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A Modification of the ASHRAE Clear Sky Model for Cooling load Calculation in Bangkok Using the Heat Balance Method

บทคัดย่อ

กรุงเทพมหานครเป็นเมืองร้อน ดังนั้นจึงทำให้ระบบปรับอากาศมีความสำคัญกับผู้คนเป็นอย่างมาก ทำให้อาคารต่างๆ จำเป็นต้องติดตั้งระบบปรับอากาศเพื่อให้ผู้อยู่อาศัยรู้สึกสบายในการประกอบภารกิจ การออกแบบทางวิศวกรรมของระบบปรับอากาศต้องเริ่มต้นจากการคำนวณภาระความเย็นของพื้นที่นั้นๆ เพื่อที่จะเลือกขนาดอุปกรณ์ของระบบปรับอากาศแต่ละอย่างได้อย่างเหมาะสม ปัจจุบันสมาคมวิศวกรรมปรับอากาศประเทศสหรัฐอเมริกาได้แนะนำการคำนวณภาระความเย็นด้วยวิธีดุลความร้อน รังสีดวงอาทิตย์เป็นแหล่งพลังงานสำคัญที่ส่งผลต่อภาระความเย็นของอาคาร ซึ่งรังสีดวงอาทิตย์นี้สามารถทำนายได้จากแบบจำลองท้องฟ้าโปร่งของสมาคมวิศวกรรมปรับอากาศแห่งสหรัฐอเมริกา (ASHRAE clear sky model) แต่ค่ารังสีที่ได้นี้ยังไม่เหมาะสมสำหรับการนำมาใช้ในการคำนวณภาระความเย็นสำหรับกรุงเทพมหานคร ดังนั้นในงานวิจัยนี้ จึงได้ทำการศึกษาลักษณะของรังสีอาทิตย์ของกรุงเทพมหานครเพื่อเป็นข้อมูลในการปรับปรุงแบบจำลองท้องฟ้าโปร่งของกรุงเทพมหานครให้สามารถทำนายค่าได้ถูกต้องยิ่งขึ้น

ในงานวิจัยได้ทำการปรับปรุงสัมประสิทธิ์ความสูญหายของบรรยากาศและตัวประกอบรังสีกระจายของแบบจำลองท้องฟ้าโปร่งของสมาคมวิศวกรรมปรับอากาศแห่งสหรัฐอเมริกาสำหรับทำนายรังสีอาทิตย์ของกรุงเทพมหานคร จากข้อมูลรังสีของดวงอาทิตย์ ณ กรุงเทพมหานคร โดยใช้สมการเดิมในการทำนายค่ารังสีอาทิตย์ จากนั้นทำการเปรียบเทียบภาระความเย็นที่ได้จากการคำนวณด้วยแบบจำลองท้องฟ้าโปร่งที่ได้จากการวิจัยและภาระความเย็นจากแบบจำลองท้องฟ้าโปร่งของสมาคมวิศวกรรมปรับอากาศแห่งสหรัฐอเมริกากับภาระความเย็นที่ได้

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จากค่ารังสีที่ได้จากการวัดจริงแล้ว พบว่าหากนำแบบจำลองท้องฟ้าโปร่งที่ได้จากการวิจัยมาใช้ในการคำนวณค่าภาระความเย็นเพื่อออกแบบระบบปรับอากาศแทนการใช้แบบจำลองท้องฟ้าโปร่งของสมาคมวิศวกรปรับอากาศแห่งสหรัฐอเมริกาแล้ว จะสามารถประหยัดค่าใช้จ่ายจากการลดการออกแบบเกินขนาดให้มีความเหมาะสมกับภาระความเย็นที่ใช้งานจริงได้ 4 ถึง 7 เปอร์เซ็นต์

Abstract

Since Bangkok is located in the tropical climate, the air conditioning system becomes the very necessary need for the comfort of everyone while doing activities in the building. Area cooling load is the key parameter in determination of appropriate cooling system specification. Recently, ASHRAE introduces heat balance method for the calculation of cooling load. Solar radiation contributes the major part of the heat gain in cooling load calculation and can be estimated using the ASHRAE clear sky model. However the ASHRAE clear sky model is found to be appropriate for the cooling load calculation in the United States but can not give the accurate results for Thailand due to the difference in climate. Therefore the present work focuses on the characteristics of Bangkok solar radiation in order to develop Bangkok clear sky model for more accurate results.

