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INSIGHTCORE

Journal of Buildings and Sustainability

2017
Vol. 1
No. 1

Parametric simulation for energy efficient building design of Kuwaiti domestic buildings

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A B S T R A C T

In this paper, a building model representative of a typical Kuwaiti dwelling has been implemented and encoded within the TRNSYS-IISIBAT environment. A typical meteorological year for Kuwait was prepared and used to predict the cooling loads of the air-conditioned dwelling. Several parametric studies were conducted to enable sensitivity analyses of energy efficient domestic buildings to be carried out, namely relating to building envelope, window type, size and direction, infiltration and ventilation. Simulation results have shown the desirable features that should be adopted in domestic buildings, with a view to modification of the energy conservation code. The sensitivity analysis shows that the classical wall is to be more energy- efficient than the AAC wall, both walls being commonly used in Kuwait.

Keywords: energy efficient building, sensitivity analysis, TRNSYS simulation program, energy conservation code.

1. Introduction

A well-defined energy conservation code with effective and energy-efficient design would have both economic and environmental benefit for the Kuwaiti government. The Ministry of Electricity and Water (MEW) issued an energy conservation code in 1983, which is still in force and has not been modified, whereas more effective energy-efficient products and techniques have been developed since. In addition, electrical energy in Kuwait is highly subsidized by the government, with complete disregard to the new products and techniques. Thus, however, practical applications using building and plant simulation programs are becoming increasingly accepted as a design tool for carrying out or confirming the performance of proposed building design to evaluate the effects of varying design parameters.

Economical and industrial development in countries, which have a dry desert climate, has led to an increasing demand for electricity, much of which is consumed by air conditioning system, which are used extensively to overcome the indoor thermal discomfort during the harsh summer season. Kuwait has a long harsh summer season extending from April to October, and the ambient temperature during this is very high. Daily average temperature often goes beyond 45^{o}C with strong solar radiation, which strikes each part of the building in turn as the sun moves around a clear sky. The solar intensities on horizontal surfaces are the greatest at mid-July, reaching 940 w/m^2, affecting roof surfaces under high intensity solar radiation (Allison, 1979). This may draw designer's and architect's attention to consider very carefully the horizontal building components, i.e. roof surface, to minimise heat gain into buildings. Domestic buildings in Kuwait are estimated to consume 75% of the electricity generated. Reduction of energy consumption in buildings is a major aim worldwide and is a particular challenge in a desert climate like that of state of Kuwait. However, other considerations affecting the energy requirements of buildings may be comprised in the following factors: building location (altitude, latitude, longitude and orientation), Local weather conditions, heat transfer and storage characteristics of the building's elements, which depend on the various thermophysical properties of the building's components: windows, doors and other openings, shading of the exterior surface, building

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dimensions, indoor temperature, number of occupants, lighting and building usage, Primary and secondary air-conditioning systems, ventilation and infiltration.

Each of these factors could influence the cooling load of the building. The degree of influence of each factor will vary from one building to another depending on the variation in architectural design, function of the building and materials used in the construction. In Kuwait, the Ministry of Electricity and Water (MEW) issued an energy conservation code in 1983, Ministry of Electricity. This code represents a set of regulations that guides the construction of new buildings. All buildings that had received authorisation to be built prior to the code do not include any energy conservation measures. The National Housing Authority (NHA)[2] undertakes to use new building materials that were not considered in the MEW code but are reliant on the information received from the Kuwait Institute for Science and Research (KISR). However, Kuwaiti-building codes as embodied in MEW or NHA specifications still lack some technical guidance regarding building envelope, window type, size and direction, infiltration and ventilation in Kuwaiti buildings.

Therefore, the aim of this paper is to arrive at a building design that is both energy-efficient and typical of local design, which may provide further guidance to enhance Kuwait's building code.

In this study, the sensitivity analysis technique is used to achieve building energy efficiency through proper selection of variables conditions and building design and materials. The latter technique with the assessment of computer simulation program i.e. TRNSYS-PREBID (multi-zone building simulation) programme (Solar Energy Laboratory, 1996) was used to study the impact of input parameters of different building cases to the simulation outputs results.

2. Methods

2.1 Techniques of sensitivity analysis for building

Sensitivity analysis for building is a technique developed for optimizing a number of system parameters. Sensitivity analysis techniques are used in building energy efficiency to minimize building energy consumption and to achieve the best load and energy characteristic with respect to building input parameters and deployment of computer simulation programs (Lomas and Eppdl, 1992; Cordon, 1992).

