BUILDING LOAD SIMULATION AND VALIDATION OF AN OFFICE BUILDING

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ABSTRACT

This paper describes the methodology to develop a well defined energy simulation model for an office building in Kuwait using DOE2.1E program. The two story building has approximately a total air-conditioned area of about 23,470 m^2 (77,000 ft^2) and daily occupancy seven and a half hours between 0730 and 1500 from Saturday to Wednesday.

The simulation period was set to be from January 1 until December 31. A typical meteorological year (TMY) was used for the coastal areas of Kuwait. The results of the model for electricity use were calibrated to match the actual electricity use for the average year of the available data for years 1998, 1999, and 2000. The monthly and annual cooling loads of the building were calculated by using the DOE2.1E. The extra heat generated from the auxiliary air-conditioning equipment, namely fans and pumps, were added to building cooling load. Likewise, the electrical consumption of all the equipment and lights were added as well. Comparison of the actual electricity use in the building with the DOE2.1E predicted electricity use showed monthly variation ranging from about -18% to about 14%, with the annual average variation being about 0.5%

Keywords: load simulation, office building, detailed audit.

INTRODUCTION

Energy simulation program is an important tool in any energy audit of building projects. It is an integral part of a complete energy audit. Most energy auditing experts suggest that the implementation of some sort of simulation program is required to achieve a precise and thorough audit. By applying such a tool, energy auditors can predict the savings obtained from any future measure(s) taken in the building.

Nowadays, building energy design often requires sufficient analytical power to study complicated design scenarios. Computer-based building energy simulation programs such as DOE2 provide this power and allow great flexibility in design evaluation. Many design offices use these programs to demonstrate to their clients the running cost for a particular building.

The paper present the findings of a study conducted to determine analytically the energy consumption of the building using the DOE2.1E building energy simulation program (LASL, 1980) in order to validate energy conservation measures that will be considered in a detailed energy audit on the same building (Al-Ragom et al,2001). It describes the approach to develop a well defined energy simulation model for the building, a model that can be used to explore for current needs as well as for future projects.

BULDING DESCRIPTION

Kuwait Institute for Scientific Research's (KISR) Shuwaikh campus is situated on the southern shore of Kuwait Bay. The campus houses several buildings scattered over an area of about 257,000 m^2. The building under study in this paper, referred as KISR's main facility, was constructed in 1982. It is comprised of two floors and underground walkways, which are used primarily as electrical cable conduits. The two floors are identical in shape except in the main entrance lobby area. The foot print area of the new addition, which is the total area encompassed by the building's external walls at the ground level, is approximately 13,500 m^2, with a total air-conditioned area of about 23,470 m^2. Inside, the building is divided into three main parts.

Part I is the first area encountered either when approaching the building from the old main building or when entering through the main doors. It is labeled as the KE area, and occupies about 5,050 m^2 of the foot print area, and about 9,795 m^2 of air-conditioned area (Figure 1). The KE area has the general shape of an inverted U. Each of the long sides has two identical floors, and the short side has two differently configured floors. On one side, the ground floor holds the cafeteria, kitchen; and the main auditorium hall; and the first floor holds two KISR divisions. On the other side, it holds KISR's main library, two divisions, meeting rooms, and management offices. Part II is the area, labeled the AO area, where the bulk of the scientific research work is performed in this building. The research staff of KISR and their laboratories occupy about 8,450 m^2 of the foot print area and about 12,630 m^2 of the air-conditioned area in the two identical floors. It has two major atriums that are two floors high in between three wings. On the far west side, there are three single-story pilot plants. Part III is the upper management area. It covers an area of about 1,044 m^2 and consists of one floor built right above the entrance lobby.

