A REVISED RADIANT TIME SERIES (RTS) METHOD FOR INTERMITTENT COOLING LOAD CALCULATION

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ABSTRACT

Most of commercial buildings are intermittently operated in practice. The use of the Radiant Time Series (RTS) method based on the continuous air-conditioning operation could result in largely underestimated peak cooling loads, and inconsistent design. Hence, a new method is developed based on the RTS. The new method only needs one more step after the current RTS design procedure, using the overall periodic transfer coefficients that have computed in this procedure. The additional cooling loads generated by the new method well agree with the results form EnergyPlus simulations. Analysis results also show that the additional peak cooling loads largely depend on building types, orientations, window sizes, and operation periods.

INTRODUCTION

Design cooling load calculation is fundamental for the design and distribution of HVAC systems (McQuiston and Spitler, 1992). Radiant Time Series (RTS) method was proposed by Spitler et al (Spitler et al., 1997), and presented later in the 2001 and 2005 ASHRAE Handbook – Fundamentals to provide an efficient alternative to other simplified cooling load calculation method (ASHRAE, 2001; 2005).

RTS method is a simplified method related to and derived from the Heat Balance (HB) method (Spitler et al., 1997). It take advantage of 24-hour periodic response factors of the wall/roof to compute the conductive heat gain and periodic radiant time factors to convert the instantaneous heat gain to cooling load to simplify the cooling load calculation procedure.

However, the RTS method is based on continuous operation of the air-conditioning system because all the design information provided for cooling load calculations is under the condition of constant space air temperature. Hence, it is unable to give the accurate design cooling load in intermittent operation where the air-conditioning system is usually not working during night. If the heat gains of the building exceed the heat loss at the off-work hours, the room air temperature will increase, which will result in heat storage in the building envelope and furniture. The release of the stored heat will lead to additional cooling load in subsequent hours. The peak cooling load for intermittent HVAC system operation is thus underestimated by RTS method. Engineers usually modified the design cooling load for non-continuous operation according to their experience, usually adding by 10% (Lin and Xu, 2008). Lin and Xu (2008) presented the modification factors for several typical building envelopes. However, these factors are relatively inaccurate and further iteration is required for buildings other than listed.

EnergyPlus is a heat balance base solution for energy analysis and thermal load simulation (EERE, 2008). It allows the analysis of intermittent air-conditioning system operation of a building. Yet this program is not suitable for pre-design stage of design cooling load calculation due to its complexity. The results by EnergyPlus will then be used for verification only.

In this paper, a simple method based on the current radiant time series method will be proposed for intermittent cooling load calculations. The method can take all the primary influence factors into account more accurately, and only needs to add one more step to the conventional RTS calculation procedure. The results will be eventually compared with the current RTS method and also verified by EnergyPlus simulation.

SIMPLE FORM OF RTS MODEL

ASHRAE Fundamentals (2005) presents RTS method for peak cooling load calculations in details. The RTS method may be further developed into the simple form by combining relative equations, and sorting and rearranging the terms in the equations (Chen and Yu 2009). The simple form of the RTS method can clearly provide an insight to the effect of different parameters on the cooling loads, and largely reduce the amount of calculations.

Cooling loads driven by temperature difference between outdoor and space air temperature may be computed by

$$q_{c,t_o}(k) = \sum_{j=0}^{23} g_{t_o,j}\left[t_o(k-j)_{24} - t_a(k-j)_{24}\right] \tag{1}$$

where

$$g_{t_o,0} = r_{rw,cv}\sum_{i=1}^{n_{rw}} c_{i,0}\left(UA\right)_i + r_{rw,cv}\sum_{i=1}^{n_{win}}\left(UA\right)_{win,i} + \sum_{l=0}^{23}\left(r_{ns,0}a_{(0-l)_{24}}\right) + m_a c_{pa} \quad (2)$$

$$g_j = r_{rw,cv}\sum_{i=1}^{n_{rw}} c_{i,j}\left(UA\right)_i + \sum_{l=0}^{23} r_{ns,j}a_{(j-l)_{24}} \quad (3)$$

with

$$a_0 = r_{rw,r}\sum_{i=1}^{n_{rw}} c_{i,0}\left(UA\right)_i + r_{rw,r}\sum_{i=1}^{n_{win}}\left(UA\right)_{win,i} \quad (4)$$