2.2 Computer simulation program

Building case studies were modelled using the computer simulation program TRNSYS (Solar Energy Laboratory, 1996) with required specific building input parameters, which have been supplied to the simulation program. The sensitivity analysis is designed to have a building cases that are the same in terms of building input parameters in the whole of the simulation input, except for the input parameter under concern (Joseph et al., 1996). As a result, the difference in simulation results can be interpreted as having only been caused by the change in the input parameter, are shown in table 3 (Spitler et al., 1989).

Descriptions of the thermophysical building materials, required building input parameters, and building cases are presented in Table 1, Table 2 and Table 3, respectively. Buildings were modelled using the TRNSYS-PREBID facility. In addition, Kuwaiti weather TMY data was prepared and generated using Type 9, the solar radiation processor (Type 16), and sky temperature (Type 69) (Shaban, 1995). This produced an hourly analysis of energy consumption and annual and peak load in buildings. The simulations were conducted to investigate the thermal characteristics and energy savings of a typical domestic Kuwaiti building. The complete TRNSYS-System configuration and formative structure of the TRNSYS-Types used for the simulation of building cases thermal performance are shown in Figure 1.

[2] The National Housing Authority (NHA) shouldered the responsibility of providing dwelling for limited income of Kuwaiti people so as to have equality of socio-economic with other prosperous Kuwaiti people, through public housing programme. The Programme was adopted in the early 1976. The housing programme is basically as a 'rent to own' strategies programme.

Table 1. Thermophysical building materials of the building case components.

Building components		Material (layers)	Thickness cm	Thermal conductivity W/mK	Density kg/m^3	Thermal capacity KJ/kgK
Type1	Exterior wall (classical)	Sand- lime block	9	1.306	1900	0.795
		Insulation	5	0.032	30	1.12
		Cement block	20	1.640	2011	0.91
		Cement plaster	2	0.944	2085	0.84
Type2	Exterior Wall (AAC)	Sand- lime block	9	1.310	1918	0.795
		Cement Plaster	2	0.972	2085	0.840
		AAC(Block)	22	0.145	489.0	0.879
		Cement Plaster	2	0.972	2085	0.840
Floor		Concrete slab	15	1.214	2297	0.921
		Sand	4	0.337	1800	0.920
		Sand cement	2	0.944	2080	0.84
		Mozaic tiles	2	1.104	2284	0.8
Roof		Mozaic tiles	2	1.104	2284	0.8
		Cement Mortar	2	0.944	2085	0.84
		Sand screed	2	0.944	2080	0.84
		Insulation	4	0.032	30	1.12
		Water Proofing	0.3	0.140	934	1.507
		Sand screed	2	0.944	2080	0.84
		Foam concrete	5	0.210	351	0.879
		Concrete slab	15	1.214	2297	0.921

Table 2. Input data for the building case required by PREBID.

PREBID-required data	Input data
Floor plan shape	Rectangular 15m x 8m
Wall area	138 (m2)
Roof area	120 (m2)
Windows area	4.3 m2 (3.6%)
Building volume	360 m3
Windows type	Sliding windows with double-glazing
U-value of the window	2.3 W/m2 K
Internal shading factor	0.82
Infiltration air change	0.4AC/hr
Building coefficient of absorption	0.57
Ground reflectance	0.2
Inside design temperature	26 ºC

Table 3. Building model cases for thermal analysis

Case No	Building cases description
Case (1)	Building model using AAC walls type and placing windows in East-West direction + Shading factor equal to 0.82 and infiltration equal to 0.4AC/h
Case (2)	Building model using Classical walls type and placing windows in East-West direction. + Shading factor equal to 0.82 and infiltration equal to 0.4AC/h
Case (3)	Case 2, but placing windows in North-South direction.
Case (4)	Case3, but infiltration value equal to 0.60 AC/h
Case (5)	Case3, but infiltration value equal to 1.0 AC/h
Case (6)	Case3 with window area of 1/16 of floor area (6.25%)
Case (7)	Case3 with window area of (9.7%)

