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Determination of the Latent and Sensible Cooling Energy Consumption for Residential Space in a Hot Region Using RLF Method

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Abstract

This paper investigates the cooling loads required to generate a comfort zone within a residential space in hot regions. Makkah, which represents one of the hottest areas in the Middle East, is considered for the current study. The study considers both latent heat gain due to heat sources within the residential space, and sensible heat gains due to heat sources outside the residential space. The cooling loads are determined using heat gain equations and climate data according to ASHRAE standards, 2017. The results show that the highest cooling loads a percentage of total load due to light, the roof, and side walls, are 27%, 19% and 7% respectively occurred during May, June, July and August, respectively. Peak hours are namely from 7 am to 5 pm

Keywords: HVAC, Simulation, Energy and Consumption

INTRODUCTION

Reducing the cooling loads is the main target of architects. Realizing the classical scheduling environs in which energy consumption and the performance of cooling system evaluation for buildings are conducted after an architectural design has been completed and structure is built [1]. Then Building Material Modeling (BIM) allows multi- precise data to be covered by a model, it created a prospect for sustainability processes investigation to be performed during the design phase [2, 3]. For conventional bungalow houses in countries with tropical weather, the annual operational energy consumption was calculated using Ecotect Analysis [4]. The alternative changes in material compositions of building components, windows, doors, walls, and roof, were examined to evaluate their impact on the building's annual operational energy consumption. Jan Široky´ et al. [5], reported that the energy consumption by using weather forecasts for the considered heating system was between 15% and 28 %, depending on numerous parameters, primarily the insulation level and the temperature is outside. In addition, the peak power request was minimized by 50% and the thermal relaxation in the building was reserved for a greater level. In hot humid climate, the outside air had to be trained to the favorite relaxation moisture and temperature before it could be delivered to indoor places. [6] Specifies 25º C as the summertime interior temperature, but in the concern of energy consumption in many constructions are considered to be 26ºC. The same conclusions have been described for dry and hot weather, where the ‘‘point of thermal variation" showed the exchanging of favorable thermal isolation. Regulation the procedure of air conditioning is performance is achieved by using the control system. The control unit usually had analog and numerical inputs that permitted the size of the variable (humidity temperature, or pressure) and digital and analog outputs to regulate the transportation medium "hot to cold or water to steam" with this configurable the conception of building computerization [7,8]. Further mentoring and control of heating and ventilation air conditioning systems are implemented through building automation interface. Another part was provided by an international standard, which identifies the coding of a data model given in the EXPRESS modeling language [9, 10, 11]. Okan Bingol and Kubilay Tasdelen [12] constructed a share of a smart home system that assimilates with the operator was the web interface. Operators could contact all the rooms of the system of the smart home, the motion controller, temperature value in the home, gas, smoke and door controller units through the web interface. The economizer is utilized to enhance a second controller, which works in synchronization with the outside thermostat and measures the outside air humidity. Such a controller is called an enthalpy control. This saves about 20 to 30 % of total cooling energy consumption according to [13, 14]. An economizer is basically a group of dampers, sensors, actuators, and logic devices composed to decide how much outdoor air to bring into a building. All houses require ventilation to confiscate stale inside air and excessive moisture and to deliver oxygen to the inhabitants. The researchers recommend mechanical ventilation systems for all houses. The quantity of ventilation requisite depends on the number of inhabitants and their life. Demand-controlled ventilation is regularly used for renewed air ventilation. Ventilation controller in commercial or public buildings confirms satisfactory air quality while consuming the slightest energy [15,16]. In Demand-controlled ventilation policies, carbon dioxide application is regularly handled as a direct parameter for ventilation [17]. However, many investigations [17, 18] pointed out that the carbon dioxide-based Demand-controlled ventilation controller approach cannot sufficiently reflect the ventilation request in a space in numerous states. The carbon dioxide concentration does not present evidence on the sufficiency of ventilation level [19, 20]. The latest standard proposes that the lowest requisite for the outside air ventilation rate should be specified by the occupation area, which accounts for area-related sources and people-related sources, as well as individual real residence [21]. The numeral of occupiers could be recognized using a steady-state technique or a dynamic technique [19, 21]. To develop the consistency of building abilities, the most significant matters demanding instantaneous care are to eliminate the reasons producing difficulties in all lifecycle' stages such as structure forecasting, design, structure, maintenance and to estimate quantitatively the consistency model of reliability [23,24]. A model using a neural network algorithm was constructed to calculate the cooling loads resulted from the heat gain due to sensible and latent as reported by [25]. The objective of the present paper is to study the cooling loads' distributions for a building model (up to 4 walls, each with a window and a roof), located at different Latitude and Longitude locations in KSA. The cooling loads are generated by solar gains, internal gains, outdoor air sensible heat, and outdoor air humidity loads.