$$a_j = r_{rw,r}\sum_{i=1}^{n_{rw}} c_{i,j}\left(UA\right)_i \quad (5)$$

The physical meaning of Equations (1-5) is that the total dynamic heat gain is equal to the product of the overall heat conductance UA and the temperature difference, $t_o - t_a$, between outdoor and indoor air at discrete time k. However, when and how much heat is transferred into room is determined by the dynamic characteristics of a building, which is quantitatively represented by conduction time factors $c_{i,j}$. and non-solar radiant time factors $r_{ns,j}$. Subscript 24 indicates the number of hours in a periodic design period over 0 – 23 hr. This means that $k - j$ should be replaced by a positive value 24 + ($k - j$) whenever $k - j < 0$. In the equations, a space under consideration has n_{rw} types of roofs and/or walls, and n_w types of windows. Since the convective ratio $r_{rw,cv}$ for roofs and walls is equal to that $r_{w,cv}$ for windows, $r_{rw,cv}$ can replace $r_{w,cv}$ for of reason of simplicity, and $r_{rw,r}$ is the radiant heat ratio. Only a part of the cooling load from infiltration and ventilation ($m_a c_{pa}$ ($t_o - t_a$)) is included because the other part depends on outdoor moisture content w_o, and is computed separately. Subscript *win* represents window. Space air temperature t_a is assumed to be constant in the current RTS method.

Cooling loads due to total solar radiation incident on the exterior surface of walls and roofs can be given by

$$q_{c,E_t}(k) = \sum_{j=0}^{23} g_{E_t,j}E_t(k-j)_{24} \quad (6)$$

with

$$g_{E_t,j} = \frac{r_{rw,cv}}{h_o}\sum_{i=1}^{n_{rw}} c_{i,j}(UA)_i\alpha_i + \sum_{l=0}^{23} r_l a_{(j-l)_{24}} \quad (7)$$

where

$$a_j = \frac{r_{rw,r}}{h_o}\sum_{i=1}^{n_{rw}} c_{i,j}(UA)_i\alpha_i \qquad (j = 0,\cdots,23) \quad (8)$$

where E_t is total solar irradiance incident on the exterior surface of walls and roofs; h_o is convective heat transfer coefficient at the exterior surface of walls and roofs; α_i is the absorbtivity of the exterior surface of wall or roof i; r_l is solar radiant time series; and subscript E_t means cooling loads due to total solar irradiance E_t.

Heat gains due to both diffuse and direct solar radiation, q_s, transmitted through windows may be expressed by

$$q_s(k) = \sum_{i=1}^{n_{win}} A_{w,i}(IAC)_i < SHGC >_i E_d(k) + SHGC_i(\theta(k))\, E_b(k)] \quad (9)$$

where A is area (m^2); (IAC) the inside shading attenuation coefficient; < $SHGC$ > the diffuse solar heat gain coefficient; $SHGC(\theta(k))$ the direct solar heat gain coefficient as a function of solar incident angle θ; E solar irradiance incident on the exterior surface of a window, subscript w represents window, d and b are diffuse and beam solar irradiance, and i is the ith window.

REVISED RTS MODEL

In the intermittent operation, the space air temperature should vary when the air-conditioning system is not working. This will cause heat storage, which then results in additional cooling loads over those in the continuous operation. This part of cooling loads cannot be estimated by the current RTS method because all the design data depends on the assumption of the constant space air temperature. Therefore, a model based on the principle of the current RTS method is presented to utilize the available design data given in ASHRAE Fundamentals (2005) for reasonable estimating peak cooling loads in the intermittent operation.

The operation schedule of air-conditioning system is assumed to be as follows:

$$\underbrace{1,\ldots,n_1-1}_{off},\underbrace{n_1}_{pre},\underbrace{n_1+1,\ldots,n_2-1}_{on},\underbrace{n_2,\ldots,24}_{off}$$

where n_1 is the pre-cooling hour, n_1+1 to n_2-1 the working hour.

Most of assumptions needed for the revised RTS model are similar to those used in the current RTS method. Heat transfer driven by temperature difference between outdoor air and space air through building envelope can be estimated by Equation (1). Radiant heat in the space does not lose to outdoor environment. The space air is well mixed, and its heat storage is negligible. Temperatures at the central line of the internal envelope and the exterior surface of the external envelope are not impacted by the variation of the space air temperature within an hour. Figure 1 shows a thermal network describing heat transfer except the convective heat loss from the space air to the interior surface of the external envelope. R is heat transfer resistance, and nodes a, i, e, v and w represent space air, and the interior surfaces of the internal and the external envelopes, the central line of the internal envelope, and the exterior surface of the external envelope. R is resistance.

