Cooling Load Calculations For Typical Iraqi Roof And Wall Constructions Using Ashrae's RTS Method

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ABSERACT

The present work is an attempt to develop design data for an Iraqi roof and wall constructions using the latest ASHRAE Radiant Time Series (RTS) cooling load calculation method. The work involves calculation of cooling load theoretically by introducing the design data for Iraq, and verifies the results experimentally by field measurements. Technical specifications of Iraqi construction materials are used to derive the conduction time factors that needed in RTS method calculations. Special software published by Oklahoma state university is used to extract the conduction factors according to the technical specifications of Iraqi construction materials. Good agreement between the average theoretical and measured cooling load is obtained and the difference between them does not exceed 9.3%.

Key words: Iraqi constructions cooling load.

حسابات حمل التبريد لتركيبات سقوف وجدران نموذجية عراقية باستخدام نظرية RTS لاشري

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الخلاصة

الدراسة الحالية هي محاولة لتقديم بيانات تصميمية لسقوف وجدران عراقية باستخدام أحدث الطرق المستخدمة من قبل جمعية اشري لحساب حمل التبريد وهي طريقة السلسلة الزمنية للإشعاع (RTS). يتضمن العمل حساب الحمل الحراري نظريا باستخدام ظروف العراق التصميمية، والتحقق منها بالقياسات العملية. تم استخدام المواصفات الفنية لمواد بناء عراقية لاشتقاق المعاملات الزمنية للتوصيل المطلوبة للعمليات الحسابية بطريقة (RTS). وقد استخدم برنامج خاص مصمم من قبل جامعة أوكلاهوما الأميركية لاستخراج المعاملات الزمنية للتوصيل وفقا للمواصفات الفنية لمواد البناء العراقية. وقد تم الحصول على توافق جيد بين معدل حمل التبريد المحسوب نظريا والمقاس عمليا ولم يتجاوز الفرق بينهما 9,3%.

1. INTRODUCTION

Among six common ASHRAE methods: Equivalent Temperature Difference (ETD), Total Equivalent Temperature Differential with Time Averaging (TETD/TA), Transfer Function Method (TFM), Cooling Load Temperature Difference/Solar Cooling Load/Cooling Load Factor (CLTD/SCL/CLF), Heat Balance Method (HBM), and Radiant Time Series Method (RTSM), the Radiant Time Series Method (RTSM) is the latest ASHRAE method for calculating the cooling load. RTSM is a simplified method that is "heat-balance based" but does not solve the heat balance equations. The storage and release of energy in the zone is approximated by a set of predetermined zone response factors, called radiant time factors (RTFs), **Spitler, et al., 1997.** The transient conduction calculation is approximated using another set of predetermined thermal response factors, called periodic response factors (PRFs) which relate conduction heat gains directly to temperatures only **,Spitler, and Fisher, 1999a** and, **Chen and Wang, 2005.** By incorporating these simplifications, the RTSM calculation procedure becomes explicit, avoiding the requirement to solve the simultaneous system of Heat Balance (HB) equations. The RTSM shares many of the heat transfer sub-models used by the HBM and has the equivalent principle of superposition used in the Transfer Function Method TFM **,Spitler and Fisher, 1999b.** Moreover, it is a rather simplified method that does not require iterative calculations like the HBM and the TFM. If the radiant time factors (RTFs) and the periodic response factors (PRFs) for a particular zone configuration are known, the RTSM may be implemented in a spreadsheet. The method is useful not only for peak load calculations, but also for estimating component contributions to the hourly cooling loads that is useful for both pedagogy and design **,Iu, 2002.**

Following the development of the RTSM, it was verified by comparing cooling loads predicted by the RTSM with cooling loads predicted by the heat balance method for a wide range of zone configurations. **Rees, et al., 2000,** compared RTSM and heat balance cooling loads for 1296 configurations, which were generated by parametrically varying significant input parameters over a wide range. This analysis conclusively demonstrated that the RTSM always produces a conservative estimate of the cooling load when compared to the heat balance method. However, the over-prediction of the cooling load by the RTSM tends to increase as the fraction of window area in the zone increases. Since the HBM and RTSM share most of the heat transfer models in the cooling load calculation, the Periodic Response Factor (PRF) and the Radiant Time Factor (RTF) models that are used exclusively in the RTSM are considered the most likely sources of error.

