THE NEED FOR BUILDING ENERGY ANALYSIS

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ABSTRACT: Buildings are large consumers of energy in Saudi Arabia and are therefore prime candidates for conservation activities. Since they are replaced very slowly and most existing buildings are not energy efficient, retrofitting would be essential to optimize energy usage. Alternative building design strategies should be explored and their impact on energy consumption should be assessed. Building energy analysis is the most effective mean to evaluate alternative energy conservation opportunities (ECOs). This ranges from simplified manual methods for rough energy use estimates to detailed computerized hourly analysis. Such analysis in the early design phases of a project will help forecast the thermal performance of buildings and explore alternative energy conservation measures, therefore, saving operating cost and helping the environment due to less energy use. This paper presents the potential of various building energy analysis tools and the need for utilizing such tools in the design process of new as well as retrofitting of existing buildings especially in Saudi Arabia.

1. INTRODUCTION

The industrial world now depends on four primary energy resources: oil, gas, coal, and nuclear energy. It will continue to do so for some time in the future. The future availability of these resources is uncertain. Energy problems involve interaction of many interdependent areas. Changes in the resources may affect cost, which leads to search for alternatives and better ways to produce them. Furthermore, lifestyles are subject to change over time to adapt to changes in economic conditions reflecting changing resources and technologies.

Probably the most effective solution toward uncertainties in energy supplies and the associated costs is to extend the life of existing resources through energy conservation. Conservation might appear to take different forms starting from the use of efficient equipment to changes in buildings and cities. The effect of these changes will be gradual in the people's life in the future.

The world three primary economic sectors of energy use are industry, transportation, and buildings. In an industrialized nation like the U.S., for example, industry and transportation account for about 64% of the total energy use with 37% and 27% each, respectively. Buildings have their substantial share of the energy consumption with as much as 36% of total energy use consumed in residential and commercial buildings. For commercial buildings, about 67% of the energy is used in the form of electricity. [1]

Many possible approaches are expected to appear to meet future energy developments related to each of these sectors of energy use. Changes in energy resources and prices are associated with changes in productivity growth. This will lead people not only to use less energy, but also to produce new systems that consume less energy. In the industrial sector, for example, continued transition from labor intensive heavy industries toward high technological electronics and computer controlled industry will become the norm. This will help to create better productivity and product quality in the future, which might balance the slowdown that usually results from higher energy prices. In the transportation sector, primary attention is more likely to be focused on new technologies to produce more energy efficient automobiles and transportation systems for optimum performance. But mass transit, ride sharing, moving closer to places of work, etc., could be approached as a public reaction to increases in energy costs.

In the buildings sector, efforts toward designing and operating energy efficient buildings will continue. One measure of energy conservation may be in the shift in resource allocation, such as reducing space air-conditioning load by the use of insulation, the use of climate responsive building materials, the construction of compact and tight building envelopes. This will be associated with development and use of energy efficient equipment.

2. ENERGY AND BUILDINGS IN SAUDI ARABIA

In Saudi Arabia, buildings have a major share of electric energy consumption, which reached 73.1% of the total electric energy use in the country for the year 1995. Industrial consumption of electric energy was 24.9% for the same year as shown in Figure 1 [2]. This includes the eastern region of the Kingdom which leads in industrial consumption due to the existing industries of Saudi Aramco and SABIC. For some other regions of the Kingdom, about 90% of electric energy consumption goes to buildings.

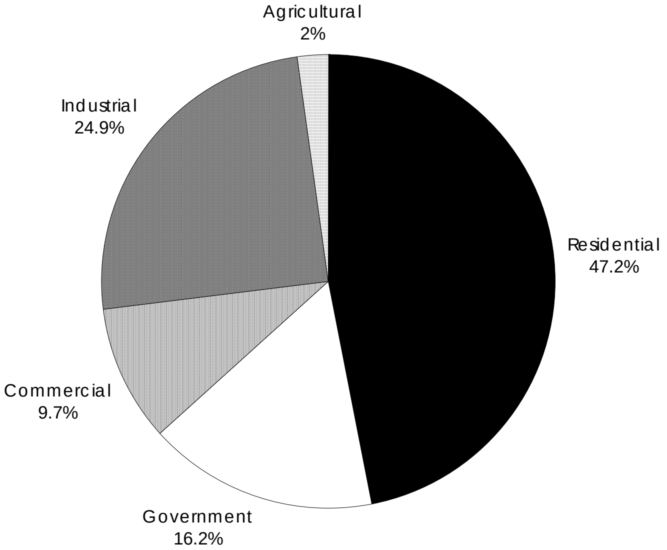

Figure 1: Saudi Electric Energy Consumption by Sector [2]

