Autoclaved aerated concrete for construction in hot regions

H. Almudhaf and F. Al-Ragom, Kuwait Institute for Scientific Research, Kuwait

Abstract

The common construction system used in Kuwait is a frame structure consisting of reinforced heavy concrete beams and columns with reinforced floors and roof slabs. Walls are constructed by filling the skeleton with masonry blocks. This type of construction is the dominating system used in the Arabian Gulf Countries and is even used in one and two story residential buildings.

Autoclaved aerated concrete (AAC) was introduced in the mid 1980's as an alternative material that can provide both the structural and heat resistance characteristics required. AAC is produced as masonry units to be constructed in RC skeleton construction, in addition to reinforced AAC panels which are constructed as a homogeneous AAC precast system.

This paper reviews the performance of buildings constructed using AAC. The structural and thermophysical properties are presented. Patterns of energy consumption of a typical building were developed using a computer building simulation program and energy savings calculated. Finally the findings are reflected on the national scale as environmental aspects of the production process, building performance and power supply requirements.

Keywords: Autoclaved aerated concrete, building performance, energy consumption, hot regions.

1 Introduction

Concrete frame structure is the common construction system in Kuwait. Such a system consists of a skeleton of reinforced concrete beams and columns with reinforced concrete floor and roof slabs. Walls are constructed by filling the skeleton with masonry blocks. This type of construction is even used in one and two story residential buildings. Load bearing wall construction is rarely used. The most commonly used masonry blocks are made of solid heavy concrete with a low compressive strength. With such practices, the unit weight of wall construction could reach 380 kg/m^2 while the unit weight of roofs reaches up to 440 kg/m^2.

Kuwait's summer lasts from April to October; it is hot, with maximum temperature reaching 50 °C or more in shade; and it is dry, although relative humidity can reach 60% in late summer and 90% in autumn and winter. Solar radiation is high; in late summer it may reach 1,100 W/m^2, and there are more than 230 days of clear sky in a year. Winter temperatures arc in the range of 10-20 °C. Rainfall, which occurs between October and May, is sparse; it may range from as little as 50 mm to more than 300 mm. Average wind speed is 3 m/s. The prevailing wind is northwesterly and is dry, since it passes over a large region of desert; the secondary wind is southeasterly and moist, since it comes in from the Arabian Gulf.

Electrical energy consumption is governed by the need for space cooling, to the extent that air-conditioning peak power consumption in Kuwait during the summer reaches 70% of the total generated . The excessive demand for air-conditioning is attributed to the extreme ambient air temperature during the summer. Though a large proportion of the increase in demand has been caused by the steady increase in per capita consumption, an important factor contributing to the increasing consumption rate is the government's subsidy to consumers, reflected by the low price of the electric unit. This is as low as 2 fils/kWh, representing 5% of the actual present cost. Another factor is the erroneous assumption that, due to the wide availability of low-cost fuel in oil-rich countries, like Kuwait, power generating costs are trivial. In fact, the production, transmission and distribution costs of electric power place a heavy burden on the state budget, in light of the world energy crisis and such factors as the import of equipment and technical skills.

2 Energy conservation measures

In response to the rapid increase in electricity demand, conservation measures had to be introduced and enforced to curtail the energy requirements in buildings. The Kuwaiti Ministry of Electricity and Water (MEW) code of practice for energy conservation in buildings [1] sets several requirements to limit the peak loads for space cooling. The peak electrical load for residential buildings is set at a maximum of 65 W/m^2. To meet such requirements, the code presents target minimum standard for energy conservation measures. Table 1 specifies maximum thermal transmission allowed for walls and roofs of heavy construction. To comply with the Kuwaiti energy code, exterior heavy walls should include a layer of 5 cm thermal insulation material while a 7 cm thermal insulation material should be embedded within heavy roof sections.

Table 1. Maximum Thermal Transmission (U-Value) Allowed for Walls and Roofs of Heavy Construction.

	Maximum Overall U-Value	
	BTU/h ft^2 °F	W/m^2K
Wall	0.10	0.57
Roof	0.07	0.40

3 Autoclaved aerated concrete

The enforcement of strict limits on the thermal resistance for exterior walls gave way to the introduction of autoclaved aerated concrete blocks as an efficient material that can provide the necessary thermal insulation properties without the use of specific thermal materials. Autoclaved aerated concrete was developed at the end of the 1920's in Sweden [2]. Cement and lime, together with siliceous fine materials such as sand, slag or fly-ash and water, are used as raw materials. A small amount of aluminum powder is added. A chemical reaction between the aluminum powder and the lime increases the volume by forming air-filled cells. The product is autoclaved for 10 hours at 10 atm at 180 °C. The autoclaving initiates a reaction between the calcium and silica to form calcium hydrosilicates.