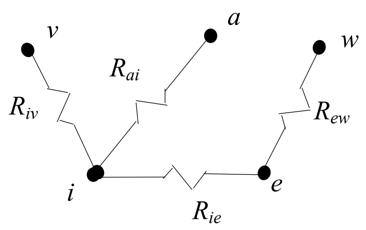


Figure 1. Thermal network in the space

The calculation approach of the RTS method for estimating cooling loads through the external envelope is used to compute heat storage driven by the variation of space air temperature. Heat transferred into the building medium, $q_{h,r}$, is approximately computed in the steady-state heat transfer as follows:

$$q_{h,r}(k) = (UA)_{total} \Delta t_a(k) \tag{10}$$

with $k = n_2, \ldots, 24, 1, \ldots, n_1$

$$(UA)_{total} = (UA)_{aiv} + (UA)_{aew} \tag{11}$$

$$(UA)_{aiv} = \frac{U'_{iv} h_c}{U'_{iv} + h_c} A_i \tag{12}$$

$$(UA)_{aew} = \frac{1}{R_{ai} + R_{ie} + R_{ew}} \tag{13}$$

where

$$R_{ai} = \frac{1}{h_c A_i} \tag{14}$$

$$R_{ie} \approx \frac{\frac{1-\varepsilon_i}{\varepsilon_i A_i} + \frac{1}{A_e F_{ei}} + \frac{1-\varepsilon_{ex}}{\varepsilon_{ex} A_{ex}}}{4\sigma T_{avg}^3} \tag{15}$$

$$R_{ew} = \frac{1}{U'_{ew} A_e} \tag{16}$$

In Equations (10-16), $(UA)_{total}$ is the overall heat transfer coefficient from air to interior surfaces; h_c is convective heat transfer coefficient over the interior surface; U' wall heat transfer coefficient without air film; A_i the interior surface area of the internal envelope; A_{ex} the interior surface area of the external walls or/and roof excluding windows; σ the Stefan-Boltzmann constant; ε emissivity; F_{ei} view factor from the exterior surface of the external walls to the interior surface of the internal envelope; T_{avg} the estimated average temperature (in degrees Kelvin) at the interior surfaces of the internal and the external envelope excluding windows; subscript *h* and *r* indicate heat and storage, and *a, i, e, v* and *w* are node or nodes through which heat transfers.

In the continuous operation, hourly cooling loads $q_c(k)$ can be computed with Equations (1) to (9). When a space is intermittently air-conditioned, the amount of cooling load $q_c(k)$ is not supplied. Hourly intermittent cooling load calculations may be based on those in the continuous operation. It may be imagined that convective heat $q_h(k)$, which is equal to $q_c(k)$, is supplied into the space. This will result in the increase of the space air temperature, $\Delta t_a(k)$, during the time period without air-conditioning. The variation of the space air temperature will cause heat storage in the building medium, and heat losses through the external envelope. The heat transferred into the envelope $q_{h,r}$ due to $\Delta t_a(k)$ will release into the space continuously, which will also lead to additional heat gains in the hours without air-conditioning, and additional cooling loads during the hours with air-conditioning. Heat balance during the hours without air-conditioning may be expressed by:

$$\begin{aligned} &q_h(k) - q_{h,r}(k) = \\ &\sum_{j=0}^{23} g_j \Delta t_a(k-j)_{24} - \sum_{j=0}^{23} r_{ns,j} q_{h,r}(k-j)_{24} \end{aligned} \tag{17}$$

where $q_h(k) = q_c(k)$ is calculated using RTS method in the above section.

Substituting Equation (10) into the above equation yields:

$$\begin{aligned} &q_h(k) - (UA)_{total} \Delta t_a(k) = \\ &\sum_{j=0}^{23} g_{t_o,j} \Delta t_a(k-j)_{24} - \sum_{j=0}^{23} r_{ns,j} (UA)_{total} \Delta t_a(k-j)_{24} \end{aligned} \tag{18}$$

Therefore, the space air temperature increase $\Delta t_a(k)$ during the hours without air-conditioning can be calculated by

$$\Delta t_a(k) = \frac{q_h(k) + \sum_{j=1}^{23} b_j \Delta t_a(k-j)_{24}}{a} \tag{19}$$

with $k = n_2, \ldots, 24, 1, \ldots, n_1$

$$a = (1 - r_{ns,0})(UA)_{total} + g_{t_0,0} \tag{20}$$

$$b = r_{ns,j} (UA)_{total} - g_{t_0,j} \tag{21}$$

where the discrete time k takes all the hours when the air-conditioning system is not working.