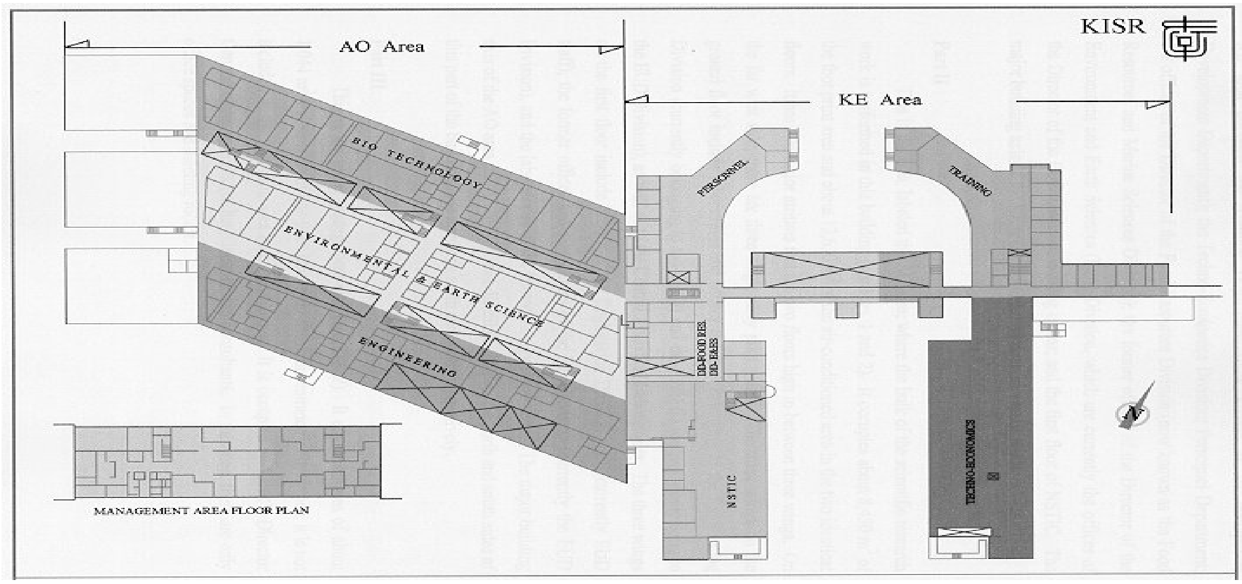

Figure 1. Plan of the Fist Floor of KISR's Main Building

BUILDING ENVELOPE

All of the exterior walls and roofing are thermally insulated and all of the windows are of the insulating double-glazed window type. An extensive array of simple and complex shading devices have also been incorporated (Table 1).

The dominant material is sand-blasted concrete (SBC), which is visible as the exterior cover of the building. All of the windows in the building utilize clever shading devices. The south-facing windows have shading surfaces placed 1.5 m parallel to and in front of them, extending the whole width of the window. The north-facing windows incorporate fins typically placed 1.8 m apart, as well as front-facing shades. This is mainly to shade early morning and late afternoon sun during summer. In the east- and west-facing windows, the glazing is fitted with considerable setback space, about 0.3 m.

Table 1. Average U-Values of Walls and Windows

Envelope Element	Walls (W/m^2K)	Windows (W/m^2K)	Both* (W/m^2K)
North	0.566	1.493	0.767
East	0.566	1.506	0.766
South	0.566	1.488	0.715
West	0.566	1.506	0.739
All walls	0.566	1.497	0.745
Roof	0.379	0	0.379
Walls + Roofs	0.46	1.497	0.557
Floors	2.9	0	2.9
Building	1.306	1.497	1.318

*Area weighted value.

THERMAL ZONES DISTRIBUTION

Each part described above was further broken down into thermal zones. The KE section (part I) contains eight thermal zones, from an air-conditioning point of view. For the purpose of simplifying the simulation model, three of the eight zones were combined as one large zone resulting in a total of six thermal zones. The other existing thermal zones were kept the same in the simulation model.

The AO section (part II) contains 15 thermal zones, from an air-conditioning point of view. For the purpose of simplifying the energy simulation process in this part of the building, these zones were reduced to seven.

There are only two thermal zones in the upper management area (part III). These zones are extensions of zones in the KE section and were kept the same in the model.

INERNAL LOADS

Occupant Load

The number of occupants during the peak hours is 365. Figure 2 shows the hourly occupancy at each hour of weekdays and weekends. Based on the Ministry of Electricity and Water's (MEW) guidelines (MEW, 1983), each office seated occupant has 67.4 W and 55.7 W of sensible and latent heat loads

Lighting Load

The total number, types, and location of lighting fixtures all over the building were accounted for a maximum load of 285 kW (Al-Nakib and Al-Ragom, 2001). Figures 3 and 4 show the lighting load profile of the building and its percentage of the maximum

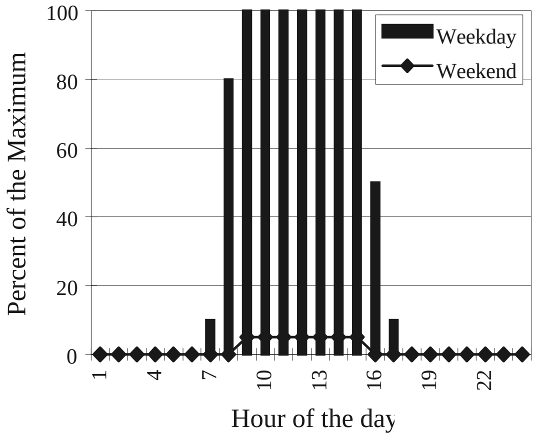

Figure 2. Building Occupant Load Profile

load at each hour of the day for a weekday and a weekend, respectively.