Several energy conservation research studies were conducted for Saudi buildings. For example, Said and Abdelrahman [3] conducted a parametric energy analysis on a detached single family house in Dhahran using DOE 2.1 energy simulation program. The study showed potentials for reducing energy consumption in residential buildings if properly designed and operated. Parameters found to have the greatest impact on building energy use were glazing area, infiltration level, walls, and roof construction in addition to the behavioral parameter of thermostat settings. As much as 38% reduction in the total annual energy consumption was reported from the study considering the combined effect of the analyzed parameters.

Al-Homoud [4,5] conducted studies on envelope optimum thermal design of residential and office buildings in hot arid and hot humid climates of Saudi Arabia. Annual energy savings of as much as 37% and 28% were achieved in the optimization of a small two-story residential building in the two climates of Riyadh and Jeddah, respectively. For three different sizes of large, medium, and small office buildings, envelope thermal optimization resulted in annual energy savings of 15%, 19%, and 40% for Riyadh for the three office sizes, respectively. For the city of Jeddah, annual energy savings of 8%, 12%, and 24% were obtained for the same offices, respectively. [4,5]

The results of such analyses indicate that Saudi buildings are prime candidates for conservation activities as most of the existing buildings are not energy efficient and retrofitting would be essential to optimize their energy usage. The most cost effective mean of assessing the effect of alternative energy design strategies is through energy analysis ranging from simplified manual estimating methods to detailed computer energy simulation programs as presented in this paper.

3. BUILDING DESIGN AND ENERGY

Different interrelated issues influence building design, and combinations of these different issues determine the choice of building components. The energy issue can play a significant role in building design process. As climate modifiers, buildings are usually designed to shelter occupants and achieve thermal comfort in the occupied space backed up by mechanical heating and air-conditioning systems as necessary. Significant energy savings could be realized in buildings if they are properly designed and operated. Energy awareness and energy management are important measures over the life of the building. However, it has always been said, "prevention is better than cure". Therefore, building designers can contribute to solving the energy problem if proper early design decisions are made regarding the selection and integration of building sub-systems.

Proper design of buildings can reduce reliance upon supplemental mechanical heating and air-conditioning systems to achieve thermal comfort. The requirements for such systems depend on the function and schedule, as well as the climate that influences the thermal performance of the building and its design. The function and schedule of the building are operational parameters over which designers have little control. The climate, however, can only be modified by the designer through proper selection and integration of the building physical components throughout the design process.

The impact of decisions on the thermal performance of a building diminishes along the different stages over its life as illustrated in the generic curves of Figure 1. Design decisions made during earlier phases of the design process cost less and have more significant impact on the performance of the building. Architects are accustomed to making their decisions based on