Generally, pre-cooling should be provided to prevent the occurring of peak cooling load at the first hour of air-conditioning operation. In this paper, the space air temperature at the pre-cooling hour, n_1, is assumed to be 0.5°C higher than constant temperature, i.e.,

$$\Delta t_a(n_1) = 0.5\ ^oC \tag{22}$$

The number of Δt_a equals to the number of hours without air-conditioning. The space air temperature increase Δt_a should be equal to zero when the air-conditioning system is working, and according to

Equation (10), the heat transferred to the envelope $q_{h,r}(k)$ should also be equal to zero at the same time.

Therefore, $\Delta t_a(k)$ can be obtained by solving the simultaneous equations given by

$$\mathbf{A}\,\mathbf{\Delta} t = \mathbf{B} \tag{23}$$

with $k = n_2, \ldots, 24, 1, \ldots, n_1$

where **A** and **B** are the coefficient matrices obtained from Equations (19) to (21). The simultaneous equations can be solved by available numerical methods.

Since any numerical approach to solving more than four simultaneous equations is generally tedious for hand calculation, it is expected to find a way to obtain the results by hand calculation. This is realized by assuming that the room air temperatures are constant when the air-conditioning system is turned off, except the first off-work hour.

At the first off-work hour, the room air temperature tends to increase rather quickly to a high value that may keep almost constant at the subsequent hours, and the average indoor air temperature at this hour is smaller than the high value. This assumption is reasonable because the temperature increase due to storage heat releasing is counteracted by generally reduced heat gains at night. This assumption is verified by the results of EnergyPlus simulations. The room air temperature variations at off-work hours (except the first one) are typically less than 1.5°C.

With the above assumption, only two equations are to be solved to obtain two variables, $\Delta t_a(n_2)$ and $\Delta t_a(n_2+1)$. However, the number of heat balance equations is still equal to the number of the hours without air-conditioning. This will produce conflicts among these simultaneous equations. The best approach to solving these conflict equations is the least square method. A simpler alternative method is to compute the average coefficients from these equations to generate two simultaneous equations first, which can be easily solved. The most simplified approach is to directly use the two equations at the two hours immediately after the air-conditioning system is shut down since they should be important equations due to the most significant variation of the space air temperature at these two hours. The two equations are given by:

$$\begin{cases} a\Delta t_a\left(n_2\right) - \left[\displaystyle\sum_{j=n_2-n_1+1}^{23} b_j\right]\Delta t_a\left(n_2+1\right) \\ \qquad = q_h\left(n_2\right) + 0.5\, b_{n_2-n_1} \\ -b_1\Delta t_a\left(n_2\right) + \left(a - \displaystyle\sum_{j=n_2-n_1+2}^{23} b_j\right) \\ \Delta t_a\left(n_2+1\right) = q_h\left(n_2+1\right) + 0.5\, b_{n_2-n_1+1} \end{cases} \tag{24}$$

The air-conditioning system will run to maintain constant space air temperature from hour n_1+1 to n_2-1. Additional cooling load $q_{add}(k)$ due to the release of stored heat in off-work hours can then be calculated after the space air temperature variations at off-work hours are calculated using the above methods. This additional cooling load can be calculated by

$$q_{add}(k) = \sum_{j=1}^{23} r_{ns,j} (UA)_{total}\, \Delta t_a (k-j)_{24} \tag{25}$$

with $k = n_1$+1 to n_2-1

The total hourly cooling load of intermittent cooling at hour k can finally be obtained by the summation of this additional cooling load and the cooling load calculated by the conventional RTS method based on continuous operation, given by Equations (1) to (9), i.e.

$$q_{total}(k) = q_c(k) + q_{add}(k) \tag{26}$$

with $k = n_1$+1 to n_2-1

RESULT ANALYSIS

Characteristics and design data of the office building

A typical office building construction located in Hong Kong was analyzed in this study. The building characteristics and weather conditions are listed in table 1. For simplicity, only lighting internal heat is considered, the infiltration and ventilation rates are set to zero, and therefore only sensible cooling loads are calculated. The latent load is not considered here because it cannot be stored, and hence it should be approximately equal to that in the continuous operation.

