy regulations should not be based merely on calculational analyses.

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THE DIFFERENCE BETWEEN CALCULATED AND MEASURED ENERGY CONSUMPTION

In 1996 Tampere University of Technology launched a study to determine the thermal performance of different types of exterior wall assemblies and to find out how accurately current heat loss calculation methods predict actual heat loss. Six test buildings similar in structure and dimensions, with the exception of the exterior walls, were the subjects of study. The floor area of each test building was 2.4 m x 2.4 m and the free floor to ceiling height 2.6 m. The ceilings and floors of all buildings were of 200-mm polyurethane, and each had a single door facing the same direction and no windows. Temperature, humidity, etc. were monitored constantly.

The exterior walls of the test houses were of the following types:

1. Polyurethane (PUR) insulated wood-framed wall, calculated U-value 0.17 W/m^{2}K
2. Insulated cavity brick wall, U=0.27 W/m^{2}K
3. Insulated log wall, U=0.29 W/m^{2}K
4. Plastered massive brick wall, U=0.86 W/m^{2}K
5. Autoclaved aerated concrete (AAC) block wall, U=0.35 W/m^{2}K
6. Massive log wall, U=0.6 W/m^{2}K.

The aim of the study was to measure how much energy the walls require for heat conduction and whether that amount could be derived from the calculated coefficient of thermal transmittance (U-value). The results for the first year indicated the performance of the structures. The summarized results for the heating season 1997–1998 are shown in Figure 1.

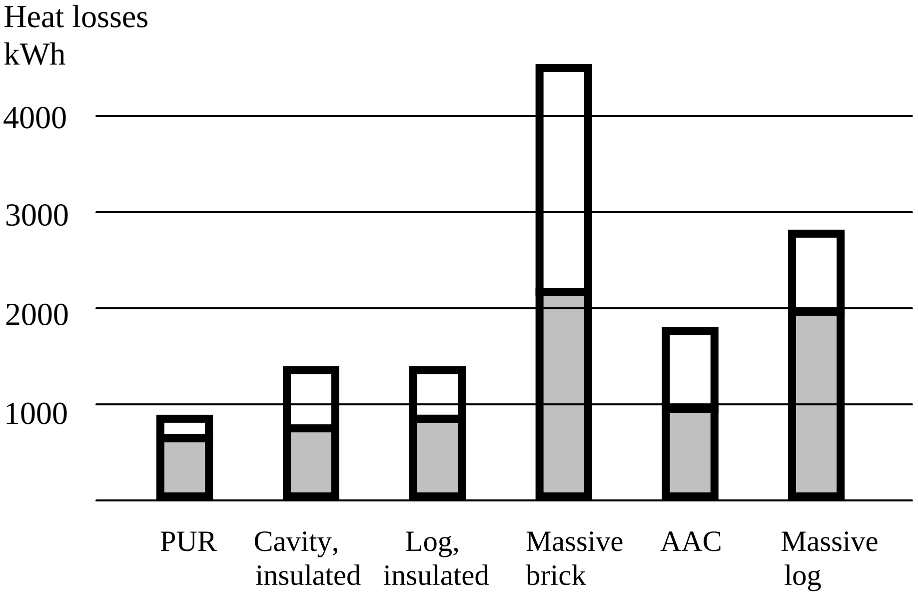


FIGURE 1
Transmission heat losses during the 1997–1998 heating season [Lindberg et al. 1998]

The grey bottom part of the columns indicates measured energy consumption during the heating season. The total height of the columns represents the calculated energy consumption based on the U-values of the exterior walls. Measured consumption was, on average, about 50% of the calculated value meaning that actual measured consumption was in all cases less than the calculated value.

The figure shows that structures with a high U-value lead to high heating energy consumption. On the other hand, the measured and calculated energy consumptions differ most.

There are three main reasons for the difference between measured and calculated energy consumption: (1) the material properties from which the U-values are calculated, (2) the areas of the walls, and (3) the solar radiation energy stored in the external part of the exterior walls.

The U-values are calculated from the thermal conductivity values of the materials. The regulations on the U-values of different structures must be observed. It is a design question. We use material properties known with some certainty. Measured thermal conductivities of materials form a distribution as all other material properties. For the calculation of a U-value, a suitable value at the upper end of the distribution is chosen. It is clear that when the aim is actual energy consumption, the real thermal conductivity of materials should be used. The difference between the average thermal conductivity and the thermal conductivity value used to calculate the U-value is quite big with some of the thermal insulation materials used in Finland.