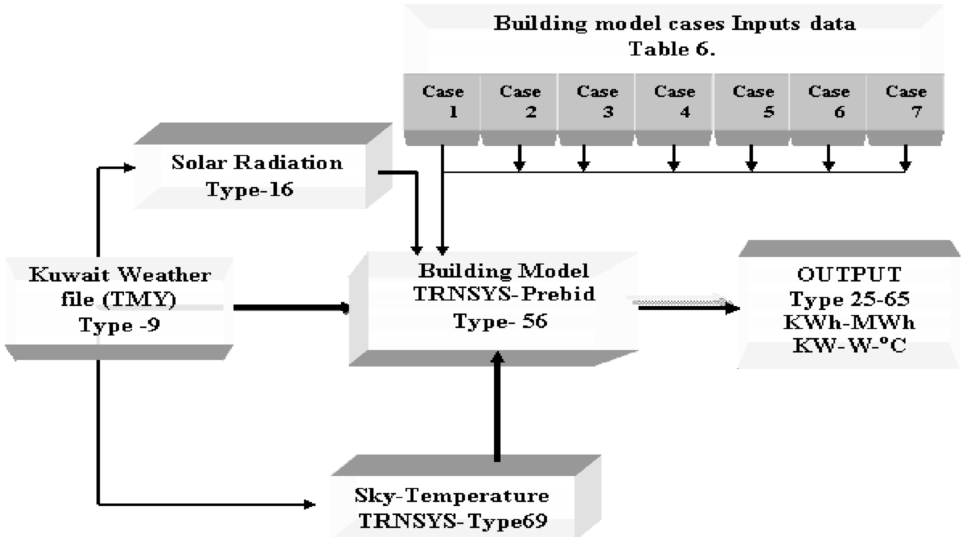

Figure 1. TRNSYS-System configuration and formative structure of the TRNSYS-Types used for the simulation of building cases thermal performance.

2.3 Building case details

The building materials of the building cases were selected as most representative of construction materials, fairly similar to a government dwelling type NHA (National Housing Authority). The dimensions of the building (single storey building) are 15m x 8m, giving a living area space of 120m2 with height of 3m (Ministry of Planning, 2004). The building floor plan is shown in Figure 2, whilst the thermophysical building materials of required input data for simulation and building model for all cases are shown in Table 1, Table 2 and Table 3 respectively. The openings to the outdoors were represented by two windows, each with an area of 1.4m^2 and a wooden door of area of 2.2 m^2. Furthermore, thermal properties of windows and door are illustrated in section 3.4. Building cases were modelled, simulated and encoded using TRNSYS-PREBID (Solar Energy Laboratory, 1996).

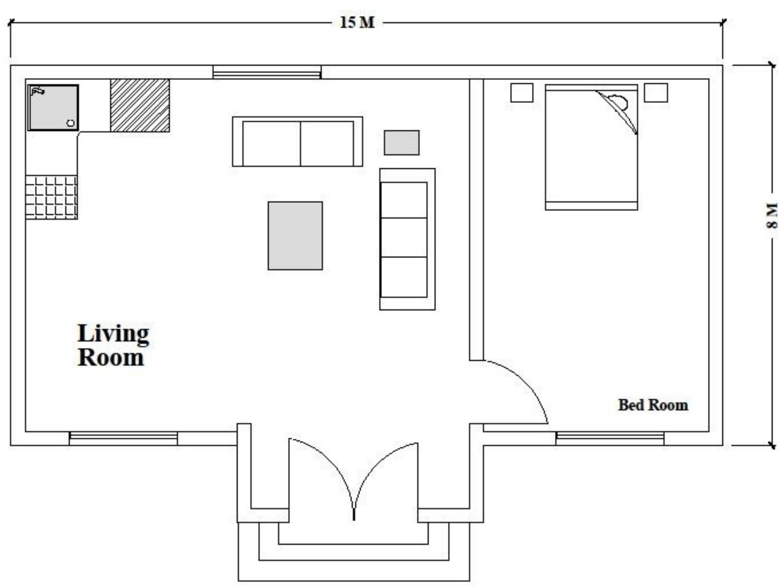

Figure 2. Detailed plan layout of the building case

3. Building construction components

The construction components of the building cases consist of building envelopes; namely exterior walls and roof. The prevailing exterior walls in Kuwaiti buildings are generally of two types; 'AAC' wall (Autoclaved Aerated Concrete) and concrete block wall (which may be called 'classical wall'). NHA (National Housing Authority) buildings are limited to these two types of wall construction. However, none of these walls have been investigated in terms of their energy conservation measures. Thus, building envelopes using wall building construction materials of Classical and AAC as well as the prevailing type of roof (i.e. flat roof) were considered in this study. Further details about construction components used in Kuwaiti building are described next.