In the present work, the existing extinction coefficient and the diffuse factor of the ASHRAE clear sky model are improved for better accuracy in the estimation of Bangkok radiation. The meteorological solar data of Bangkok are used as the input to the ASHRAE and Bangkok clear sky models for the cooling load of test building calculation. The results obtained are then compared with the cooling load of actual measured solar data. It is found from the results that by using Bangkok clear sky model in cooling load calculation gives approximately 4-7 percent cost reduction from over design.

Introduction

Prior to the design of the air-conditioning system, the maximum probable cooling load of each room or space cooled must be estimated. The air-conditioning system would extract just enough heat to match the heat gain to the room. However most of time, air-conditioning would have great excess of capacity because of the over predicted of cooling load.

Solar radiation is a major heat gain of a building. Air-conditioning system consumes much electricity to maintain the indoor temperature for the comfort of everyone while doing activities in the building. When the sky is clear, the building heat gain from solar radiation is particularly high. ASHRAE has a model to estimate solar radiation when the sky is clear. Since ASHRAE introduces heat balance method for the calculation of cooling load, its clear sky model is now being used worldwide in cooling load estimating software.

The ASHRAE clear sky model was developed using data from some rural area in United States. The improper value of model parameter made the great value of radiation prediction when use that model in Bangkok. To use the model at different locations to predict solar radiation, first it have to modify the existing extinction coefficient and the diffuse factor of the ASHRAE clear sky model because of the local different sky condition.

In this study, extinction coefficient and the diffuse factor of the Bangkok sky were evaluated and used instead of the original ASHRAE extinction coefficient and the diffuse factor in the ASHRAE model to predict the incident solar radiation that could be expected in Bangkok on an average sunny day. The data from new extinction coefficient and the diffuse factor were computed in computer software for estimating the cooling load of the sample building and compared it with the cooling load from original ASHRAE model.

Solar Radiation

Solar radiation has important effects on building heat gain. In the building design, the total radiation striking a surface over a specified period of time is required. The solar radiation reaching the earth consists of direct and diffuse radiation. Direct radiation is that portion of the radiation that has penetrated the atmosphere without having been scattered or absorbed. Diffuse radiation is the scattered radiation that comes from the sky from all directions. Radiation may also reflect onto a surface from nearby surfaces. The total radiation Gt on a surface normal to the sun's rays is thus made up of normal direct irradiation GND, diffuseirradiation Gd, and reflected irradiation GR

$$Gt = G_{ND} + G_d + G_R \quad (1)$$

Equation (1) is applicable in general regardless of whether the day that is clear or overcast. On a totally overcast day, there is only diffuse radiation (GND = 0). On a clear day, the diffuse radiation is only a small fraction of the direct normal radiation.

ASHRAE Clear Sky Model

In designing an air conditioning system, the equipment is sized for operation when the building is subjected to high solar irradiation. A clear sky allows a high level of solar flux to reach the earth and ASHRAE has a clear sky model for estimating the hourly solar irradiation on the earth surface. The model is semi-empirical and it is described in McQuiston and Spitler (2005). The direct solar radiation incident on a surface oriented normal to the sun's ray is represented by

$$GND = \frac{A}{\exp(B / \sin\beta)} \quad (2)$$

Where

GND = normal direct irradiation. (Btu/hr-ft2 or W/m2)

A = apparent solar irradiation at airmass equal to zero (Btu/hr-ft2 or W/m2)

B = atmospheric extinction coefficient

β = solar altitude

Values of A and B are given in Table 1 from McQuiston and Spitler (2005) for the twenty-first day of each month. The data in Table 1 when used in Equation (2), do not give the maximum value of GND that can occur in any given month, but are representative of conditions on average cloudless days.

Table 1

Solar Data for Twenty-First Day of Each Month.

Month	A (W/m^2)	B	C
Jan	1,202	0.141	0.103
Feb	1,187	0.142	0.104
Mar	1,164	0.149	0.149
Apr	1,130	0.164	0.164
May	1,106	0.177	0.177
June	1,092	0.185	0.185
July	1,193	0.186	0.186
Aug	1,107	0.182	0.182
Sep	1,136	0.165	0.165
Oct	1,166	0.152	0.152
Nov	1,190	0.144	0.144
Dec	1,204	0.141	0.141

From: McQuiston et al. (2005)

The clear sky model approximates the diffuse radiation falling on a horizontal surface as a fraction of the direct normal irradiation. Where C is the diffuse radiation factors are also given in Table 1.

$$G_d = (C)(G_{ND}) \quad (3)$$

Modification of the ASHRAE Clear Sky Model

Solar radiation data were obtained from Meteorological Service Bangkok. The station records the hourly average values of the global radiation and the diffuse radiation. The data we took to use in new model is show in Table 2.