The space to be considered has one external wall, three internal partitions, one roof and floor. The constructions are the same as those described in Table 22 on page 30.29 of 2005 ASHRAE Handbook – Fundamentals (ASHRAE, 2005). The wall conduction time series (CTS) for three types of external walls and the solar and nonsolar RTS values for the zone are calculated by the PRF/RTF Generator software (Iu, 2006) developed by Building and Environmental Thermal Systems Research Group at Oklahoma State University. The hourly outdoor dry-bulb temperatures are calculated by EnergyPlus using the maximum dry-bulb temperature and daily temperature range. The window is uncoated double glazed, 3mm clear type pane and 6 mm air space (Type 5a from Table 13 of Chapter 31 of ASHRAE Handbook (ASHRAE, 2005).

Table 1 Building and operation characteristics

Hong Kong	
Latitude, (°)	22.33
Longitude (°)	114.18
Time zone	+8
Design day	Jul-21
Maximum dry-bulb temperature (°C)	32.9
Daily temperature range (°C)	4.5
Summer indoor temperature (°C)	24
Building Properties	
Floor dimension (L × M) (m)	6 × 4
External wall dimension (L × H) (m)	6 × 3
Interior surface convective heat transfer coefficient	3.08
Interior Surface emittance	0.9
Lighting load (kW)	1.0
Convective fraction	0.36
Schedule	07:00-21:00
Air-conditioning system	
Pre-cooling hour	06:00-07:00
Pre-cooling indoor air temperature (°C)	24.5
Schedule	07:00-21:00

Result analysis

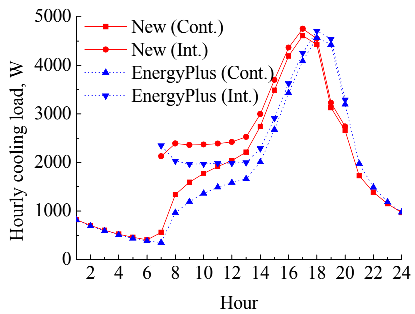
A large number of cases are calculated using a FORTRAN program developed according to the method proposed. Simulation results are compared to those generated by EnergyPlus (EERE, 2008) for verification since EnergyPlus is well accepted for energy calculation.

The primary objective of this study is to reasonably and consistently estimate the peak cooling load in the intermittent operation of different buildings. Therefore, the estimated cooling load increase from the continuous operation to intermittent operation should be verified. Figure 2 shows the variation of hourly cooling loads in both continuous and intermittent operation. The hourly cooling loads of intermittent operation are generally larger than those of continuous operation, and the difference is larger at the first few hours when the air-conditioning system is started and become smaller in the subsequent hours.

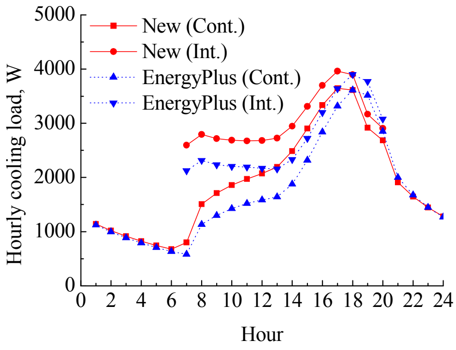
Table 2 shows the peak cooling loads computed by the new method and EnergyPlus for a space with a west facing wall and window, in which Q is the peak cooling load, and cont. and int. represent 'continuous' and 'intermittent', respectively. Examination of Table 2 indicates that differences between the peak cooling loads generated by EnergyPlus and the new method are the highest for the medium weight building, but much smaller for the other two types of buildings. This may be due to the intrinsic features of RTS method EnergyPlus simulation method. It can also be observed that the cooling load increases estimated by the new method and EnergyPlus are approximately the same, varying from 0.1% to 3.1%.