A series of investigations of the Radiant Time Series Method (RTSM), in some cases, leading to improvements to the method was introduced by **Nigusse, 2007.** It included sub-models, supporting data, or facilitation of implementation in a wide range of computing environments. These developments comprise the improved RTSM procedure, which accounts for transmission of radiant heat gains back to the outside by conduction through fenestration or other high conductance surfaces. As a result a new set of radiative / convective splits were established to facilitate implementation of the RTSM in a range of computing environments, and parametric investigation to establish the method limitations and provide design guidance.

The radiant time series method (RTSM) has effectively replaced the manual load calculation procedures and has attracted interest **, Nigusse, 2007** due to:

1) Its amenability to spreadsheet implementations as opposed to the Transfer Function Method, which requires iteration.
2) Captures and depicts the physics involved in the Conduction Time Series Factor (CTSF) and Radiant Time Factor (RTF) coefficients, unlike the Transfer Function Method.
3) Has essentially the same accuracy as the TFM.

1.1. The Concluded Concepts from the Previous Studies

From the above, there are some concepts can be concluded such as:

1. The radiant time series method (RTSM) is suitable and applicable to estimate the cooling load using the local climatic data in any region without correction formulas.
2. Because the RTSM approximates the heat balance concepts using set of zone response factors, the accurate results is ensured, beside the simplified equations.
3. The progress in the field of electronic computers, simplifies the insertion of the actual construction data of the local roofs and walls in the cooling load calculations, using RTSM without need to choose the nearest constructions from ASHRAE tables, as in the previous.

1.2. The Object of the Present Work

The present work aims to appraise the ASHRAE's Radiant Time Series Method (RTSM) with the introduction of Iraqi data which includes:

- outside design temperatures
- solar radiation values
- heat transfer coefficients
- building material characteristics

2. CALCULATION PROCEDURE IN RTS METHOD

The general procedure for calculating a cooling load for each load component is shown in **Fig. 1** and includes:

1. Calculate 24 h profile of component heat gains for the design day as follows:

   a. For conduction through walls, and roofs, first account for conduction time delay by applying conduction time series. The Conduction Time Series (CTS) are series of 24 factors tabulated in ASHRAE's issues for different construction types of roofs and walls and grouped according to the thermal properties of structure (U value, mass per unit area, and thermal capacity (m*c)). These factors are denoted by c_f in the present study, and represent the hourly percentage of converting the heat conduction across the external construction (walls and roofs) to hourly heat gain. The conduction through exterior walls and roofs is calculated using conduction time series (CTS) as follows:

Wall and roof conductive heat input at the exterior at *n* hours ago is defined by the familiar conduction equation:

$$Q_{i,t-n} = UA(T_{e,t-n} - T_i) \quad (1)$$

where T_i is the indoor temperature and $T_{e,t-n}$ is the sol-air temperature at *n* hours ago and is expressed as:

$$T_{e,t-n} = T_{o,t-n} + \frac{\mu}{h_o} I_{t,t-n} - \frac{\varepsilon \Delta R(t)}{h_o} \quad (2)$$

Conductive heat gain through walls or roofs can be calculated using conductive heat inputs for the current hour and past 23 hours and conduction time series , **ASHRAE, 2009:**

$$Q_t = c_{f0}Q_{i,t} + c_{f1}Q_{i,t-1} + c_{f2}Q_{i,t-2} + c_{f3}Q_{i,t-3} + \ldots + c_{f23}Q_{i,t-23} \quad (3)$$

c_{f0}, c_{f1}, etc. represent the conduction time factors. Multiplying of the conduction time factors by the U value gives the periodic response factors, p_r and equation (3) may be rewritten as:

$$Q_t = p_{r0}A\left(T_{e,t} - T_i\right) + p_{r1}A\left(T_{e,t-1} - T_i\right) + \cdots + p_{r23}A\left(T_{e,t-23} - T_i\right) \quad (4)$$

b. For other components of heat gain (fenestration, ventilation and infiltration, internal, and etc.), the same procedure is applied as in any other method as follows:

i. Solar and thermal heat gain through fenestration is calculated as (ASHRAE 2009):

$$Q_{fs} = I_b * SHGC(\theta) * A_f * IAC(\theta) + (I_d + I_r) * SHGC\rangle_D * A_f * IAC\rangle_D \quad (5a)$$

$$Q_{fth} = U * A_f * (T_o - T_i) \quad (5b)$$

where I is the solar radiation. The subscripts b, d, and r refer to beam, diffuse and reflected portions respectively. $SHGC(\theta)$ and $SHGC\rangle_D$ are the solar heat gain coefficients as a function of the incident angle θ and the diffuse radiation respectively. $IAC(\theta)$ and $IAC\rangle_D$ are the indoor solar attenuation coefficient functions of the incident angle θ and diffuse radiation respectively.