3.1 Classical wall

The classical wall was introduced into the construction field in the early 1940s after the discovery of oil in Kuwait. Its initial form consisted of a concrete block and cement mortar. The elements of this wall developed gradually until the late 1970s, when thermal insulation was added. Detailed cross-section of a classical wall is shown in Figure 3. Classical walls are preferable and acceptable to Kuwaiti people for several reasons, these are:

- The classical wall is cheap in terms of its labour and materials.
- It is available and is produced locally in Kuwait by many construction factories.
- It is a strong wall and can tolerate holes to hang pictures or any other aesthetic items.
- Appropriate-skilled manpower is available in Kuwait for its construction.

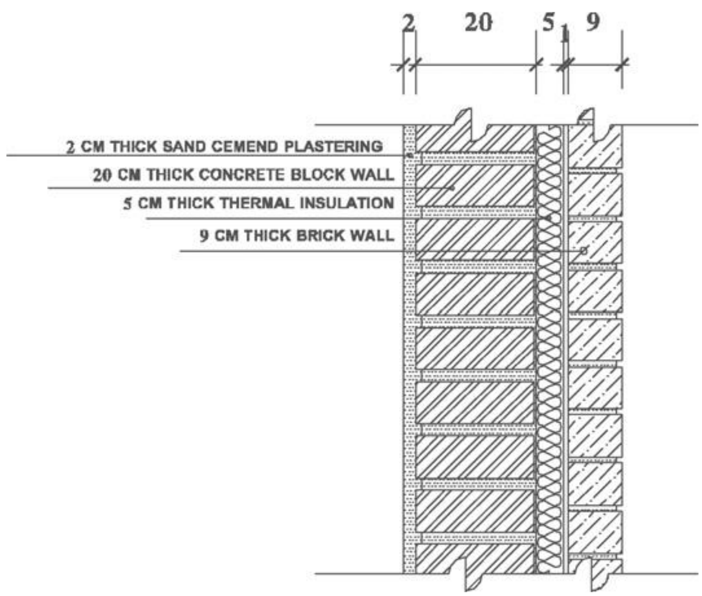

Figure 3. Detailed classical wall.

3.2 AAC Wall

'AAC' (Autoclaved Aerated Concrete) is a cementitious matrix made by introducing air or gaps into the prepared slurry. The air is usually entrapped in a closed cell form (ACICO, 1996). Since the early 1980s, the AAC Block has become popular in Kuwait's construction market. The technology of the AAC was brought from Germany through a local company called National Industries Company (NIC). However, NIC recently installed a plant that produces aerated concrete blocks (called the 'Azel' block) or the AAC block in Kuwait itself. The AAC blocks are made usually with bulk densities in the ranges 400- 800 kg m-3. Due to the good thermal insulation properties of this material, it was proposed as a replacement for the classical wall (see Table 1 type1 and type2). Thermophysical properties of the AAC blocks were investigated by Kuwait's Institute for Scientific Research (Kellow et al., 1987). The results found were that the AAC block comes in three different density ranges: 50-240 kg m-3, 245-480 kg m-3 and 485-730 kg m-

3, corresponding to 'lightweight', 'medium weight', and 'heavyweight', respectively. The thermal conductivity (k) values for the AAC blocks designated lightweight, medium weight and heavyweight are 0.12, 0.13 and 0.16 Wm-1C-1 respectively (ACICO, 1996; Al-Mudhaf et al., 1997). However, the most common AAC block used in Kuwait is one with a thermal conductivity equal to 0.145 Wm-1C-1. AAC block has been used in the Kuwaiti construction industry (to replace the classical wall) regardless of its advantages and disadvantages for the following reasons:

- The AAC block works as two construction components in one element, namely; block and thermal insulation.
- The AAC block is light; therefore, it requires thickness for it to be used in exterior walls. It should be at least 20-25 cm thick to have a strong wall.
- The cost of the AAC block is close to the cost of the classical wall if thermal insulation is added. However, costs could be a lot higher if a layer of wire mesh (chicken mesh) was to be installed over the AAC block to strengthen and bond the cement plastering with AAC block.
- There are only two construction factories that produce the AAC block locally in Kuwait.
- It is not strong enough to tolerate holes in the wall to hang pictures or any other aesthetic items.

Despite the advantages and disadvantages of the two walls, the AAC block has been used by the National Housing Authority (NHA), the private sector and government buildings, irrespective of energy consumption issues. Detailed wall cross-section of AAC is shown in Figure 4.