Autoclaved aerated concrete has a low bulk density and a particularly favorable ratio between material strength and bulk density. The lower bulk density consequently causes a lower consumption of raw materials which is shown by the way of comparison to other building materials in figure 1 [3]. Furthermore, autoclaved aerated concrete posses remarkable possibilities for waste processing and recycling. Since the material can be easily cut and sawed with simple tools making it possible to reduce the waste in the site to a minimum. A main feature in that is the recycling processes used in typical AAC plants.

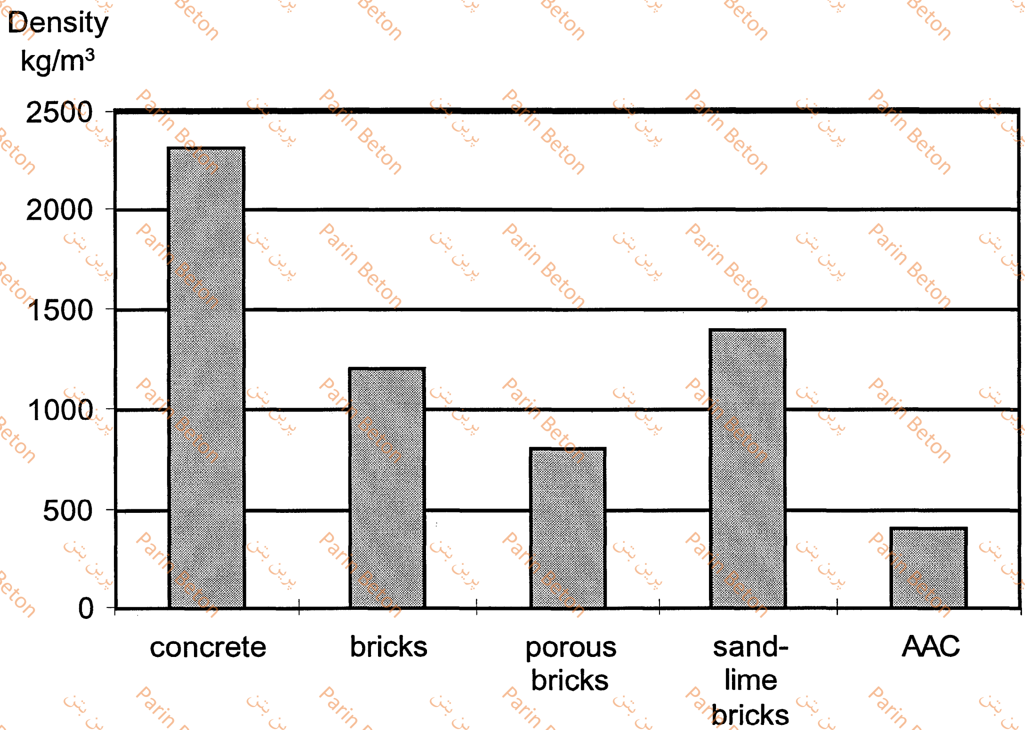

Fig. 1 Consumption of raw materials in the production of building materials [3].

Autoclaved aerated concrete, being a light weight material, provides a useful thermal inertia because it possesses an advantageous combination of mass, thermal conductivity and specific heat properties. This means that autoclaved aerated concrete can reduce the extremes of internal temperature compared with buildings made of lighter structures (which have minimal thermal capacity) or heavier structures (providing less thermal insulation). During the warm season, the thermal inertia of an autoclaved aerated concrete roof of normal thickness works in such a way that inside the building the rise of temperature due to solar radiation is delayed by as much as 6-12 hr, counted from the time of the day when the solar radiation is at its maximum. After this time the effect of radiation decreases considerably. The roof then emits its accumulated heat during the cooler part of the day. Consequently, the capacity of the power plant required for heating or cooling (and the energy required for their operation) can be reduced. Figure 2 presents a typical dynamic heat flow in which there is a time variation of the exterior surface temperature, but the interior temperature is kept constant by heating or air-conditioning [4].