The amount of heat energy lost through an exterior wall is linearly dependent on the wall area. In the exterior wall of a building, the area can be based on internal or external dimensions, or some area in between can be used. Differences between the areas are large due to the thickness of the insulation.

Traditionally areas based on the external dimensions of insulations have been used. That is a sound principle from the viewpoint of design as it allows providing sufficient heating power for each room with view to the coldest possible situations. Apparently various calculation models use areas based on external dimensions.

Analysis of the measurement results shows that actual consumption should be evaluated based on dimensions close to internal dimensions. For instance, the higher energy consumption at an outside corner is reduced by the decreasing temperature difference around the corner area. The internal section of the corner has a lower temperature than inside air while the external sections have a higher temperature than the outside air. This smaller temperature difference thereby reduces energy consumption.

A third key factor is the effect of the thermal mass of the external surface of the exterior wall in cutting energy consumption. It is explained in the following chapters by two examples.

THE EFFECT OF THE THERMAL MASS OF THE EXTERNAL SECTIONS OF EXTERIOR WALLS ON ENERGY CONSUMPTION

Figure 2 presents a single daily measurement result. The measurement date was March 13, 1998 and the structure the southern façade of an insulated cavity brick wall. The structure from the inside out is: 130-mm brick, 125- mm mineral wool, 30-mm wool sheathing, 20-mm ventilation gap, 85-mm clay brick.

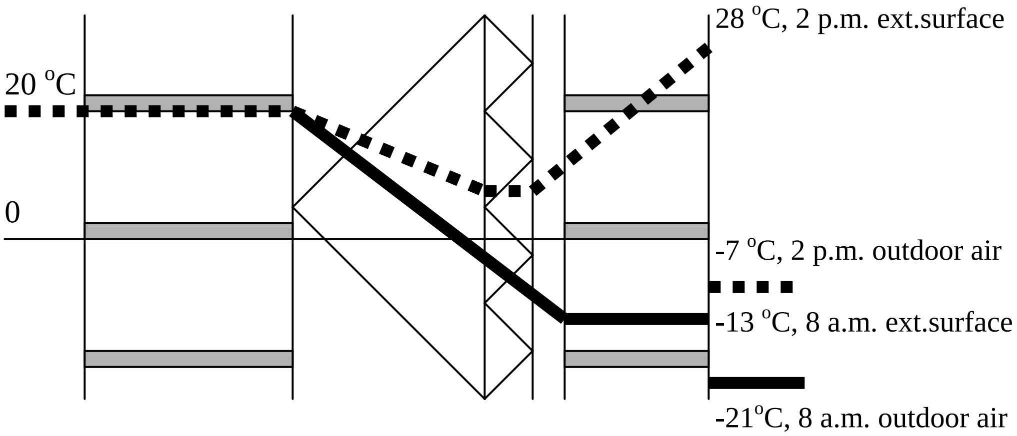


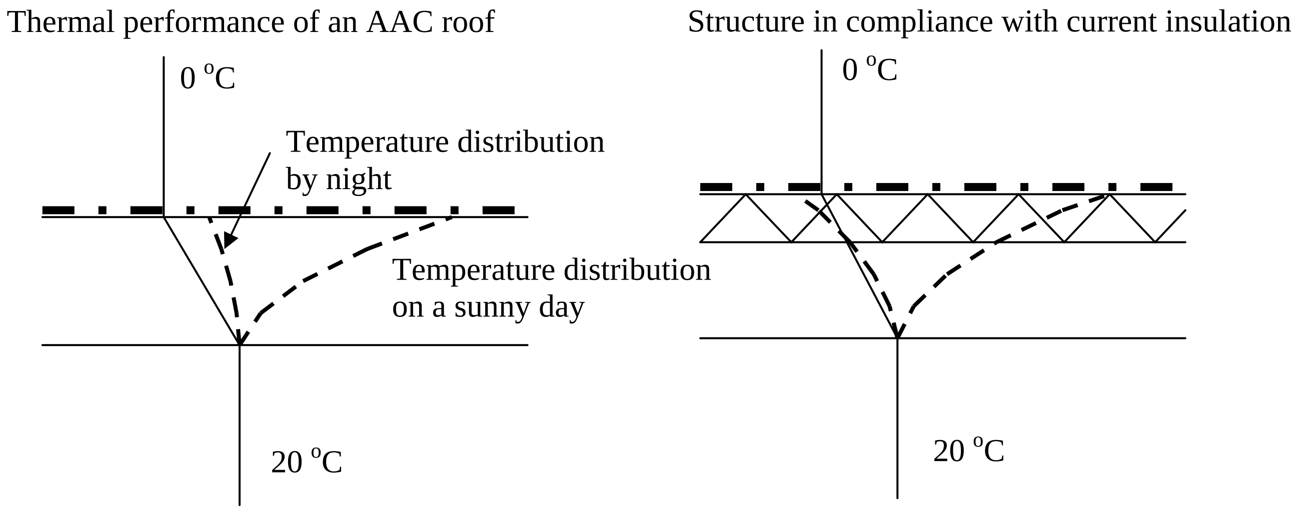
FIGURE 2
Temperature distribution of an insulated cavity brick wall [Lindberg et al. 1998]