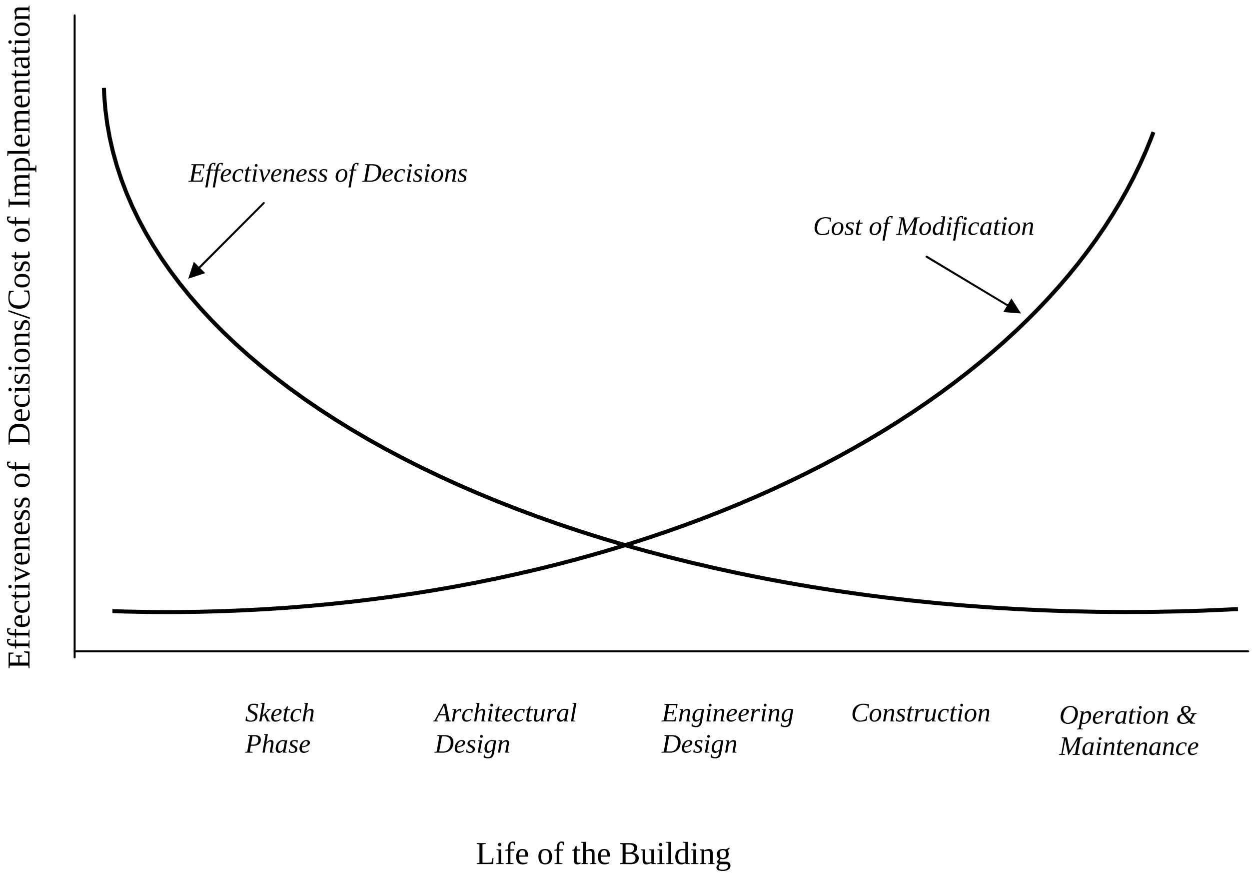

Figure 1: Cost of decision and its impact on the performance of the building through the various stages over its life.

personal experience. However as much as experience is necessary, reliance upon an individual's experience alone may lead to inaccurate and inefficient decisions. The complexity of problems associated with contemporary buildings and the many variables and interrelations that link them cannot adequately be penetrated by a series of implicit evaluations. Such approaches tend to produce deficient buildings in too many aspects [6].

"In attempting to cope with the problems of present-day buildings, architects have sought to expand the amount and kind of information at their command. The behavior of structures, operation of mechanical systems, effect of micro climate, physical as well as social and perceptual behavior and requirements of people, urban configuration and development- all have been grist to the architectural mill. It has been found that a host of factors, once not even considered, must be taken into account in the designing of buildings. And, with the advanced technology, knowledge, and living standards, their number is continually being augmented. All these additions to the architectural repertoire can greatly improve the effectiveness of architectural solutions, and have in fact done so." [6: p. 3].

Technological advances in building structural systems and materials, heating, air-conditioning, lighting and other human comfort-designed systems as well as human needs and requirements for new spatial arrangements and new building types and the associated costs-all lead to the necessary integration of building technology and aesthetics with the function of buildings. The increasing costs of energy and the environmental impact of the various sources of energy make optimum energy use a major objective in the design and operation of contemporary buildings. Therefore, performing the necessary energy analysis can help designers reach at guided solutions in building design/operation decisions. Various building energy analysis methods are available ranging from simplified manual methods to detailed hourly-computerized programs.