METHODOLOGY

Residential Cooling energy consumption calculation

As shown in figure (1), the sensible cooling load estimation is obtained from heat gain due to surrounding walls, and doors, in addition to surfaces through which the solar energy is leaked to the residential space. The space occupants play a tangible part of the cooling loads in addition to infiltration, ventilation. Total latent cooling load is the result of three sources outdoor air infiltration and ventilation as well as occupants, and other households' utilities. The HVAC system design should be based on room-by-room considering conditioned airflow required to establish the proper design of the distribution system.

Peak Load Computation

The sensible and latent cooling loads, which are computed in this section, are the peak cooling loads due to the different heat sources described above. Equation 1 and 2 determine the cooling loads due to solar energy penetrating exterior transparent surfaces and partitions to unconditioned space. Ventilation/infiltration, occupant, and appliances and distribution cooling loads are determined by equations, 3, 4, and 5 respectively.

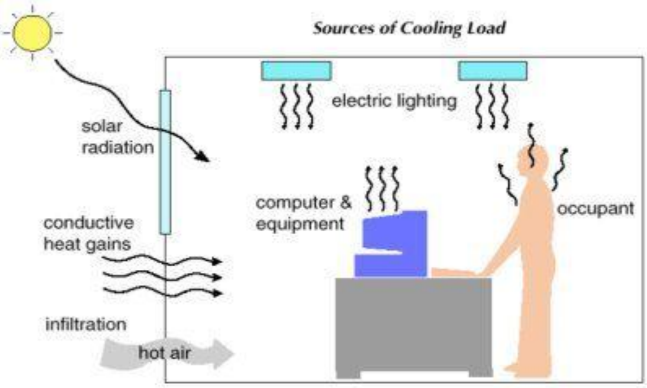

Figure 1. Components of building a cooling load

Equation 6 calculates the total sensible heat. Equations 7 and 8 determine the latent cooling loads due to Ventilation/infiltration and Internal gain. The total latent cooling load is described by equation 9. The power of the cooling unit is based on the peak cooling load for each space (zone) is required to be calculated. The cooling loads' estimation equations are based on Residential load Factor method (RLF) [26] as shown in table 1. The equations constants CF, U, Cs, and C_l are obtained for the present case study location from tables found in [26]. The location is at latitude 21.433, longitude 39.767 and elevation 787 [26]. The number of people occupants is 3. The radiative factors for people, light, and equipment are 0.7, 0.7, and 0.2.

Table 1. The cooling loads' calculation equations [26]

Cooling load type	**Cooling load sources**	**Equation**	**No**
Sensible heat loads	Exterior transparent surfaces	q_{fen} =A(CF)	1
	Partitions to unconditioned space	$q = AU\Delta t$	2
	Ventilation/infiltration	$q_s = C_s Q\Delta t$	3
	Occupants and appliances	$q_{\mathrm{ig,s}} = 136 - 2.2A_{cf} + 22N_{oc}$	4
	Distribution	$q_d = F_{dl}\sum q$	5
	Total sensible load	$q_{\mathrm{s}} = q_{\mathrm{d}} + \sum q$	6
Latent Heat loads	Internal gain	$q_{ig,l} = 20 + 0.22A_{cf} + 12N_{oc}$	7
	Ventilation/infiltration	$q_{vi,l} = C_l Q\Delta w$	8
	Total Latent load	$q_l = q_{vi,l} + q_{ig,l}$	9