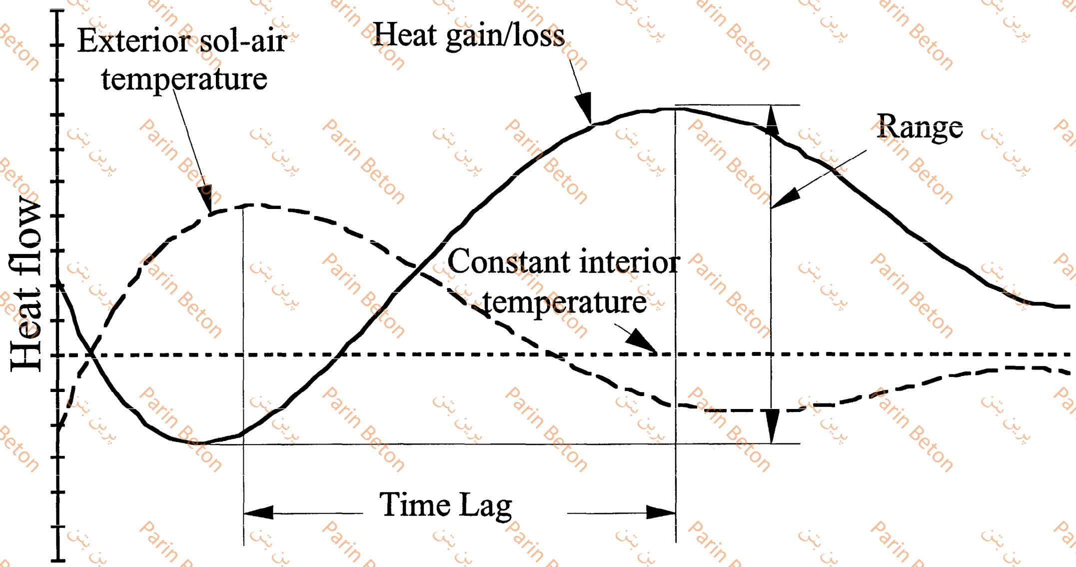

Fig. 2 Dynamic heat flow [4].

4 Use of autoclaved aerated concrete in Kuwait

Autoclaved aerated concrete blocks are produced in Kuwait in densities ranging from 450 to 600 kg/m^3. The most common size is 60 x 20 x 20 cm. A special 2-mm thick epoxy glue mortar is used to bond the blocks. With its superior thermal insulation properties, a 20 cm thick autoclaved aerated concrete block wall finished with sand cement rendering and sand lime brick can satisfy the Kuwaiti energy code without the addition of a thermal insulation material.

Precast autoclaved aerated concrete panels are also produced for use in roof wall construction. Typical panel size is 25 x 60 x 200 cm with densities reaching up to 900 kg/m^3. A building constructed using autoclaved aerated concrete panels precast system in the building envelope (roof and walls construction) will maintain the advantages of this type of construction to its full extent when compared with the mixed system currently used in Kuwait where autoclaved aerated concrete blockwork is integrated with a heavy reinforced concrete frame structure.

5 Energy consumption patterns

To analyze the effect of energy consumption, a typical Kuwaiti house was considered. The technique employed to predict the thermal performance of the building used computer based building simulation. Figure 3 shows a typical hourly power consumption for the building constructed using conventional heavy weight wall and roof systems for both insulated and uninsulated cases. On the national scale, power consumption have been increasing steadily as shown in figure 4. It should be noted that the drop in 1991 was due to the interruptions induced by the Iraqi invasion during 1990/91.

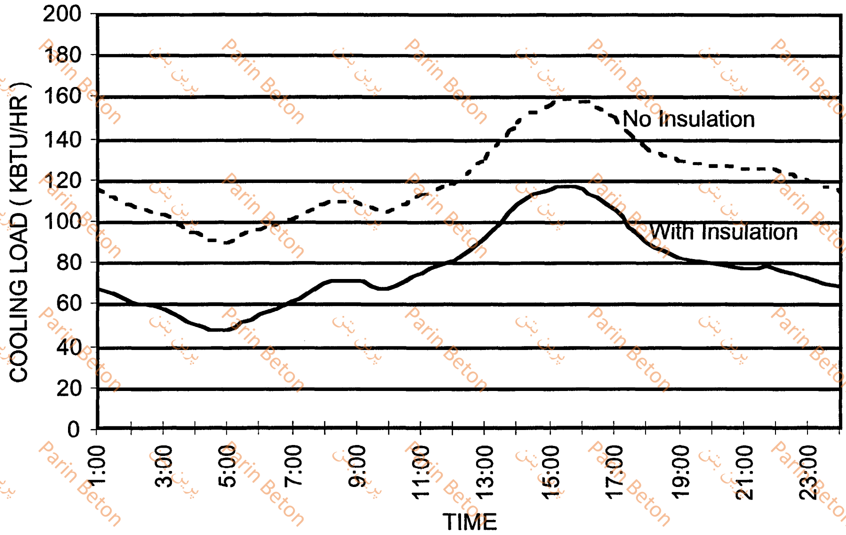

Fig. 3 Typical hourly power consumption for a Kuwaiti house.

