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GRAPHICAL DEGREE-DAY DATA FOR SIMPLIFIED BUILDING ENERGY CALCULATIONS FOR SAUDI CITIES

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Abstract

Degree-days data is very useful in simplified building energy estimate calculations for comparing the heating requirements from one location to another as well as for the purpose of studying trends and comparing systems or alternatives. This paper presents graphical heating and cooling degree-day data for various Saudi cities. Such graphical presentation will allow flexibility in finding degree-day values at any balance point temperature for the respective locations. This will be useful to building designers and engineers in performing simplified energy calculations for Saudi climates especially in the early design stages of buildings.

Key words:

Energy calculations, graphical, variable-base, degree-days, cooling, heating, Saudi Arabia

INTRODUCTION

Building energy analysis performed for the purpose of estimating the required heating and cooling energy is very important to building designers, engineers, and owners as well as policy makers. Early design decisions are the most effective as the cost of making changes to improve the thermal performance of buildings at later stages in their life is high and sometimes not very effective. Building energy analysis is normally peformed for any or all of the following reasons:

1. evaluation of alternative designs, systems, subsystems, components;
2. allocation of annual energy budgets;
3. compliance with energy standards;
4. economic optimization.

There are two basic levels of building energy analysis tools. These are simplified energy calculations and detailed energy calculations. The selected method and/or program of analysis should satisfy project requirements. Many factors are usually considered when selecting an energy analysis method/program (ASHRAE 1997) including accuracy, sensitivity, speed, cost, reproducibility, ease of use, availability of required data and quality of the output.

Hourly energy analysis and/or monitoring of energy consumption will provide detailed estimates of energy use in buildings. However, it might still be costly and/or the necessary data required for detailed analysis might not be available. Even in the age of hi-tech computer technology and speed, simplified energy analysis methods such as those based on the concept of degree-day and balance point temperature remain valuable tools.

If the purpose of building energy analysis is to study trends, compare systems or alternatives, then simplified analysis methods can be used. These methods, although less accurate, might be more practical for the estimation of energy use and the evaluation of early design alternatives especially for skin-load dominated structures such as residences. However, for a detailed energy analysis of building energy systems and sub-systems and life cycle cost analysis, more comprehensive tools will be required.

GRAPHICAL DEGREE-DAY DATA

Erbs et. al. (1983) conducted a statistical analysis of weather data and developed a useful procedure for calculating monthly degree-days based on monthly average ambient temperatures, $\overline{T}_{A,m}$. This procedure was utilized to obtain tabulated variable base heating and cooling degree-days over long-term (ranging from 11 years for some cities to 25 years for others) monthly average outdoor temperatures for 24 Saudi cities representing different climates of the Kingdom (Al-Homoud 1998). The monthly average temperatures used in the analysis were extracted from the Statistical Year Book of the Kingdom for the years 1971 to 1995 (CDS 1971-1995), which were originally obtained from the Metreology and Environmental Protection Agency (MEPA) annual reports.

Annual heating and cooling degree-day data for the Saudi cities shown in Figure 1 is graphically presented as shown in Figures 2.a through 2.f for heating and in Figures 3.a through 3.f for cooling. Data for each four cities within the same geographical area is grouped together in one graph and is made

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available to building designers and engineers to offer them an easy tool in conducting simplified energy estimating calculations for any base temperature. Degree-day values interpolation for in-between balance point temperatures provide additional flexibility for wider range of base temperatures evaluations.