The figure shows the rough temperature distribution at 8 a.m. and 2 p.m. At 8 a.m. outdoor air temperature was about -21 °C, while the ventilation gap air temperature was about -13 °C – much higher than outdoor air temperature. According to measurements, the temperature distribution in the insulation layer was close to that of the stationary state.

At 2 p.m. outdoor air temperature was -7 °C, the external surface of facing brickwork was + 28 °C and ventilation gap air temperature about +10 °C.

The measurement results can be explained by the fact that, except in the dead of winter, solar radiation heats the modular brick. In March, the temperature of the external surface of a brick wall may reach +30 °C. Measurements showed that the temperatures of walls facing other directions also increase significantly.

The ventilation gap air is generally assumed to be of the same temperature as outdoor air, and the cladding is ignored in calculations. However, the thermal energy from solar radiation stored in the cladding during daytime warms the air in the ventilation gap and has a big momentary impact on the need to offset heat loss. This advantage is not available throughout the year, but its impact is much greater than believed. Based on these measurement results, the energy stored in the mass near the exterior surface diminishes the need to offset heat loss through exterior walls.


Thermal performance of an AAC roof

Structure in compliance with current insulation

FIGURE 3
Thermal performance of an AAC roof at a certain moment

During the winter of 2002–2003 the temperatures in the autoclaved aerated concrete roof structure of a Finnish factory were measured constantly. A rough summary of the measurement results at a certain point in time is shown in Figure 3. The thickness of the reinforced AAC elements was 300 mm, and they had roofing felt glued on top.

The average daily temperature at the moment of examination was 0 °C and the indoor air temperature +20 °C. Both of the graphs in Figure 3 have a curve representing the stationary temperature distribution. The left one shows how solar radiation striking a dark felt roof affects the temperature of the structure below it. It is known that the effect can be substantial, even tens of degrees. At night the felt cools, but the heat storage capacity of AAC keeps the elements warm. The end result is that the external surface of the AAC roof remained above the mean outdoor air temperature even during the night.

During winter the structure performs as follows. Snow on the roof insulates the structure for its part and reduces conduction heat loss. When the snow melts away, the AAC stores significant amounts of energy from solar radiation. Naturally, that advantage cannot be achieved throughout the year. Based on the measurements the total impact of heat storage capacity on energy savings was about 20 %.

This result can be interpreted, for example, so that the structure has a lower effective U-value than calculated. Presently, this effect cannot be taken into account. The graph on the right in Figure 3 shows the structure built according to current regulations. The temperature curves are similar, but the element temperatures vary much less and the advantage of the massive structures of the left graph do not exist.

CONNECTION BETWEEN INCREASED LIVING STANDARD AND NEED OF HEATING ENERGY

The climate change has resulted in worldwide energy saving measures, for instance, in the form of better insulation of buildings. Extra insulation is a question often dealt with in building physics and renovation. The following example illustrates the wider impact of this development.