Table 2

solar radiation data for Analysis

data type	station	period	Source
direct irradiation	Bangkok	year 1998-2004	Calculation
diffuse irradiation	Bangkok	year 1998-2004	Meteorologial Service

Atmospheric Extinction Coefficient (B)

Model 1 (B_1)

The analysis of atmospheric extinction coefficient (B1) is to distinguish the maximum irradiation of each hour every month for use with the following linear relation.

$$B\,[1/(\cos\psi] = -\ln\,[G_{ND}/A] \qquad (4)$$

The air mass [1/ (cosψ] is plotted versus term ln [G_{ND}/A], where ψ is the sun's zenith angle of Bangkok, G_{ND} is the measured normal direct radiation of Bangkok clear day and A is apparent solar irradiation. The atmospheric extinction coefficient (B_1) is the slope of the plot.

Model 2 (B_2)

We obtained B_2 from the relation equation as shown in Equation (5), where G_{ND} is the absolute maximum normal direct irradiation of Bangkok between years 1998-2004.

$$B_2 = -\cos\psi\,\{\ln\,[G_{ND}/A]\} \qquad (5)$$

The values of B_1 and B_2 for the different months are shown in Table 3 together with the B values of ASHRAE clear sky model.

Table 3

ASHRAE atmospheric extinction coefficient (B_{ASHRAE}) and Bangkok atmospheric extinction coefficient (B_1 and B_2)

Month	B_{ASHRAE}	B_1	B_2
Jan	0.141	0.528	0.429
Feb	0.142	0.521	0.335
Mar	0.149	0.539	0.285
Apr	0.164	0.473	0.244
May	0.177	0.508	0.290
June	0.185	0.534	0.215
July	0.186	0.469	0.261
Aug	0.182	0.489	0.236
Sep	0.165	0.580	0.325
Oct	0.152	0.557	0.358
Nov	0.144	0.549	0.353
Dec	0.141	0.528	0.374

Diffuse Radiation Factor (C)

C is obviously the ratio of diffuse irradiation on a horizontal surface to direct normal irradiation. The parameter C is assumed to be a constant for an average clear day for a particular month.

Model 1 (C1)

When the measured value of G_d is plotted versus the predicted G_{ND} at the same hour, the local diffuse factor C_1, is the slope of the plot.

Model 2 (C2)

We obtained C2 from the relation equation as shown in Equation (6), where Gd is the different of the maximum total irradiation and maximum direct irradiation.

$$C_2 = G_d / G_{ND} \qquad (6)$$

The values of C1 and C2 for the different months are shown in Table 4 together with the C values of ASHRAE clear sky model.

Table 4

ASHRAE diffuse radiation factor (C_{ASHRAE}) and Bangkok diffuse radiation factor (C_1 and C_2)

Month	C_{ASHRAE}	C_1	C_2
Jan	0.103	0.239	0.181
Feb	0.104	0.260	0.167
Mar	0.149	0.300	0.163
Apr	0.164	0.222	0.148
May	0.177	0.345	0.246
June	0.185	0.325	0.161
July	0.186	0.233	0.209
Aug	0.182	0.242	0.156
Sep	0.165	0.368	0.265
Oct	0.152	0.320	0.285
Nov	0.144	0.247	0.210
Dec	0.141	0.210	0.121

Cooling Load Calculation by Computer Program

We calculated the cooling load of the sample building by the heat balance method. The model 1, model 2 and ASHRAE model would take into calculate the hourly cooling load by computer program. The results obtained are then compared with the cooling load of actual measured solar data. The air conditioning is designed for maintain the required comfort conditions in maximum cooling load. From the calculation, we found that the maximum cooling load was in April and we used this value for air conditioning selection.