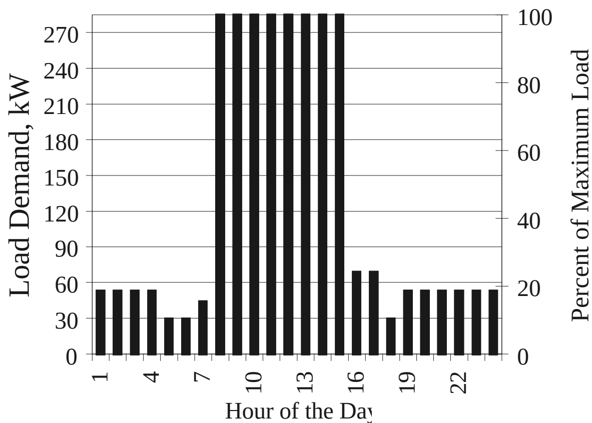

Figure 3. Weekday Hourly Lighting Load Profile

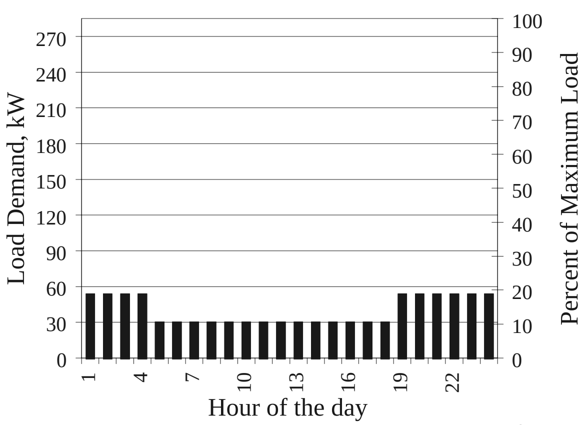

Figure 4. Weekend Hourly Lighting Load Profile

Equipment Load

The building has typical office equipment that can be found in any office building, such as computers, printers, typewriters, etc. Also, there are laboratory equipment, which include the sophisticated and hi-tech machines of significant capacity. Furthermore, there are equipment that belongs to the kitchen. Each type should be regarded separately. Therefore, a detailed survey of all the equipment and machines along with their patterns of use was an essential part in the simulation program (Al-Ragom et al., 2001).

The maximum loads for offices, laboratories, and kitchen equipment were 118, 552, and 29 kW, respectively. Figures 5, 6, and 7 show the weekday load profile and their percentages of the maximum load at each hour of the day for an office zones, a typical laboratory zone, and the kitchen respectively. The hourly weekend load profiles for the offices and laboratories equipment were unvaried at 5.5 kW (4.6% of maximum) and 183 kW (33.1% of maximum), respectively. As for the equipment in the kitchen, the weekend profile of the hourly load was unvaried at 8.3 kW (29.4% of the maximum).