4. BUILDING ENERGY ANALYSIS METHODS

There are two basic levels of energy analysis tools. Simplified energy calculations and detailed energy calculations. Energy analysis of buildings is carried out for any/all of the following reasons:

1. Evaluation of alternative systems, subsystems, components, etc.
2. Allocation of annual energy budget.
3. Satisfying energy targets (e. g. government requirements).

The selected method of analysis should satisfy project requirements. Many factors are usually considered when selecting an energy analysis method. Such factors include:

- Accuracy
- Sensitivity
- Speed and cost
- Reproducibility
- Ease of use
- Availability of required data

The following is an overview of some of the commonly used energy estimating methods, some of which use single measure, and others utilize multiple measures where more than one index analyzed.

4.1 Degree-Day Method

Degree-day method is suitable for energy consumption estimates of small buildings. Such calculations are simple enough to be carried out by hand. However, simple computer programs are also used to conduct the calculations. Although estimates from such calculations are rough, they help to give an idea about the energy consumption trends for small buildings.

This procedure is based on the assumption that, on a long term average, solar and internal gains will offset heat loss when the mean daily outdoor temperature is 18.3° C (65° F), and that energy consumption will be proportional to the difference between the mean daily temperature and 18.3° C (65° F). This method is very useful in comparing the heating requirements from one location to another.

$$DD_m = \sum_{d=1}^{D_m} (18.3 - \overline{T}_A)^+ \tag{1}$$

Where:

DD_m = degree-days for month m

D_m = number of days per month

$\overline{T}_A$ = daily average ambient temperature = $\dfrac{T_{\max,d} - T_{\min,d}}{2}$

+ sign indicates that only positive values are added.

Then:

$$E = \frac{24 \cdot HL \cdot DD}{\Delta T_{des} \cdot \eta \cdot V} C_D \tag{2}$$

Or:

$$E = \frac{24 \cdot UA_0 \cdot DD}{\eta \cdot V} C_D \tag{3}$$

Where:

E = Energy usage (fuel requirements) for the estimated period.
HL = Design heat loss based on $\Delta T_{des.}$, including infiltration; W
DD = K-Days, based on 18.3 ^oC balance temperature.
ΔT_{des} = Design temperature difference $(T_R - T_A)$; K.
η = Correction factor; efficiency of equipment (rated full load)
η = 1.0 for efficiency of 100%.
V = Heating value per unit of fuel as in Table 1.
C_D = Correction factor for heating efficiency vs. degree-days (function of outdoor design temperature)
C_D = 1 if DD are based on actual $T_{bal..}$
= 0.77 if 18.3 ^oC (65 ^oF) is arbitrary used as the balance temperature.
UA_0= Building area-conductance product, often called "Building Loss Coefficient "BLC"; W/K.

Table 1. Typical fuel heating values

Fuel	Heating Value	
Natural gas	39 MJ/m^3	(1,050 Btu/ft^3)
LP gas (Propane)	25 MJ/m^3	(90,000 Btu/gal)
No. 2 fuel oil	39 MJ/m^3	(140,000
Electric		3,413 Btu/kWh

However, degree-day method has the following shortcomings:

1. Good only for heating.
2. No precise consideration of internal heat gains. Applicability is limited to residential buildings where envelope transmission and infiltration are the load dominating factors.
3. Conservative, with better insulation levels and increased internal loads results can be overestimated, C_D utilized.
4. Based on average conditions and does not account for day-to-day weather variations nor for the effect of temperature on equipment performance.

4.2 Variable-Base Degree-Day Method

Variable-base degree-day method is a generalization of the widely used *DDM*. It retains the familiar degree-day concept, but counts degree-days based on the *balance point temperature* for the building, which is the outdoor temperature at which neither heating, nor cooling is required. At this temperature the internal and solar gains offset the losses from the structure of the building. It is below this temperature when heating is required. This temperature is fundamental for simplified energy calculations.