ii. Total heat gain from infiltration or ventilation is

$$Q_{inf} \; or \; Q_{\upsilon} = \rho_a * \dot{V}_a * \Delta h \quad (6)$$

where Δh is the enthalpy difference.

iii. Heat gain due to lighting, occupancy and equipment are;

For lighting,

$$Q_{Li} = W F_{ul} F_{sa} \quad (7)$$

For occupancy, occupants emit sensible and latent heat at a metabolic rate depending on the state of activity. Tables of ASHRAE summarize design data for common conditions.

For equipment,

$$Q_{em} = (P/E_M) F_{UM} F_{LM} \quad (8)$$

where P is the motor power rating, E_M is the motor efficiency, F_{UM} is the motor use factor, and F_{LM} is the motor load factor.

2. Heat gain through all components, are calculated for each hour, and then divided into two portions according to **Table 1.** The hourly convective portion heat gain, which is converted directly to hourly convective cooling load, and, the hourly radiant portion heat gain.

3. Apply appropriate radiant time series (table 19 and 20 in chapter 18 of, **ASHRAE Handbook of Fundamentals 2009** to the radiant heat gains to account for time delay in conversion to cooling load. The radiant time series are the series of 24 factor denoted by r in the present study and represent the hourly ratio of converting the radiant part of hourly heat gain to hourly cooling load.

The radiant time series or Radiant Time Factors (RTF) are thus generated from heat balance procedures between interior surfaces radiant heat gain and room air for different types of structures, fenestrations, and furnishing. These factors are tabulated for specific cases, (as indicated in table 19 and 20 in chapter 18 of ASHRAE Handbook of Fundamentals 2009) to use them directly for the certain application instead of performing inside surface and room air heat balances. Converting the radiant portion of hourly heat gains into hourly cooling loads is accomplished by the following equation:

$$Q_{clr,t} = r_0 Q_{r,t} + r_1 Q_{r,t-1} + r_2 Q_{r,t-2} + r_3 Q_{r,t-3} + \ldots + r_{23} Q_{r,t-23} \quad (9)$$

4. The hourly radiant portion cooling load calculated in 3 above is then added to the hourly convective cooling load to obtain the total hourly cooling load for a certain component.

5. After calculating cooling loads for each component for each hour, sum them to determine the total cooling load for each hour and select the hour with the peak load for design of the air-conditioning system.

Tables 19 and 20 (in chapter 18 of ASHRAE Handbook of Fundamentals 2009) of radiant time factors introduce representative solar and non-solar radiant time series data for light, medium, and heavyweight constructions. The two different radiant time series solar and non-solar are used as follows:

a. **Solar**, for direct transmitted solar heat gain (radiant energy is assumed to be distributed to the floor and furnishings only) and,
b. **Non-solar**, for all other types of heat gains (radiant energy assumed to be uniformly distributed on all internal surfaces). Non-solar RTS apply to radiant heat gains from people, lights, appliances, walls, roofs, and floors. Also, for diffuse solar heat gain and direct solar heat gain from fenestration with inside shading (blinds, drapes, etc.), the nonsolar RTS should be used.

The radiant time series representative zone construction for tables 19 and 20 is indicated in table 21 in chapter 18 of, **ASHRAE Handbook of Fundamentals 2009**.