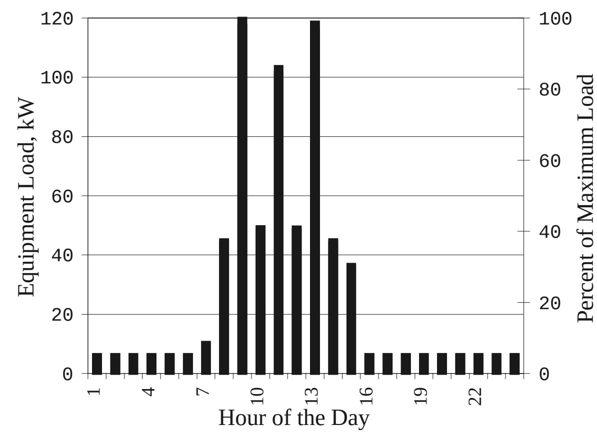

Figure 5. Weekday Hourly Load Profile for a Typical Office Zone Equipment

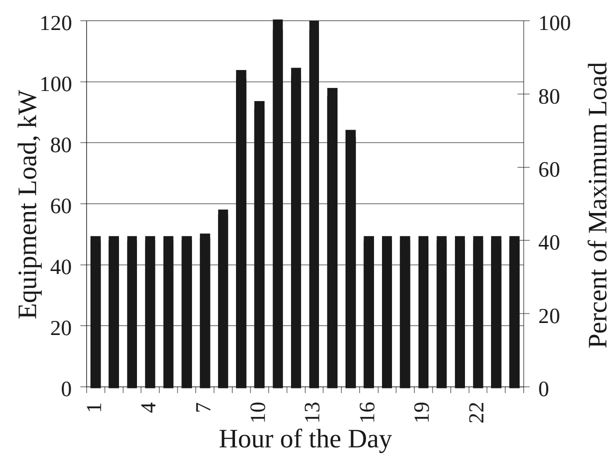

Figure 6. Weekday Hourly Load Profile for a Typical Laboratory Zone Equipment

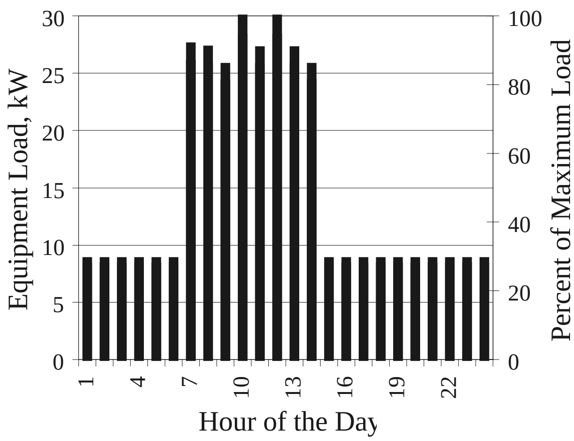

Figure 7. Weekday Hourly Load Profile for Kitchen Equipment

MODELING SIMPLIFICATION, INPUT AND ASSUMPTIONS

The major simplification made in this model was the repositioning of the main axis of the AO area (part II). Looking at the building floor plan (Figure 1), non-rectangular surfaces are apparent. To avoid such surfaces, which are non-permissible in the DOE2.1E program, the major axis of the AO area was realigned by turning it 30° to be inline with the other areas. In this way, all of the non-rectangular surfaces become rectangular while maintaining the same area for these surfaces. Similar simplifications were also considered for the north section of the KE area. Two curved walls and their roofs were reshaped into rectangular surfaces while maintaining the same area (Figure 1).

The simulation period was set to be from January 1 until December 31. A typical meteorological year (TMY) was used for the costal areas of Kuwait (Shaban, 2000) as the weather file needed to run the simulation program. The data were provided by KISR's weather station at latitude of 29.3° N and longitude of 47.9° E. Table 2 presents the monthly average values of important weather parameter from the TMY data used.

Table 2. Average Values of TMY Parameters

Month	Average DB Temp (°C)	Maximum DB Temp (°C)	Ave. Wind Speed (m/s)	Average RH (%)	Daily Total Solar Radiation (Wh/m^2d)
Jan.	13.8	17.8	3.6	63.7	4,038
Feb.	15.8	19.3	4.0	71.3	4,937
Mar.	19.6	23.6	4.3	60.9	5,445
Apr.	25.1	30.4	3.2	59.8	6,811
May	31.4	36.1	4.3	46.6	8,003
Jun.	34.3	40.3	4.7	44.6	7,416
Jul.	35.8	42.1	4.6	45.9	8,170
Aug.	37.8	45.9	3.1	49.8	7,063
Sep.	33.7	40.0	4.2	41.2	7,087
Oct.	27.8	34.3	3.5	50.6	4,971
Nov.	20.5	25.3	3.9	64.5	4,748
Dec.	15.2	18.7	3.7	69.4	4,287

CALIBRATION AND RESULTS

The DOE2.1E model consists of all the inputs affecting the cooling load, created under the LOADS part of the input file. The model did not go beyond that to describe the existing heating, ventilating, and air-conditioning (HVAC) system in the building, which is usually done in the SYSTEMS part of the input file. This part was done manually.

The results of the model for electricity use were calibrated to match the actual electricity use of the building. The actual electricity use data taken from the electricity meters is available for 1998, 1999, and 2000. Since TMY weather file was used for the model, its electricity use was calibrated against the average for the three years.

The monthly and annual cooling loads of the building calculated by DOE2.1E program are given in values of thermal energy, i.e. watt-hours or BTUs. These values were converted to electrical watt-hours. Since the chillers are set to operate at a maximum part load ratio of 65%, they are about 18 yrs old, and work under high ambient temperature of about 46°C (Maheshwari et al, 2001), it is rightfully assumed that they consume 1.7 kilowatts of electricity per one ton of cooling. This is in accordance with the MEW's maximum kilowattage per ton (MEW/R-7, 1983).