Traditionally, 18.3 ^oC (65 ^oF) used to be the base temperature for calculating heating degree-days. However, The actual balance temperature of the house depends on many factors such as the type and quality of construction, the level of insulation used, the sources of gains, the thermostat setting, as well as the behavior of the occupants which-all could vary from country to country, from region to region, and even from house to house within the same locality. All these factors make the use of 18.3° -base temperature inaccurate. Therefore, one single balance point temperature might not be enough and the need for variable base temperatures becomes necessity for the purpose of simplified energy calculations in buildings.

When different balance temperatures are experienced over the day and night due to changes in the operation of the building or thermostat settings, the degree-days for the month *m* and period i, $DD_{m,i}$ can be obtained as:

$$DD_{m,i} = \sum_{i=1}^{n}\sum_{d=1}^{D_m}(T_{bal,i} - \overline{T}_{A,d})^{+} \tag{4}$$

The total heating energy required can be given as:

$$Q_{htg,sys} = 24\sum_{i=1}^{n}[UA_0 f_i DD_{m,i}] \tag{5}$$

Where:

n= Number of operating periods
f_i= The time fraction for the period *i* out of *24* hours *(N_i/24)*

Then the energy used will be:

$$E = Q_{htg,sts} / \eta \tag{6}$$

Where:

η= Heating system efficiency.

Variable-base heating and cooling degree-days data for various Saudi cities are published by Al-Homoud [7] for use in simplified energy calculations.

4.3 Bin Method

The bin method consists of performing an instantaneous energy calculation at many different outdoor dry bulb temperature conditions, and multiplying the results by the number of hours of occurrence of each condition. Bin method is characterized as:

1. Good for heating and cooling energy calculations
2. Bins = temperature bins, usually *2.8° C (5 °F)* in size with three daily eight hours shifts.
3. Useful for analysis of individual systems, equipment, etc.
4. Accounts for the part load performance of HVAC equipment.

The modified-bin method is defined by ASHRAE [8] for calculating annual energy use of buildings using temperature bins for given locations. This method is suitable for buildings between 500 and 2,500 square meter. ASEAM (A Simplified Energy Analysis Method) is a public domain program written in BASIC that uses ASHRAE's modified bin method for calculating the energy consumption of residential and simple commercial buildings. ASEAM requires information on the design of the building and uses standard algorithms to calculate both zone and building peak loads as well as automatic sizing of the equipment based on the calculated loads. Life cycle cost analysis is also incorporated within the program. Different output reports can be obtained including building energy performance standards (BEPS) reports for each run. [9]

4.4 Detailed Building Energy and Systems Simulation

Simulation models are flexible tools that can be used effectively for analyzing the behavior of systems. A simulation model is normally used to produce a set of selected measures that reflect the performance of the simulated system. In simulation models, the relationships between input and output are implicitly expressed through model sub-systems that are logically linked to one another. In building design, simulation models are used to evaluate the performance of building systems with given predetermined values for the associated design variables. A great deal of information can then be obtained for evaluating the performance of the building system under given conditions.

Given complexities in contemporary buildings as well as advances in computer technology, computer-aided building energy simulation proved to be an effective tool that can be used as an aid to, not a replacement for, building designers in the decision making process. Available energy simulation models are useful and powerful tools for the evaluation of the thermal performance of buildings. They can provide extensive performance information on the selected building and they considering the dynamic behavior of the system as well as part load behavior (the effect of part load on equipment efficiency). They require the following input data with varying details:

1. Weather and geographical data
2. Building physical data, internal loads, and operational characteristics.
3. HVAC system and equipment characteristics.

Detailed energy calculations apply hour-by-hour energy simulation. Such programs are used to simulate the energy consumption in a building and its sub-systems for every hour of an average weather year. They offer detailed analysis of a buildings' energy use accounting for all factors such as building schedule, occupancy as well as building mass. They also offer life cycle cost analysis with different output options depending on the individual program.

Hourly simulation models proved to be powerful and useful to designers and their use has been extensive in the design of buildings. Well known examples include DOE-2 by the U.S. Department of Energy which is a public domain program that can be used for analyzing the energy behavior of buildings and their associated heating, ventilating and air-conditioning (HVAC) systems. DOE-2 utilizes hourly weather data to calculate the hour-by-hour performance and response of a building with known description. It can also provide users with an economic analysis of the energy use and the costs and benefits of altering the design [10].