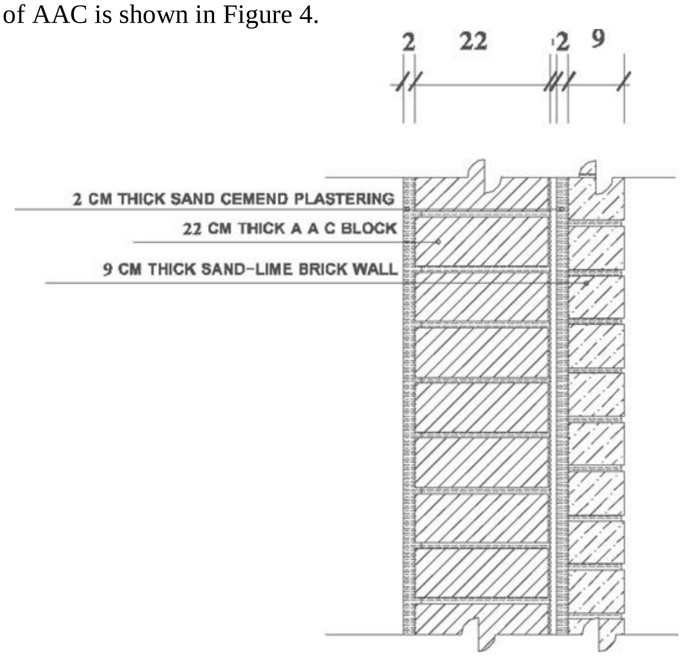

Figure 4. AAC block wall.

3.3 Roof

The traditional flat roof is almost universal in Kuwait. The roofs of dwellings were extensively used for sleeping areas before mechanical cooling was known and were also used as storage. However, the main reason why flat roofs continue to be largely used is due to the fact that Kuwaiti family members are increasing in number and size and they prefer to live together rather than move to another place. Therefore, more building space is required and can be obtained by extending either horizontally or vertically. Therefore, the flat roof is a more flexible and cheaper way for this type of building construction to be extended than any other roof. In view of this, the flat roof is very popular and is used by most Kuwaiti people. It is also specified by the Kuwaiti Government through the NHA housing program as well as by most of the private buildings in Kuwait. Thus, the building case of this study will have a flat type of roof. The thermophysical properties of the roof are shown in Table 1 and its detailed cross-section is shown in Figure 5.

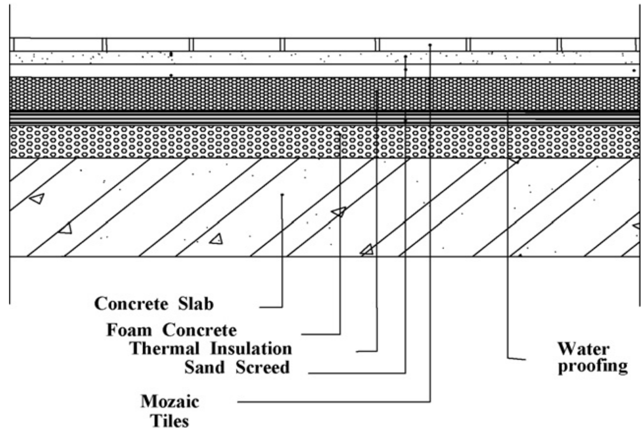

Figure 5. Detailed construction section of Kuwaiti flat roof

3.4 Openings

Windows and doors in Kuwaiti buildings are varied in their thermal performance and material properties. In the following section, the windows and door are investigated, to promote a guideline strategy that may address future energy conservation codes.

3.4.1 Windows

Most windows in Kuwaiti buildings nowadays consist of a double pane of 6mm or 8mm-thick glass. Window frames and glazing are manufactured locally in Kuwait with U-values for single-pane-glass windows equal to 5.8W/m^{2}K and 2.7W/m^{2}K for double-pane-glass. There are some imported glazing's with high thermal insulation that are used in commercial buildings. This latter type of 'insulated' glazing has a high thermal insulation achieved by using an air film with an insulated sheet between glazings (of the double pane). This type of glazed window is now being produced in Kuwait, but high costs are involved in manufacturing such materials.