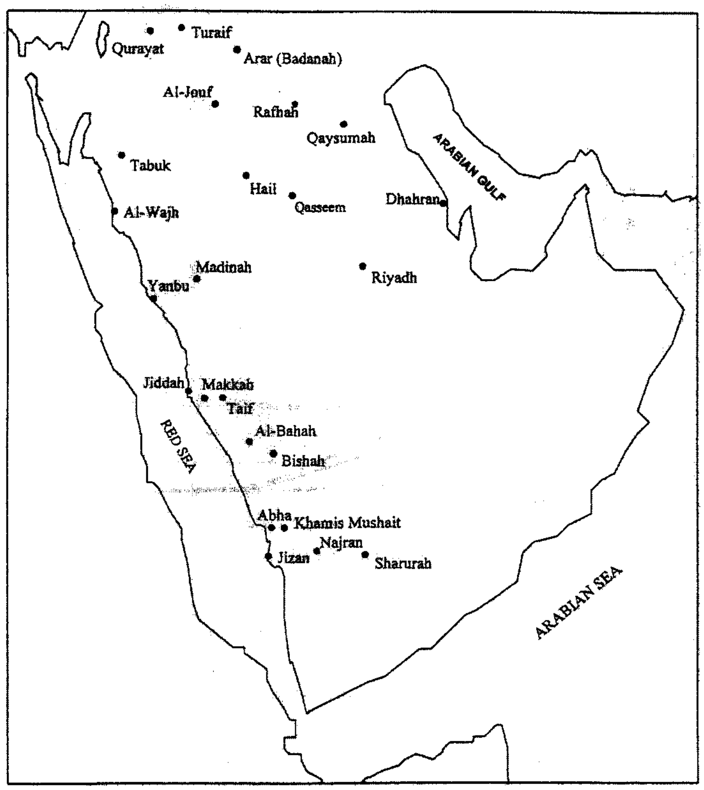
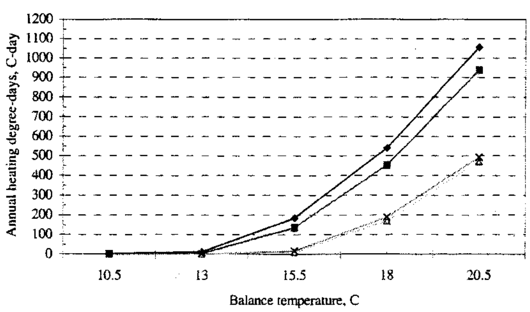


Figure 1. Locations of Saudi Cities with Graphed Degree-Day Data (Al-Homoud 1998)



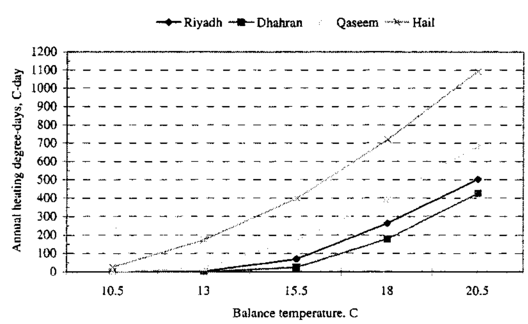
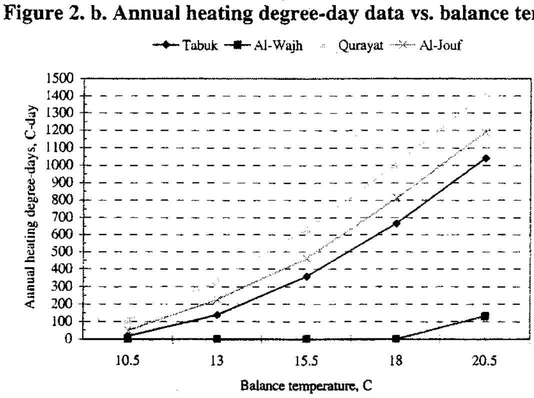


Figure 2. a. Annual heating degree-day data vs. balance temperature
Figure 2. b. Annual heating degree-day data vs. balance temperature



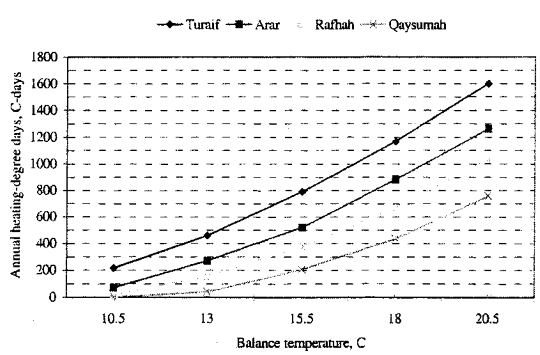
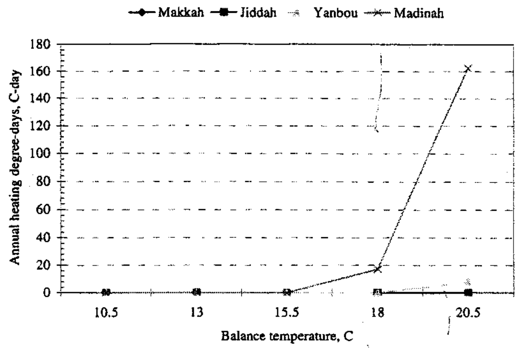


Figure 2. c. Annual heating degree-day data vs. balance temperature
Figure 2. d. Annual heating degree-day data vs. balance temperature

Degree-days can be used to characterize the severity of a climate and is very useful in energy estimate calculations for comparing the heating requirements from one location to another. Once local heating/cooling degree-day values are obtained for the desired base temperature, annual heating/cooling energy requirements for the respective building can they be estimated as explained in the following section. Such calculations are simple enough to be carried out by hand. However, simple computer programs are also used to conduct the calculations.