RESULTS AND DISCUSSIONS

Outdoor weather situations influence cooling loads. Historical outdoor design temperatures, daily range, and indoor air temperatures are the base for calculating the cooling loads. The statistical climate data are collected for the different locations in KSA. Outdoor and Indoor Design Temperatures are chosen according to ASHRAE Standard states. The comfort zones suitable to hot temperature season are assigned. The temperature variations between outdoor and indoor air will not account for solar heat radiation [26] reported the Climate Design Information for 4 peak months. Generally, for the hottest and the most humid months of the year at MAKKAH, Saudi Arabia, the monthly mean temperatures are 94.4, 97.4, 97.1, and 97.2°F for May, June, July, and August, respectively. An overall, much-estimated rule of the scan was that the *n*% annual cooling design condition was approximately equal to the 5*n*% monthly cooling condition for the hottest months. The current assessments of cooling loads are suitable for computing wet-bulb and daily dry temperature profiles. Figure (2) shows various solar fluxes of the total irradiation in MAKKAH for side wall and roof incidence fluxes. It illustrates that the solar fluxes increase from 0 Btu./hr.Sqft at 6 is up to their peak values of 150 and 325 Btu./hr. Sqft at 1 pm for side wall (S wall) and the roof respectively. The incidences of fluxes start to decay to 0 Btu./hr.Sqft at 7 pm.

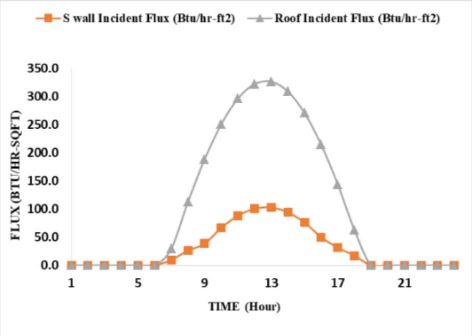

Figure 2. Solar Irradiation Distribution at (May, June, July, and August) (MAKKAH)

Solar-air temperature ($T_{\text{sol-air}}$) is a variable used to calculate the cooling load of a building and define the total heat gain through external surfaces. Figure (3) demonstrates that the highest air temperature, side wall solar-air (s wall temperature) and roof sol-air are 90, 120, and 160 F at 1 pm.

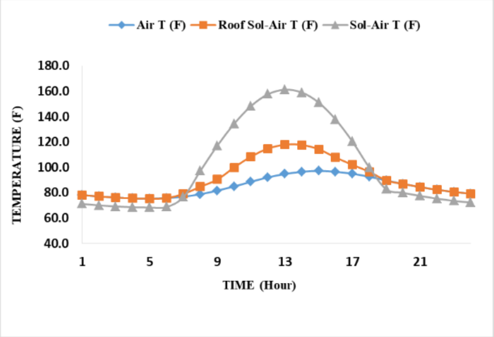

Figure 3. Air Temperature and solar-Air temperature Distribution (May, June, July, and August) (MAKKAH)

Figure (4) shows the heat gained by conduction through the side walls and roof surfaces. It has been shown over the 24 hours that the heat gained is 3000 Btu./hr. and 600 Btu./hr. through the roof and side wall respectively at about 5 pm Which represent the maximum energy consumptions required for cooling.

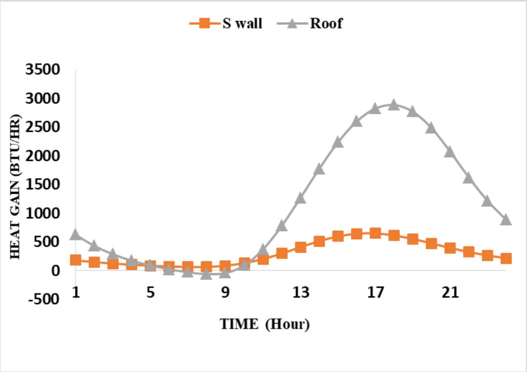

Figure 4. Conduction Heat Gains (May, June, July, and August) (MAKKAH)

Figure (5) shows the cooling loads due to the latent heat gain, (which includes the cooling load required for appliances load, people, and infiltration), sensible heat and their summation. The cooling load due to light, side wall, and appliances represent the highest contributions to cooling loads around 27 % 19% and 19% of total load respectively from 8 am up to 5 pm. During the night hours, the contribution of the light and roof cooling loads are the highest. This suggests that reducing the light cooling load will to minimizing the energy consumption.