Building Load Analysis and System Thermodynamics (BLAST) is another computer program that was developed for predicting energy consumption and systems performance and costs of new or retrofit building designs of different types and sizes. Hourly building energy analysis for mechanical equipment design as well as checks for compliance with design energy budgets can also be obtained [11].

Another example is TRNSYS, which is a transient system simulation program developed at the Solar Energy Laboratory at the University of Wisconsin-Madison. The TRNSYS program is written in FORTRAN with a modular structure that allows for the addition of new mathematical models. It is intended for analyzing the transient behavior of systems [12].

Another microcomputer-based building energy simulation program is ENERWIN [13], developed at Texas A&M University. This hour-by-hour weather and building energy simulation model estimates the annual energy performance of buildings, including daylighting as well as systems simulation. The program is written in FORTRAN and incorporates an hourly simulation model that permits the simulation of less than full months and still maintains its statistical integrity for energy calculations. It allows the simulation of any multiple of seven days each month. The use of this abbreviated mode, in which as few as 2,016 hours are simulated annually, reduces the computer run time by 75 percent compared to that of other similar approaches [14,15].

The greatest advantage of such models is realized mostly in simulating the behavior of large and complex systems to provide detailed information on their performance. Although these programs can provide extensive hour-by-hour simulation of the building heating and cooling systems with different output options including life cycle cost analysis, they require some time in learning how to use them, preparing the input and running them.

5. WHY ENERGY ANALYSIS FOR SAUDI BUILDINGS?

The complexities in contemporary buildings and the harsh climatic conditions of most Saudi regions make the use of air-conditioning a prerequisite to operate thermally comfortable buildings in many parts of the Kingdom. The reliance upon mechanical air-conditioning systems requires a lot of energy, which necessitates utmost efforts from building designers and operators in optimizing thermal performance of such buildings. The need for building energy analysis in Saudi buildings can be summarized as follows:

- Buildings are replaced very slowly and decisions on their design will last for a long period of time.

- Early design decisions are the most effective and the cost of making changes to improve thermal performance of buildings at later stages in the life of a building is high and sometimes not effective.

- Most building owners/users are not aware of the energy issue and how much energy is needed to operate their buildings.

- Due to the harsh climatic conditions of the Kingdom, buildings in most regions can not be operated without mechanical air-conditioning and ventilating systems to control the indoor conditions.

- Buildings are large consumers of electric energy in Saudi Arabia which amount to more than 73% over the Kingdom and more than 90% in most parts of the Kingdom (those regions with sparse industrial activities) [2], and therefore prime candidates for conservation efforts.

- There are no energy performance standards for Saudi buildings and therefore no criteria for what we can consider energy efficient building.

- The demand for electric energy is soaring all over the Kingdom and different building energy conservation opportunities (ECOs) can be assessed and evaluated using available building energy analysis tools toward optimum use of available energy sources and making electric energy available to others at less cost.

- The prices of energy are not stable and proper analysis and design can pay back in a more near future.

- Government subsidies for electric energy prices might not continue forever.

- Thermal insulation is not the only energy conservation measure and does not always have the same effectiveness for all types of buildings. Its effectiveness will vary according to the function and location of the building. Internal load dominated (ILD) buildings where internal heat gain is the major source, for example, will not be served as effectively by just adding insulation as would the case be in skin load dominated (SLD) structures. Other ECMs might be more effective at less cost and this can be assessed through the proper building energy analysis.

- Conservation is the best approach to use less energy. It helps extend the life of existing energy resources, has less environmental impact, and reduces the cost of production as well as consumption. Alternative building energy conservation measures (ECMs) can not be evaluated without proper energy analysis.

6. CONCLUSIONS AND RECOMMENDATIONS

There are potientials for reducing energy consumption in Saudi buildings. Most existing buildings are not energy efficient and there are no standards or guidelines for the design new energy efficient buildings for the Saudi climate. The following is a summary of recommendations for building designers, researchers and government authorities toward future energy efficient buildings in Saudi Arabia:

- Building energy performance standards (BEPS) should be developed for various types of buildings in the Kingdom. Acceptable maximum building energy use index (e.g. $kWh/m^2/year$) should be set for different building types at different regions of the Kingdom.