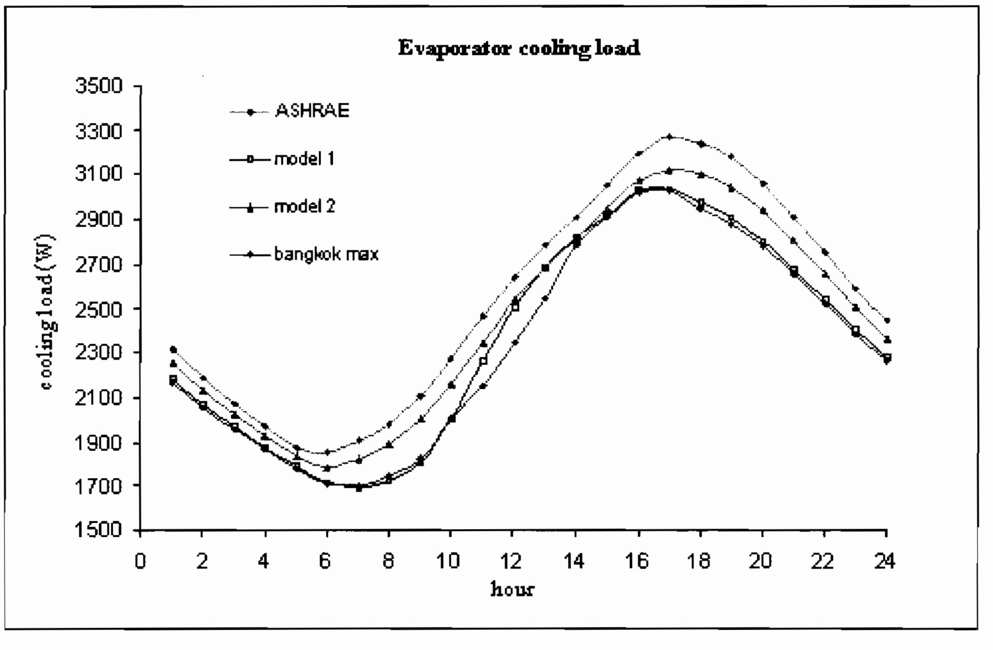

Figure 2 hourly cooling load in April

Table 5

Comparison of the building cooling load from solar models and maximum measured data.

Month / Model	ASHRAE (W)	Model 1 (W)	Model 2 (W) data	Measured (W)
April	3,267.84	3,036.84	3,118.84	3,025.84
August	2,571.84	2,410.84	2,477.84	2,401.84
Dececmber	2,729.84	1,993.84	2,12184	1,995.84

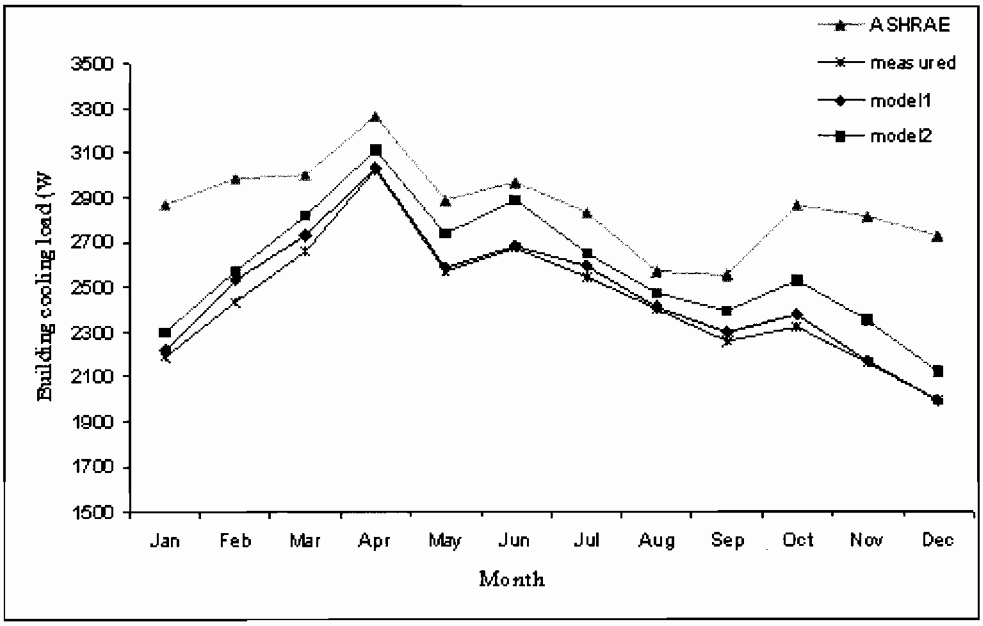

Figure 3 building cooling load from solar models and measured data in each month.

Conclusion

A large amount of radiant heat gain from ASHRAE clear sky model causes significant over design. The results of the research found that the cooling load calculation in Bangkok by using the developed clear sky model is more efficient design than ASHRAE clear sky model. The using of Bangkok clear sky model in cooling load calculation gives approximately 4-7 percent cost reduction from over design.

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