When the sun's energy impacts on a building's envelope, heat will enter either directly through the transparent areas or it will be absorbed and the heat will enter the building by conduction through opaque elements. Inappropriate sizes of window openings could result in a large area of glass, which in the case of Kuwait's buildings could be a major source of heat gain. Inappropriate choice of glass may transmit up to 85% of the heat gain from incident sunlight (Al-temeemi et al., 1995; Saini, 1980). The total heat gains for a common Kuwaiti window in four directions were evaluated over a 24-hour period and are shown in Chart 1 (Allison, 1979). Referring to Chart 1, for the case of the total heat gain through a common Kuwaiti window type plotted over 24 hrs for a day in mid-July, the highest total

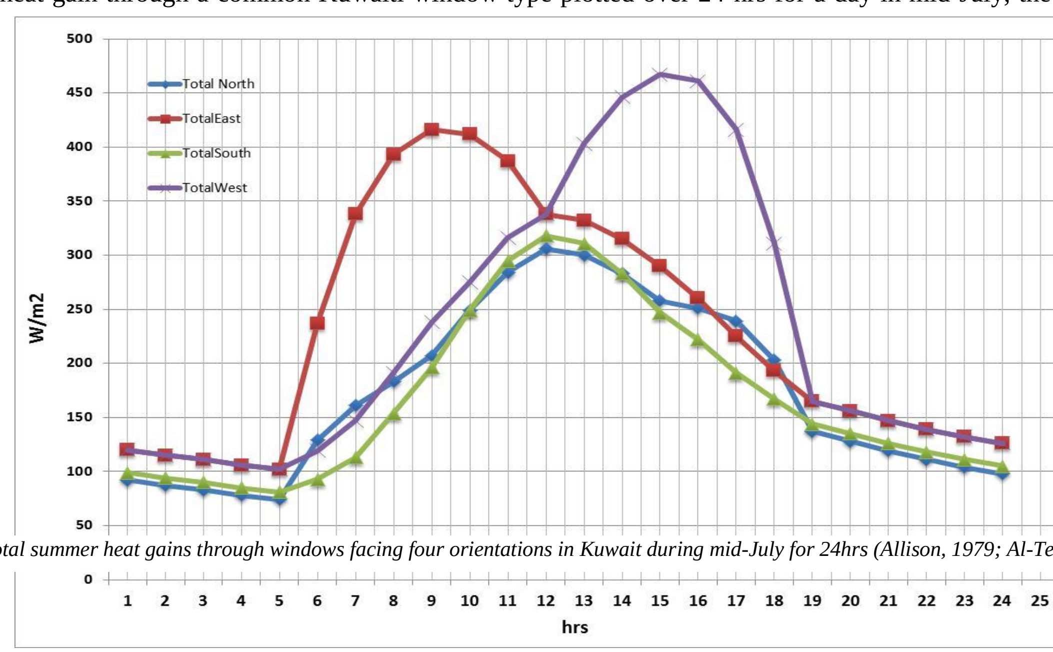

Chart 1. Total summer heat gains through windows facing four orientations in Kuwait during mid-July for 24hrs (Allison, 1979; Al-Temeemi et al., 1995)

heat gain occurs at 15.00 hrs with a value of 467Wm-2 from a window facing west, whereas a total of 416 Wm-2 at 09.00 hrs occur when facing east. For north and south, the highest total heat gains were equal to 306 Wm-2 and 318 Wm-2, respectively, at 12.00 hrs.

Researchers have suggested that a glass area of 1/16 of the floor area of a room should be satisfactory for lighting purposes in a hot dry climate (Saini, 1980). The issues are accounted for in the selection of building design cases for further simulation, see case 3, case 6 and case 7 (Table 3).

3.4.2 Door

One door of 1 metre wide and 2.2 metres height is used in this study. It consists of plywood on two sides with a 35mm air gap in between. This is a typical construction material for a door in Kuwait buildings. The door pervading thermal resistivity is 0.606 m2 C W-1, as facing north.

4. Simulation results

4.1 Building parametrical study for energy consumption analysis

Simulations were conducted on the building case using material properties shown in Table 1 and Table 2. In order to arrive at an energy-efficient building case, several building cases were considered with the respect to the influence of building envelope, window type, size and direction, ventilation, together with infiltration rate. Simulated cases are shown in Figure 1 and summarised in Table 3.