- Building energy performance standards compliance checklist should also be developed for proper implementation and enforcement of rules.

- Municipalities in cooperation with electric companies should assure compliance with such standards for approval of new and retrofitting projects for provision of services.

- Design/consulting offices should be asked to provide energy analysis to each project they design. The impact of alternative building design strategies on the energy requirements should be at least an additional option offered to clients by engineering design offices. Simplified energy analysis should be a minimum requirement with detailed hourly energy analysis for large projects where additional cost might be charged.

- Subsidies and/or loans should be provided for improving energy conservation measures in new as well as retrofitting of existing buildings. Energy analysis is the best tool in evaluating such ECMs.

- Research and development of suitable energy analysis tools should be encouraged and supported through Saudi universities and research centers.

- Research and development related to alternative energy resources should also be encouraged and supported through Saudi universities and research centers.

- Universities' academic departments dealing with the design, operation, and/or maintenance of buildings should offer courses and training for their students in energy analysis in buildings.

- The responsible authorities such as Ministry of Electricity and other organizations should study national building energy conservation and management program. Such a program should help optimize the use of national energy resources through public awareness, development and implementation of energy standards, utilization of energy efficient systems and equipment as well as the support of energy research and development.

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REFERENCES

[1] Shaw, A., Editor, *Energy Design for Architects*. The Fairmont Press, Ga., 1989.
[2] Electrical Affairs Agency (EAA), Electricity Growth and Development in the Kingdom of Saudi Arabia. Ministry of Industry and Electricity. Riyadh, Saudi Arabia, 1995.
[3] Said, S. A. and M. Abdulrahman, "Energy Efficiency of a Building in the Eastern Province of Saudi Arabia: Parametric Analysis with DOE 2.1A", ASHRAE Transactions, Vol. 95, Pt. 1, pp. 147-152, 1989.
[4] Al-Homoud, Mohammad S., "Optimum Thermal Design of Air-Conditioned Residential Buildings", Building and Environment, Vol. 32, No. 3, pp. 203-210, 1997.
[5] Al-Homoud, Mohammad S., "Optimum Thermal Design of Office Buildings", International Journal of Energy Research, Vol. 21, pp. 941-957, 1997.
[6] Handler, Benjamin A., *Systems Approach to Architecture,* New York: American Elsevier Publishing Co., 1970.
[7] Al-Homoud, Mohammad S., "Variable-Base Heating and Cooling Degree-Day Data for 24 Saudi Arabian Cities", ASHRAE Transactions, Vol. 104, Part2, 1998.
[8] Knebel, David E., *Simplified Energy Analysis Using the Modified Bin Method,* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1983.
[9] Fireovid, James A. and Lynn R. Fryer, *ASEAM Users Manual*. 2nd Ed., Washington, DC: ACEC Research and Management Foundation, 1987.
[10] Lawrence Berkeley Laboratory, *DOE-2 Users Guide*. Berkeley, CA, Supported by the U.S. Department of Energy, 1979.
[11] Blast Support Office, *BLAST Fact Sheet,* University of Illinois: Urbana-Champaign, 1993.
[12] The Solar Energy Laboratory, *TRNSYS Users Manual,* University of Wisconsin-Madison, 1988.
[13] Texas A&M University, *ENER-WIN 96.04 Users Manual,* Department of Architecture, College, Station, TX, USA, 1996.
[14] Degelman, Larry O., "ENERCALC: A Weather and Building Energy Simulation Model Using Fast Hour-by-hour Algorithms." *The Fourth National Conference on Microcomputer Applications in Energy,* April 25-27, Tucson, AZ, 1990.
[15] Degelman, Larry O., "A Statistically-Based Hourly Weather Data Generator for Driving Energy Simulation and Equipment Design Software for Buildings." *Proceedings of Building Simulation '91, The International*

Building Performance Simulation Association, Sophia-Antipolis, Nice, France, Aug. 20-22, pp. 592-600, 1991.