In addition, the extra heat generated from the auxiliary air-conditioning equipment, namely, fans and pumps, were also considered as part of the building cooling load, as well as the electricity used by such auxiliary equipment. Calculating the electricity used by the auxiliary equipment was simple since they were left on 24 h/d all year round (Maheshwari et al, 2001). In the case of fans, where they are placed along with the motors in the air-stream of the cooling distribution ducts, all of the energy consumed by these equipment directly affects the cooling load. In the case of the chilled water pumps, where the motor is placed outside the chilled water stream, cooling load is the energy consumed times the motor efficiency. Figure 8 shows a comparison of the actual electricity use in the building with the DOE-2 predicted electricity use. This figure shows that there is close agreement between the two. The monthly variation between actual and modeled electricity use ranges from about -18% to about 14%, with the annual average variation being about 0.5%.

CONCLUSION AND RECOMMEDATIONS

The large differences occurred between the actual and predicted electricity use was mostly visible during the severe summer months, namely, July and August. This deviation in the DOE2.1E model prediction is mainly due to the severity of the fresh hot air drawn inside the building coupled with the ducting and piping load gain which were both not accounted for. The model as it is right now is sufficient to be used further to develop the simulation of the air-conditioning systems in the building. This will build the ability to conduct a detailed energy audit on the building's HVAC system. It will also support many other energy conservation measures such as building retrofit opportunities and deployment of energy efficient strategies without adversely affecting the indoor environment.

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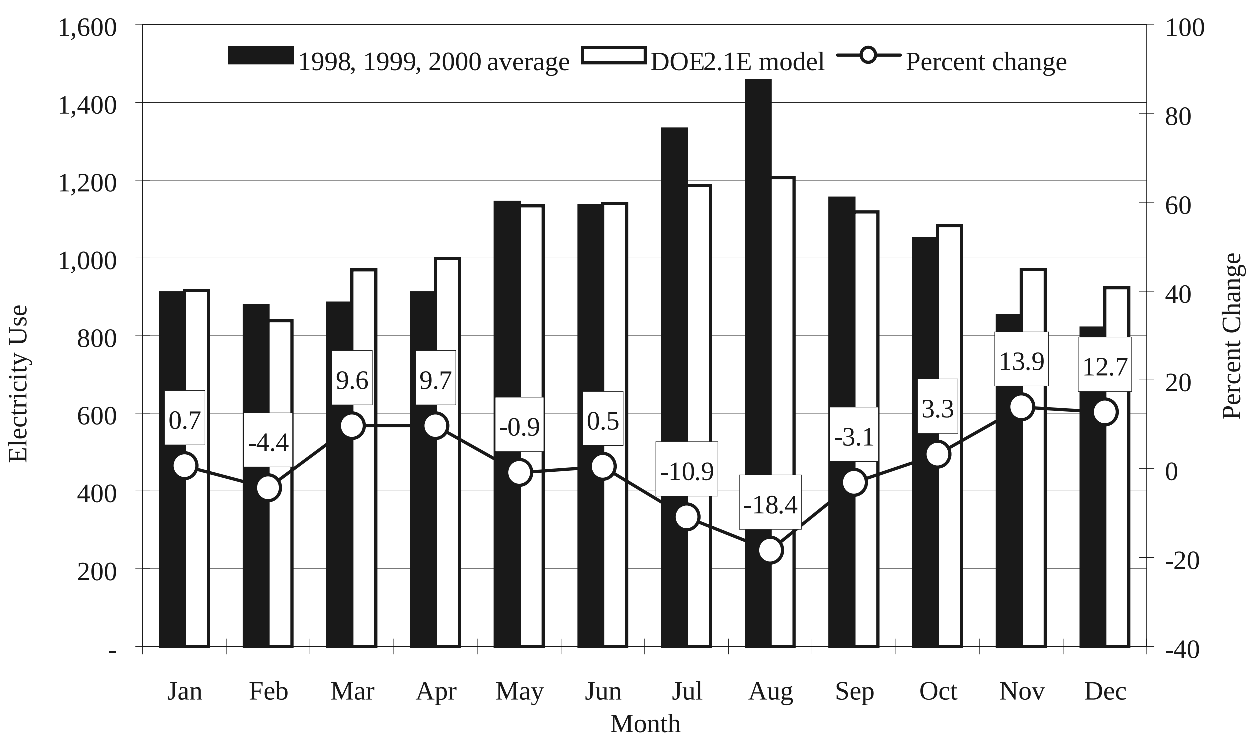

Figure 8. Actual vs. Modeled Electricity Use

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