Tables 3 and 4 indicate the peak cooling load increases from the continuous operation to the intermittent operation due to different orientations, operation time lengths, window sizes, and building types. The difference of peak cooling loads tends to increase with the envelope weight and to decrease with percentage of glass ratio. Because heavyweight envelope usually contains larger thermal capacity and inertia as compared to lightweight and medium weight ones, the intermittent operation increasingly impacts the peak cooling load with increasing of envelope weight. It can be seen from Table 3 that for the space with 50% fenestration in the external envelope, the peak cooling load increases averagely from 3% for the lightweight envelope, 8% for the medium weight, and about 15% for the heavyweight. The difference is the largest for east facing spaces. When the latent load is taken into account, the percentage of cooling load increase would be reduced because an identical latent cooling load will be added for both continuous and intermittent operation.

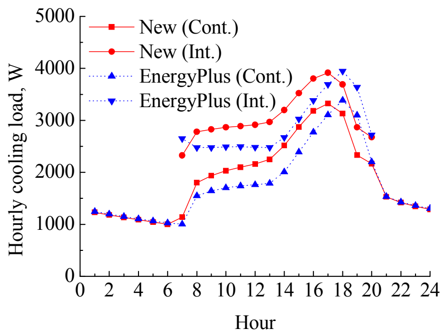
Table 4 indicates that the peak cooling load increase from the continuous operation to intermittent operation tends to increase with the decrease of operation period length (the schedule of lighting is set the same as the operation schedule of the air-conditioning system in this comparison). This effect is considerable and should be taken into account. For instance, the cooling load increase is almost doubled when the operation time is changed from **07:00-23:00 to 07:00-19:00.** The short operation period allows more heat to be stored in the heat storage medium, and therefore results in largely increased peak cooling load. This implies that the simple and traditional measure of multiplying the peak cooling load of the continuous operation by a constant factor, 10% for instance, for the intermittent operation is not rational.



(a) Lightweight envelope



(b) Medium weight envelope



(c) Heavyweight envelope

Figure 2 Comparison of hourly cooling loads by EnergyPlus and new method for continuous and intermittent operation of west facing spaces with the glass ratio of 50%

Table 5 shows the results obtained by the most simplified method, i.e. direct solving the two Equations (24). It can be observed that these results well agree with those in Table 3, generated by the new method (solving all the simultaneous equations established during the hours without air-conditioning). Therefore this approximate method should be acceptable for intermittent cooling calculation. Unlike the new method that may require iteration calculations, this simplified method is straightforward, and only needs to solve two or three equations. It is thus suitable for hand or spreadsheet calculation.

CONCLUSIONS

The RTS method currently recommended by ASHRAE Handbook is based on the continuous operation of a constant space air temperature constant. Most of commercial buildings, if not all, are intermittently operated in practice. The use of the current RTS method could result in largely underestimated design cooling loads. A new method has been developed, which is fully based on the RTS method. The first part of the new revised RTS method is exactly the same as the current RTS method in principle, but simplifies the calculation procedure. The overall periodic transfer coefficients computed in the first part will be used to estimate the additional peak cooling load due to a change from the continuous operation to the intermittent operation. The total peak cooling load in the intermittent operation can be obtained by the summation of the peak cooling load in the continuous operation and the additional peak cooling load computed in the second step.

A large number of simulations on different building constructions, glass ratios and orientations, and air-conditioning operation periods are conducted. The results show that the peak cooling load of intermittent operation computed by the new method may be 2 – 25% larger than that of continuous operation by RTS method. The additional peak cooling load increases with increase of envelope weight, and decreases with increase of glass ratio and operation period. For a west-facing space with the glass ratio of 50%, the additional cooling load is about 2-5% for lightweight envelopes, 5-10% for medium weight ones and 10-20% for heavyweight ones. This value also varies for different orientations, and may reach its largest for east-facing buildings. When the latent load is taken into account, the percentage of cooling load increase would be reduced. The additional cooling loads generated by the new method have been verified by EnergyPlus simulations, and the average differences are small and should be acceptable.

The additional peak cooling loads in the intermittent operation could be very large and should not be ignored. The traditional measure of multiplying the peak cooling load of the continuous operation by a factor cannot provide consistent design cooling loads. The new method developed can give reasonably accurate intermittent design cooling loads.