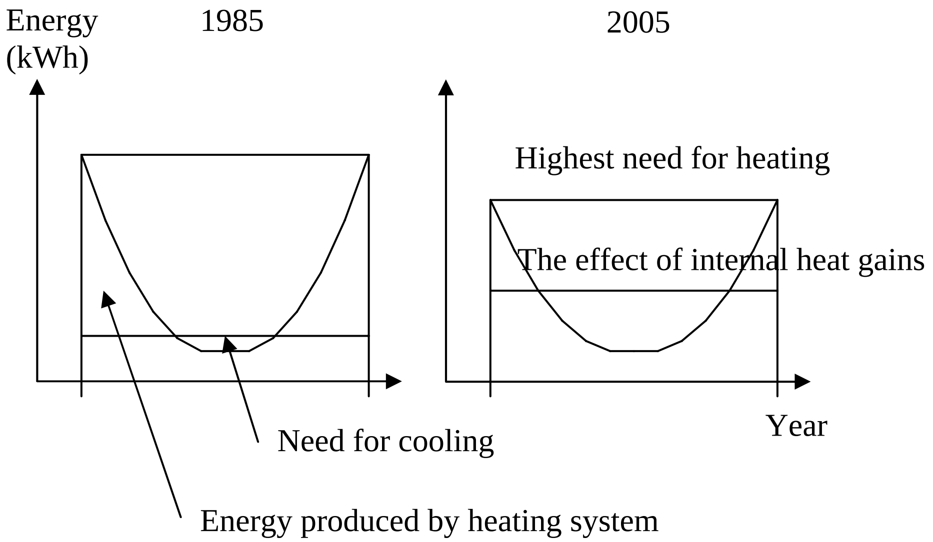


FIGURE 4
Annual use of energy for heating in different decades [Lindberg & Leivo 2005]

Figure 4 examines two buildings of identical size and shape at two different points in time. The buildings differ as to insulation level due to tightened building regulations, construction quality, and electricity consumption due to a higher standard of living. The comparison is rough and only suggestive.

The graph on the left represents a building, for example a single-family house, built in 1985 while the graph on the right represents the same house built 20 years later. The horizontal axis represents a full year starting from January on the left and ending with December on the right. The vertical axis represents the energy needed for heating, or more specifically, the energy required at a certain time.

The top horizontal line represents the total heating power that must be available for a building in order to get over the coldest part of winter. The line is at a lower level in the newer building due to better insulation and construction. The difference is difficult to assess because the comparison cannot be made for practical reasons. The real relative difference could be approximately as shown in Figure 4.

The lower horizontal line represents the amount of internal heat gains. Their main source is the use of electrical equipment. That energy is known to be expensive, but on the other hand, it has offset the energy supplied by the heating system. The standard of living and, above all, electricity consumption have increased significantly in the studied period meaning that the energy produced by electrical equipment has also increased substantially. A comparison is difficult to make also in this case, but the amount of internal heat gains can be roughly estimated to be twice as high in the newer building than in the older one. The curved lines in the figures represent the effect of different seasons and the heating energy requirements in different seasons.

The arrow in the left graph in Figure 4 shows the energy need to be covered with the heating system. It is needed during the cold winter period. During summer internal heat gains and outdoor air as such require cooling. The need for cooling is also shown with an arrow. Previously cooling systems were not used in normal single-family houses because the need for cooling concentrated mainly on a short period in summer. It is remarkable that the heating system and internal heat gains complemented each other, that is, both sources of energy were utilized in heating.

The graph on the right shows that due to the diminished need for energy and the increase in internal heat gains, the heating system supplies an increasingly smaller share of the total energy consumed. The heating system is also necessary only during the coldest period of each year. Internal heat gains actually create a need for cooling during most of the year. Cooling systems are nowadays used even in single-family houses. This is well justified, but the total effect is hard to estimate, for example from the point of view of global warming.

Energy savings as such are worth pursuing in all areas. Tighter insulation regulations on new buildings bring only marginal overall savings. Bigger savings can be realized in existing buildings – especially by influencing the use habits of occupants and other building users.

When viewing the issue from a wider, let's say a Central European, standpoint, one cannot help but wonder about their thermal insulation requirements which are often stricter than in Finland. Yet, they have a very high standard of living and a large cooling need.

CONCLUSIONS

Some thoughts on energy consumption were presented in the above. They are based on the results of numerous measurements and other research. Although they were presented in summary fashion, they nevertheless show clearly that we are not in full control of issues related to energy need. There are significant aspects related to the performance of buildings that should be taken into account when revising regulations.

In addition to the impact of the occupants, there are five other important factors related to energy consumption of buildings that need to be considered: heat loss from conduction through building envelope, energy used by ventilation systems, savings from ventilation air heat recovery, air infiltration and occupants attempting to prevent the resulting draft. If there is infiltration through the building envelope, occupants tend to raise indoor air temperature which increases conduction heat losses and energy loss through ventilation and reduces the energy efficiency of the heat recovery system. One of the main requirements for buildings that will result in major savings in energy use is improving the airtightness of the building envelope. The most effective overall means to reduce energy consumption, however, is to influence the occupants to save energy.

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