4.2 Energy consumption for the building cases

The seven building cases, shown in Table 3, were simulated using TRNSYS-PREBID (Solar Energy Laboratory, 1996). The results are shown in Table 4, and comprise the hourly peak energy consumption, the monthly total energy consumption and the annual total energy consumption, all for space cooling. Chart 2 and Chart 3 show this information in histogram form for the cases. The monthly and annual total energy consumption for building case 3 is seen to be the most energy efficient of the cases considered, with monthly and annual total energy consumption figures of 1.64 MWh and 14.68 MWh, respectively. The monthly and annual total energy consumptions for case 5 are the highest in terms of energy consumption (2.04 MWh and 16.11 MWh, respectively). This energy consumption is due mainly to the relatively high infiltration component (i.e. equal to 1AC/h). The results show that infiltration, which is the rate of uncontrolled air exchanged through unintentional openings such as windows, gaps, door cracks and wall cracks, accounts for an increase in 19.7% in the energy consumption with respect to building case 3. Infiltration could be reduced in many ways; for the case of Kuwait, this could be done by mainly using weather strippers for windows and doors. The effect of increasing window areas (in cases 6 and 7) shows an increase of 3.8% and 7.1% in annual energy consumption, respectively, with respect to case 3 (see Chart 4). In table 5, the results of hourly peak and annual energy consumption per unit floor area (W/m2, kWh/m2) which is the hourly peak and annual energy consumption divided by the floor area of the building case, showed that case 3 has the lowest peak and annual domestic energy consumption per building floor area of 45.2 W/m2 and 122.3 kWh/m2 respectively.

Table 4 Energy consumption analysis for the seven cases

Case no.	Peak energy consumption W	Monthly total energy consumption MWh	Annual total energy consumption MWh	Annual energy consumption (%) with respect to case (3)
Case (1)	5490	1.69	14.86	1.2%
Case (2)	5440	1.66	14.71	0.2%
Case (3)	6430	1.64	14.68	0.0%
Case (4)	5760	1.78	15.16	3.2%
Case (5)	6430	2.04	16.11	8.9%
Case (6)	5740	1.80	15.26	3.8%
Case (7)	6020	1.95	15.80	7.1%

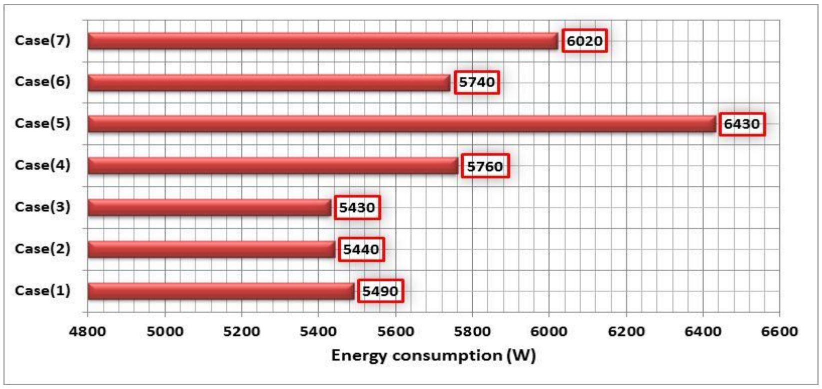

Chart 2. Bar chart showing the peak energy consumption for all building cases

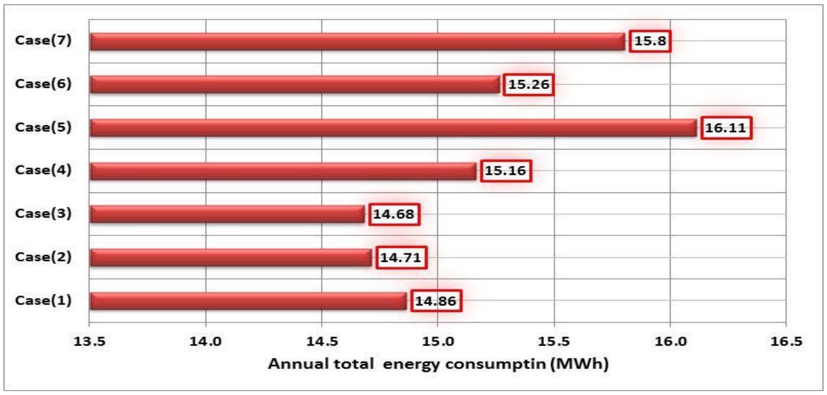

Chart 3. Bar chart showing the annual energy consumption for all building cases.