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NOMENCLATURE

q	Thermal load, W
g	Periodic heat transfer coefficient, W/K
U	U-factor with air film, W/(m^2·K)
A	Area of wall or window, m^2
c	Wall conduction time series
r_{ns}	Non-solar radiant time series
R	Thermal resistance
$r_{rw,cv}$	Convective ratio of sensible heat gain
$r_{rw,,r}$	Radiant ratio of sensible heat gain
n_{rw}	Number of external wall and/or roof
n_{win}	Number of windows
F	View factor
Δt_a	Space air temperature increase, °C
m_{air}	Mass flow rate of outdoor air, kg
c_{pa}	Air specific heat, J/(kg·K)

Table 2 Peak cooling loads by EnergyPlus (E+) and new exact method for a west-facing space

% Glass	Wall type	Q by E+, W		Q by new, W		Error, %	
		Cont.	Int.	Cont.	Int.	Cont.	Int.
10%	light	1829.28	1902.32	1946.60	1991.24	6.41	4.67
	medium	1751.71	1898.04	1622.99	1711.60	7.35	9.82
	heavy	1450.93	1753.46	1428.72	1631.36	1.53	6.96
50%	light	4571.41	4708.38	4609.34	4682.92	0.83	0.54
	medium	4160.34	4411.76	3644.06	3819.75	12.41	13.42
	heavy	3386.58	3946.73	3325.54	3676.34	1.80	6.85
90%	light	6994.68	7159.11	7233.29	7318.68	3.41	2.23
	medium	6161.16	6508.11	5655.53	5873.20	8.21	9.76
	heavy	5020.51	5736.43	5180.92	5622.39	3.19	1.99

Table 3 Peak cooling load difference (%) between continuous and intermittent cooling for eight orientations

% Glass	Wall type	Difference at eight orientations, %							
		N	NE	E	SE	S	SW	W	NW
10%	Light	2.57	8.86	8.31	7.48	3.99	2.46	2.45	2.13
	Medium	6.76	10.34	11.56	9.14	7.05	6.41	6.11	5.95
	Heavy	16.88	22.57	22.19	21.44	16.65	15.80	15.96	15.69
50%	Light	3.47	5.28	4.81	6.05	3.16	1.89	1.87	1.90
	Medium	6.60	10.01	9.09	8.92	5.89	5.26	5.78	5.30
	Heavy	14.14	17.50	16.11	16.38	13.13	13.03	12.74	12.55
90%	Light	2.98	4.61	3.67	4.70	2.68	1.57	1.54	1.57
	Medium	5.62	8.21	8.01	7.26	4.91	4.56	4.97	4.91
	Heavy	12.43	14.77	13.77	14.03	11.34	11.41	11.13	10.98

Table 4 Peak cooling loads difference (%) by EnergyPlus (E+) and new exact method for west facing building

% Glass	Wall type	Difference at three operation period by two method, %					
		07:00-23:00		07:00-21:00		07:00-19:00	
		E+	New	E+	New	E+	New
10%	Light	3.04	1.92	3.99	2.45	5.67	3.25
	Medium	6.26	4.61	8.35	6.11	13.14	7.87
	Heavy	15.85	12.12	20.85	15.96	27.58	20.24
50%	Light	2.06	1.41	3.00	1.87	4.75	2.52
	Medium	4.24	4.30	6.04	5.78	10.35	7.61
	Heavy	12.22	9.47	16.54	12.74	23.37	16.70
90%	Light	1.61	1.19	2.35	1.54	3.73	2.00
	Medium	3.94	3.73	5.63	4.97	8.53	6.40
	Heavy	10.52	8.29	14.26	11.13	20.16	14.51

Table 5 Peak cooling load difference (%) between continuous and intermittent cooling by the approximate method

% Glass	Wall type	Difference at eight orientations, %							
		N	NE	E	SE	S	SW	W	NW
10%	Light	3.39	11.66	10.95	9.88	5.41	3.28	3.30	2.98
	Medium	9.06	13.50	14.69	11.96	9.07	8.10	7.78	7.58
	Heavy	20.00	26.57	25.97	25.23	19.74	18.50	18.55	18.26
50%	Light	5.01	7.80	6.74	8.33	4.29	2.70	2.75	2.77
	Medium	8.79	13.08	12.11	11.58	7.60	6.85	7.56	7.03
	Heavy	17.14	21.11	19.49	19.81	15.88	15.76	15.41	15.19
90%	Light	4.56	7.11	5.51	6.83	3.80	2.45	2.51	2.52
	Medium	7.75	11.13	10.93	9.78	6.55	6.19	6.83	6.73
	Heavy	15.37	18.24	16.99	17.30	13.95	14.13	13.81	13.63