On energy conservation characteristics of autoclaved aerated concrete

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The paper discusses aspects related to the energy conservation characteristics of autoclaved aerated concrete (AAC). These include thermal properties, thermal inertia and dynamic thermal behaviour, the new California Energy Standard with its concern for total energy utilization and the pioneering recognition of the thermal inertia of 'light mass', some experimental evidence of lower energy consumption, and measurements of the air tightness of AAC buildings. As a building material, AAC is likely to become increasingly important in energy conservation.

NOTATION

\( A_e \) External temperature amplitude
\( A_i \) Interior temperature amplitude
\( C \) Thermal conductance (W m\(^{-2}\) K\(^{-1}\))
\( R \) Thermal resistance (m\(^2\) K W\(^{-1}\))
\( R_a \) Thermal resistance of air gap (m\(^2\) K W\(^{-1}\))
\( R_e \) Thermal resistance of external surface (m\(^2\) K W\(^{-1}\))
\( R_i \) Thermal resistance of internal surface (m\(^2\) K W\(^{-1}\))
\( R_t \) Total thermal resistance (m\(^2\) K W\(^{-1}\))
\( t \) Thickness (m)
\( TIF \) Thermal inertia factor
\( U \) Thermal transmittance (W m\(^{-2}\) K\(^{-1}\))
\( \lambda \) Thermal conductivity (W m\(^{-1}\) K\(^{-1}\))

1. INTRODUCTION

In the past, energy use in buildings was of little concern since energy resources were considered relatively plentiful and inexpensive. The emphasis was not on energy characteristics of the building enclosure but on the provision of space heating and cooling equipment for the desired level of comfort. In the United States, the greater part of all the energy used in a typical house is devoted to environmental conditioning. Few houses were built with an air leakage rate of less than one-half building volume per hour (0.5 air changes per hour). More typical construction has an air leakage of 1 to 1.5 air changes per hour [1]. Heating the leakage air often accounts for one-third or more of all the heating energy requirements of the house.

Historically, the construction cost or sale price of housing has dominated investment decisions in the housing market. As a result, energy conservation features that were incorporated into the building design were often based on comfort considerations or on a reduction in the costs of heating and cooling equipment rather than on a reduction of long-term operational costs.

With the crisis of the early 1970s the spiralling cost of energy became the subject of intense international concern. In the US, the total annual expenditure on energy per household, including space heating and cooling, doubled between 1970 and 1975 [1]. The rise in the price of fuels relative to that of labour and materials has focused attention on total life-cycle costs. This shift in emphasis from short-term first-cost and speculative factors to the energy conservation technologies stimulated by life-cycle cost analyses and by new government code requirements will cause a number of major physical changes in new construction over time. Design emphasis
on the shell of a house has the potential to halve the energy requirements of homes. Life-cycle performance standards for new building design will lead to a shift from high insulation values, which are based on a steady-state heat flow concept, to an emphasis on dynamic thermal analysis. Energy consumption is influenced not only by insulation factors but also by peak heat flows and the times at which they occur, which in turn depend on the thermal inertia and dynamic characteristics of the building envelope.

Autoclaved aerated concrete is a lightweight cellular material manufactured in the factory in the form of masonry units or large reinforced elements for walls, floors or roofs. A number of its properties are highly conducive to energy conservation. This paper discusses these aspects, in particular primary energy of manufacturing, thermal properties, thermal inertia and dynamic behaviour, and the potential for low air leakage.

2. PRIMARY ENERGY OF MANUFACTURING

The energy required to produce AAC can be divided into three parts [2]: the energy to produce the raw materials and the auxiliary materials contained in AAC, energy required to transport the raw materials to the factory, and the direct energy for the actual factory production of AAC. Table 1 shows the details of total primary energy consumption of AAC as determined in an investigation of AAC blocks, of an average density of 505 kg m\(^{-3}\), made at seven factories of a West German manufacturer during the period of 1980 to 1983.

The total average primary consumption in 1983 has decreased 8.5\% in four years due to improved utilization and reuse of high-pressure steam in autoclaving. In this respect AAC compares favourably with other materials for wall construction. According to published values, only pumice concrete and sand-lime bricks have slightly lower values [3,4].

3. THERMAL PROPERTIES

3.1 Thermal conductivity and conductance

Thermal conductivity, \(A\) (W m\(^{-1}\) K\(^{-1}\)), measures the insulating ability of a homogeneous material. It represents the quantity of heat flowing per unit time by conduction through a unit thickness of a unit area of the material, across a unit temperature gradient, i.e. when the difference in temperature between the two sides is one degree. It is assumed that temperature on either side of the material and the distribution of temperature throughout the material are uniform and constant with time, i.e. steady-state conditions. The lower the value of thermal conductivity, the better the insulating ability of the given material.

The thermal conductivity of AAC depends primarily on its density: the higher the density the higher the thermal conductivity. Also moisture content has a significant effect. Other influencing factors include raw materials and pore structure. Table 2 gives typical values for dry AAC of different densities. In comparison with normal-weight concrete the thermal conductivity of AAC is about one-tenth, thus providing superior insulation.

Immediately after autoclaving AAC contains typically 30\% of water by weight of dry material. When it reaches equilibrium after construction the moisture content drops to about 3 to 4\% by weight. Field samples taken in Germany have shown that 90\% had a moisture content of less than 5\% by weight [6]. The increase of thermal conductivity with moisture is about 4\% for each 1\% increase of moisture content.

Thermal conductance, \(C\) (W m\(^{-2}\) K\(^{-1}\)), measures the insulating ability of a given material with its particular thickness (\(t\)). Thus, it is equal to thermal conductivity divided by thickness: \(C = \frac{A}{t}\).

3.2 Thermal resistance

The thermal resistance, \(R\) (m\(^2\) K W\(^{-1}\)), of a homogeneous material is the reciprocal of its thermal conductance: \(R = \frac{1}{A}\). Similarly the thermal resistance of the exterior surface (\(R_o \approx 0.04\)), the interior surface (\(R_i \approx 0.107\)), and of an air gap (\(R_g \approx 0.16\)) are all obtained from the reciprocals of their respective thermal conductance. Thermal resistances are additive. For composite construction, the total thermal resistance \(R_T\) is the sum of the resistances of the various components, including any solid materials, air spaces and surface films.

3.3 Thermal transmittance

Thermal transmittance, \(U\) (W m\(^{-2}\) K\(^{-1}\)), is similar to thermal conductance but it measures the insulating abil-