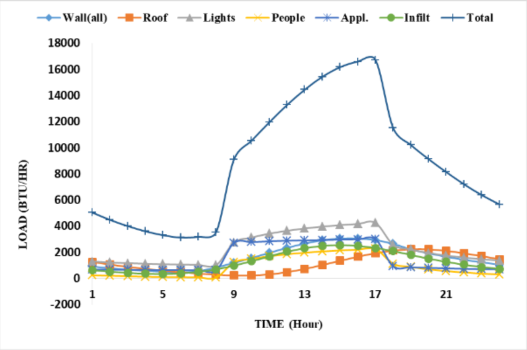

Figure 5. Cooling Load (May, June, July, and August) (MAKKAH)

Figures (6) and (7) illustrate the total cooling loads during the July and August months for different cities which represent latitude and longitude inside KSA. The time intervals were reported in the summer months of July, and August, which are the peak months of cooling energy consumption over 24 hours. The figures show that the energy consumption reaches the peak from 1:00 pm to 5:00. It is observed the highest cooling loads in cities having hot climates and high humidity such as Jeddah and Dammam because these cities are close to the water surfaces.

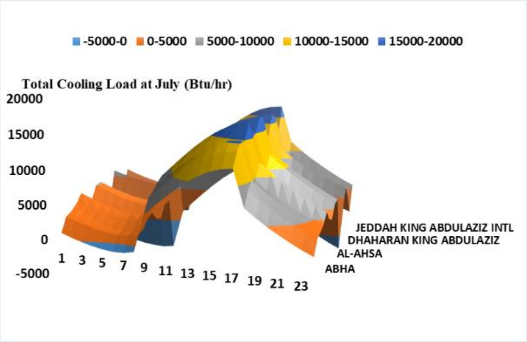

Figure 6. 24-hour total cooling loads ((Btu/hr.) in July at different locations (KSA)

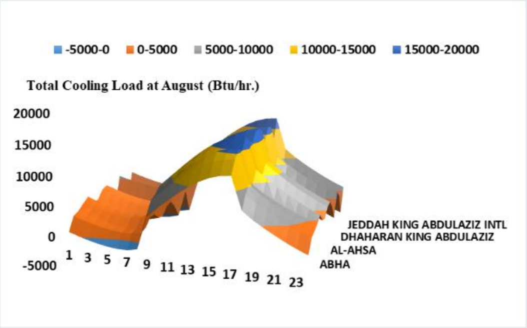

Figure 7. 24-hour total cooling loads ((Btu/hr.) in August at different locations (KSA)

CONCLUSIONS

This investigation shows that the cooling load due to the electrical light is about 27% of the total cooling load during night hours. During the day hours, the cooling load due to heat gain through the roof and the side walls is about 19 % and 7% respectively. This suggests that reducing light load and using heat insulating material for the roof and side walls will decrease the total cooling loads.

NOMENCLATURE

q_{fen}	Exterior transparent surfaces cooling load, Btu/h
A	Net surface area, ft^2
CF	Surface cooling factor, Btu/h·ft^2
U	Construction U-factor, Btu/h·ft^2·°F
Δt	Cooling design temperature difference, °F
C_l	Air latent heat factor, 4840 Btu/h·cfm at sea level
C_s	Air sensible heat factor, 1.1 Btu/h·cfm·°F at sea level
C_t	Air total heat factor, 4.5 Btu/h·cfm·(Btu/lb) at sea level
N_{oc}	Number of occupants
q	Heating or cooling load, Btu/h
Q	Air volumetric flow rate, cfm
t	Temperature, °F
ΔW	Indoor-outdoor humidity ratio difference, lb*w*/lb*da*
F_{dl}	Distribution loss factor

Greek Symbols

Δ Increment of variable

Subscripts

avg average

s sensible or solar

cf conditioned floor

oc occupant

opq opaque

ig internal gain

dl distribution loss

d diffuse, distribution

l latent

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