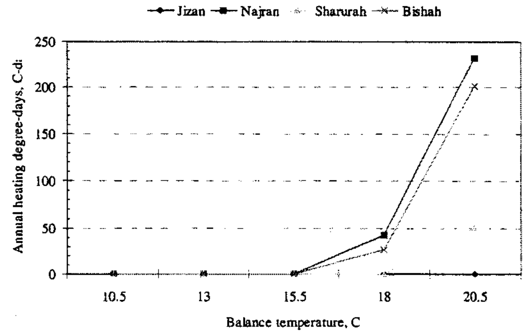
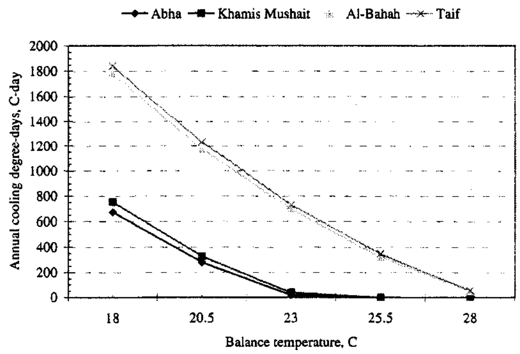


Figure 2. e. Annual heating degree-day data vs. balance temperature
Figure 2. f. Annual heating degree-day data vs. balance temperature



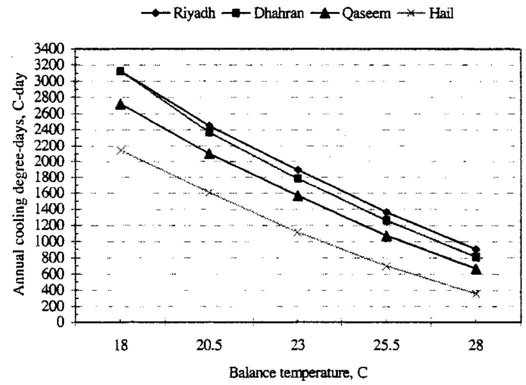
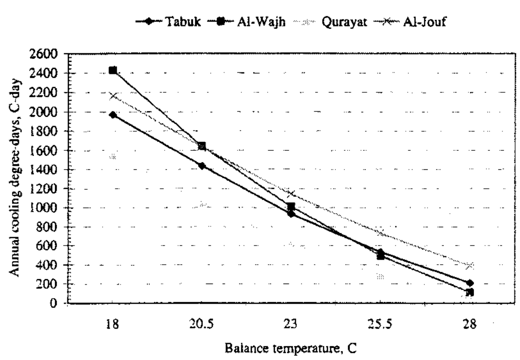


Figure 3. a. Annual cooling degree-day data vs. balance temperature
Figure 3. b. Annual cooling degree-day data vs. balance temperature



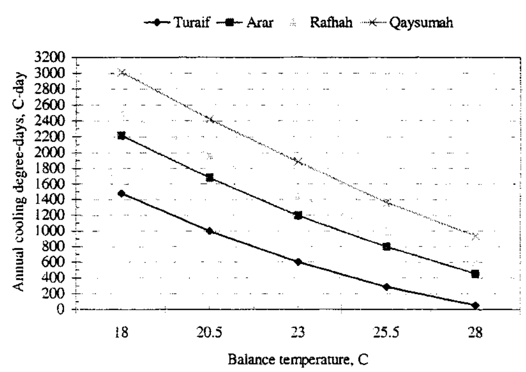
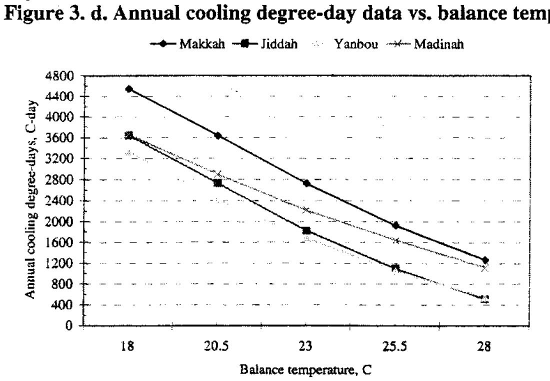


Figure 3. c. Annual cooling degree-day data vs. balance temperature
Figure 3. d. Annual cooling degree-day data vs. balance temperature