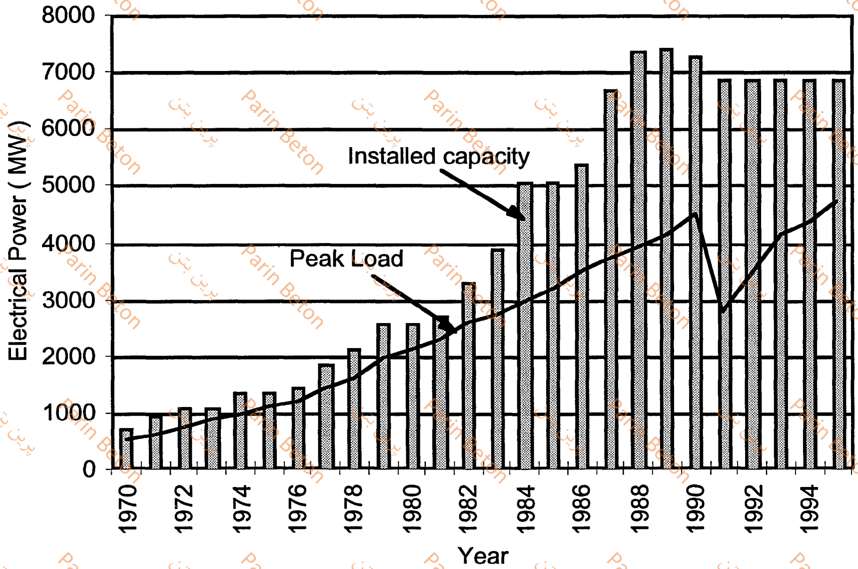

Fig. 4 Peak power consumption compared to installed capacity in Kuwait [4].

As discussed earlier, buildings constructed using autoclaved aerated concrete are expected to posses different hourly power consumption pattern in which the peak load is expected to shift compared to the traditional heavy weight structures. As autoclaved aerated concrete is considered lighter in mass, it is predicted that the peak load will occur with a less time lag compared to heavy structures. Hence if the overall peak load for the residential sector, which represents 85% of the total number of power consumers in Kuwait [5], occurs on 4:00 pm, the amplitude of such peak load can be reduced by shifting to other construction systems that can maintain a different peak time, in this case autoclaved aerated concrete.

Assuming a target of 30% of residential buildings constructed using autoclaved aerated concrete, expected to maintain a time lag that is 2 hours shifted from the 4:00 pm current peak time, will reflect on a peak load shaving of around 260 MW on the national scale. Further demonstration analysis and studies are required to determine the exact reduction in the national peak load as conservatively expressed earlier. It should be noted that achieving such percentage of residential buildings that utilize autoclaved aerated concrete construction is not a difficult goal. A direct sector that can be targeted is the governmental housing program that is expected to deliver around 1000 housing unit annually.

6 Discussion and recommendations

Autoclaved aerated concrete is a building material which can be produced with low consumption of raw materials some of which are recycled waste. It offers remarkable heat insulation characteristics while maintaining strength requirements.

The light weight and thermal inertia properties of the material provides a useful energy consumption pattern that, when integrated with other buildings of different mass, can contribute effectively in peak load reduction on power plants.

A national plan need to be developed for the optimum distribution of buildings as heavy, medium and light weight construction. The optimization will contribute further into reducing the electric peak load consumption. To encourage such shift in the construction industry, incentives need to be developed. Such incentive may be lower prices of the electric unit or defining a lower thermal resistance requirements for light weight walls and roofs. Some authorities have recognized the thermal inertia contribution, such as the California Energy Commission which defines lower R-values [3].

References

1. Ministry of Electricity and Water (1983) Code of Practice for Energy Conservation in Kuwaiti Buildings, Report R-6, Kuwait.
2. Dubral, W. (1992) On production and application of AAC worldwide. Autoclaved Aerated Concrete: Properties, Testing and Design, edited by F. W. Wittman, E&FN Spon, London.
3. Hums, D. (1992) Ecological aspects for the production and use of autoclaved aerated concrete. Autoclaved Aerated Concrete: Properties, Testing and Design, edited by F. W. Wittman, E&FN Spon, London.
4. RILEM Recommended Practice (1993) Autoclaved Aerated Concrete: Properties, Testing and Design, E&FN Spon, London.
5. Ministry of Electricity and Water (1996) Statistical Year Book, Kuwait.