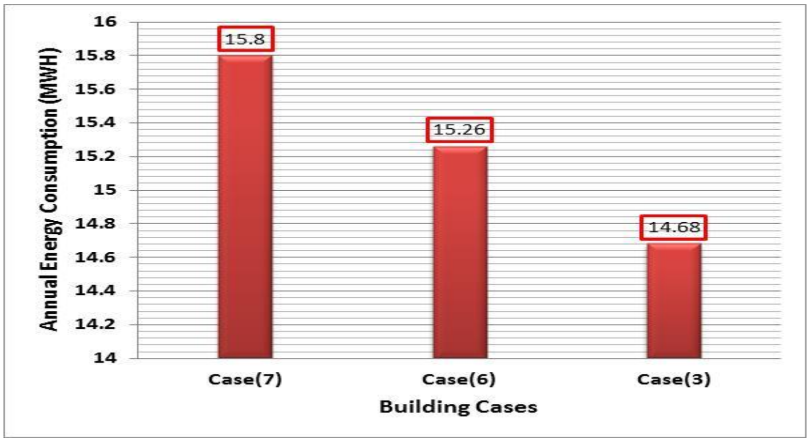

Chart 4. Bar chart showing the effect of different glazing areas on building case 3, case 6 and case 7.

Table 5. The peak and annual total energy consumption per square meter (area of floor plan).

Case no.	Peak energy consumption W	Peak energy consumption W/m2	Annual total energy Consumption MWh	Annual total energy Consumption kWh/m2
Case (1)	5490	45.75	14.86	123.3
Case (2)	5440	45.33	14.71	122.6
Case (3)	6430	53.58	14.68	122.3
Case (4)	5760	48	15.16	126.4
Case (5)	6430	53.58	16.11	134.3
Case (6)	5740	47.83	15.26	127.2
Case (7)	6020	50.17	15.80	131.7

5. Design guidance for Buildings in Kuwait

The results of the energy consumption analysis using TRNSYS-PREBID with the seven study cases of the building shows the following trends:

1. Use of the classical wall (case2) gives a reduction in annual energy consumption equal to 0.2% compared to the use of the AAC wall (case 1), which equals to 1.2 %, in comparison with building case 3, see Table 4.
2. It was found that the infiltration component of the building case was the major contributor to the building's energy consumption (cases 3, 4 and 5). Thus, any effort to reduce energy consumption should be aimed towards decreasing the amount of uncontrolled air leakage. In building case 5, it was found that the infiltration value of 1AC/h is a main contributor to energy consumption in Kuwaiti buildings. The annual energy consumption of building case 4 with an infiltration value of 0.6 AC/h shows an increase of 3.2%, while building case 5 with an infiltration value of 1AC/h shows an increase of 8.9%, respectively, in comparison with building case 3.

3. The window area plays an important role in building energy consumption in the Kuwaiti environment. When the area of the window glazing was increased as in building case 6 and case 7, energy consumption increased to 3.8% and 7.1 %, respectively, with respect to case 3. Therefore, using large areas of glass in buildings in Kuwait is a major source of solar heat gains. There are certain treatments to the glazing that may reduce heat gains. For example, using double glazed windows can reduce heat gains by at least 10%, and also the placement of windows will have a considerable effect. Windows in the direction of north-south receive the least amount of radiation (see Figure 6). Therefore, windows in the Kuwaiti environment should face toward the north-south direction.
4. Case 3 presented in Table 3, Table 4 and Table 5 emerges as the best case from those simulated, as its annual energy consumption was found to be the minimum with a value of 14.68 MWh. Case 3 corresponds to the use of the classical wall construction, orientating windows in a North-South direction, and having a relatively low infiltration.

6. Summary and conclusions

Parametric studies were conducted on exemplar building cases, where the materials were chosen as shown in Table 1. Seven cases were considered, which represented the designs typical of Kuwaiti domestic buildings. The effect of building envelope, window types, size and direction, infiltration and ventilation were investigated. The classical wall is shown to be more energy- efficient than the AAC wall, both walls being commonly used in Kuwait. The building cases were applied using details of building layout, as shown in Figure 1. Whilst not exhaustive, the simulations have shown the desirable trends that should be adopted in the design of domestic buildings in Kuwait. This can aid the development of future building codes. One case (i.e. case 3) has been identified as being the most energy-efficient from amongst those investigated. Finally, it is important to note that the trends in energy consumption (observed as parameters were changed) have been as expected, giving confidence in, and confirming the validation of, the building simulations process.

Furthermore, it should be emphasised that the data in the building cases shown in Table 3 does not cover all the building code’s necessary data. This is simply an attempt to fulfil the need for updated information on energy implications of building materials and design for Kuwait. This will contribute to the establishment of an enhanced building code of practice for Kuwait, though a comprehensive treatment of this issue is beyond the scope of this study.

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