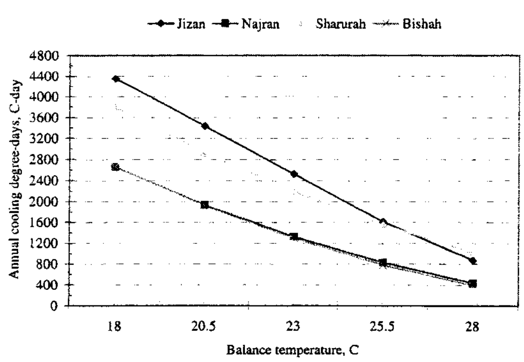


Figure 3. e. Annual cooling degree-day data vs. balance temperature
Figure 3. f. Annual cooling degree-day data vs. balance temperature

DEGREE-DAY EVALUATION

The variable-base degree-day method counts degree-days based on the ***balance point temperature***, $T_{Balance}$, 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. Heating is required only when $T_A \angle T_{Balance}$.

Traditionally, 18.3 ^oC (65 ^oF) used to be the base temperature for calculating heating degree-days. However, The actual balance temperature of a building depends on many factors such as the type and quality of construction, the level of insulation used, the internal and solar heat gains, the thermostat setting, as well as the behavior of the occupants, all of which 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 the traditional 18.3^o base temperature inaccurate and unreliable. Therefore, one single balance point temperature is clearly not enough, and the need for variable base temperatures becomes a virtual necessity for the purpose of simplified energy calculations in buildings.

An instantaneous steady-state energy balance on the building yields:

$$0 = UA_0 (T_R - T_{Bal}) - g \qquad (1)$$

which in turn yields:

$$T_{Bal} = T_R - \frac{g}{UA_0} \qquad (2)$$

For an average period of one month, the average hourly rate of solar and internal heat gains over the month, $\bar{g}$, is used and the monthly average balance temperature becomes:

$$T_{Bal} = T_R - \frac{\bar{g}}{UA_0} \qquad (3)$$

Once the building balance point temperature is determined, heating/cooling degree-day data can be obtained for the balance temperature in question from the graphs presented in this paper as shown in Figures 2a-f through 3a-f. Once the monthly heating degree-days are determined, the total heating energy requirements for the building can be calculated as follows:

$$Q_{htg,sys} = 24UA_o DD_{hi} \qquad (4)$$

Then the heating energy used will be:

$$E = Q_{htg,sys} / \eta_h \qquad (5)$$

where:

η_h = heating system efficiency

This means that once the design heating load or the overall building loss coefficient is determined, annual heating energy requirements can be estimated based on the number of heating degree-days at the analyzed location.

The total cooling energy required, Q_{clg}, can also be given as:

$$Q_{clg.} = 24UA_o DD_c \qquad (6)$$

This cooling energy calculation applies to buildings with a constant UA_o where ventilation is not introduced and windows and other openings are assumed to be kept closed. However, during the intermediate or cooling season, natural or fan-powered ventilation can be utilized to eliminate heat gains and postpone mechanical cooling. Therefore, mechanical air-conditioning will be needed only after the outdoor temperature exceeds a certain maximum temperature, T_{Max}, which corresponds to a building heat loss coefficient, $UA_{o,max}$, that considers open windows for ventilation such that (ASHRAE 1997):

$$T_{Max} = T_R - \frac{\bar{g}}{UA_{0,max}} \qquad (7)$$

and the total cooling energy required is given as:

$$Q_{clg(T_{max})} = 24UA_o\{[DD_{c(T_{Max})}] + [(T_{Max} - T_{Bal})N_{d,max}]\} \qquad (8)$$

where $N_{d,max}$ = the number of days in the cooling season with $\overline{T}_A \rangle T_{Max}$

Generally, cooling energy calculations based on degree-days are more difficult than for heating. Heat gains, ventilation rates, and occupants' behavior in operating windows and air-conditioning vary. Fan energy for fan-powered ventilation must also be included. Humidity effects and interrupted operation need also to be carefully considered. This is especially more critical during mild weather when T_A is close to T_{Bal} where greater uncertainty is expected (ASHRAE 1997).

Despite these limitations, the degree-day evaluation can give reasonable annual heating energy estimates especially for skin-load dominated buildings given that proper base temperature is used. It helps in giving an idea about energy consumption trends and comparing alternatives.

CONCLUSIONS

Graphical heating and cooling degree-day data for various Saudi Arabian cities were presented in this paper. The data was based on estimates from long-term monthly average temperatures. This graphical presentation is hoped to provide building designers and engineers with the necessary information to perform simplified energy calculations in order to make proper decisions regarding early energy design alternatives for Saudi buildings. Annual heating and cooling degree-day values at variable balance point temperatures can be obtained for the respective locations which provides building designers with more flexibility and convenience.

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