2.1. Evaluation of Periodic Response Factors (PRFs) of Roof and Wall Constructions

Iu and Fisher 2001, published a software program called Periodic Response Factor / Radiant Time Factor (PRF/RTF) Generator. They used the most developed accurate methods to derive the conduction transfer function coefficients and the periodic response factors that are needed to calculate the heat gain from walls and roofs. Giving the physical properties of any structure with any number of layers, this software can yields the conduction transfer function coefficients, the periodic response factors, and the U value, in addition to the radiant time factors for the certain space. The physical properties that must be given include; thickness, thermal conductivity, density, and specific heat for each layer of a homogeneous material constituting the wall or roof. For non-homogeneous materials and for air gaps and air films in and outside the structure, the equivalent thermal resistance is the input instead of the other physical properties. **Fig. 2** shows the dialog box used for creating the input file

This program is very useful and reasonable when the used structures are different to those mentioned in the ASHRAE issues. Therefore, this software is used in the present study for typical Iraqi construction materials.

3. EXPERIMENTAL VERIFICATION OF RTSM

Fig. 3 shows the schematic floor plan of a 24 hr air-conditioned space in the second floor of the maintenance department building of the medical city in Baghdad (33.3^o N latitude and 44.4^o E longitude) for the test space. The inlet conditioned air comes through a 24x24 cm ceiling diffuser at 6 m/s supply velocity. The space construction components detailed are in **Table 2.**

Table 3 presents the thermal properties of the materials of the roof and wall constructions.

Inserting the thermal properties of the building materials in the dialog box of PRF/RTF Generator program gives the periodic response factors that are needed to calculate the heat gain of the roof and walls. **Table 4** listed the periodic response factors of roof and wall constructions of **Table 2.**

Thus, the theoretical cooling load can be calculated by apply Eqs. (2, 4, 5a, 5b, and 9).The values of p_rs are taken from **Table 4** for the concrete roof and the thermo-stone walls. The heat gain per unit area for the concrete roof and the thermo-stone wall for the NE and NW directions are given in **Tables 5a. and 5b.** respectively. The fenestration specifications are given in **table 6**, and the values of *r*s are selected from table 19 in chapter 18 of, **ASHRAE Handbook of Fundamentals 2009** for heavy weight, no carpet and 10% of glass to wall ratio. **Table 7** lists these r values.

The experimental verification of the calculated cooling load was accomplished by measuring the average indoor air temperature, the supply air temperature and flow rate. The sensible heat extraction was calculated as:

$$Q_{s.h} = \dot{m}_a * c_p * (T_i - T_s) \quad (10)$$

where $\dot{m}_a = p\dot{V}_s / RT_s$ (11a)

$$\dot{V}_s = \upsilon_a * A_c \quad (11b)$$

and $c_p = 1.006 + 1.840 * w_s$ (11c)

where the specific heat of dry air and water vapor were taken at 1.006, and 1.840 kJ/kg.K respectively for the range of air conditioning temperatures and w_s is the moisture content. The approximated value of c_p is equal to 1.012 kJ/kg.K.

The heat extraction rate is equal to the cooling load if the indoor temperature of the space is constant. The latent load inside the space was zero for no occupancy.

4. RESULTS AND DISCUSSION

Fig. 4 shows the time delay of the roof and the external wall of the tested space. The time delay of the construction type can be defined as the difference between the hour of the peak heat gain in the space and the hour of the peak heat input at the external surface, **Nigusse, 2007.** The exterior and interior air conductance can be included in the wall and roof constructions. The time of the peak outer heat input to the construction is the time of the peak value of the sol-air temperature. Therefore, the time delay is the difference in the times of the peak heat gain and peak sol-air temperature. The value of the time delay is independent of the direction of the construction or the date at which it is calculated. It is only dependent on the material types of the construction and the inner and outer air conductance. The concrete roof of the tested space has 12 hours' time delay. The presence of the Styrofoam as an insulating material and the heavy weight of the roof slow the heat flow and reduce the peak and total heat gain, in addition, they make the time delay of the peak heat gain longer. The thermo-stone walls of the test space have 8.5 hours' time delay. This is because the thermo-stone has low thermal conductivity which results in a reduction of the heat gain across the wall. This reduces the exterior heat input and delays the hour at which the peak load occurs.

Fig. 5 shows the components of heat gain and cooling load of the test space using RTS method on July 8, 2011. The effect of the weight construction on the damping of the cooling load values is clearly apparent. The fenestration load component is the largest component because of the big area of the window, in spite of the shading of the concrete curtain wall. **Fig. 6** shows the comparison between total theoretical cooling load and the measured heat extraction rate. Also, it shows the indoor and supply air temperatures. The values of the measured load (heat extraction rate) fluctuate at the early hours of the morning and the last hours of the evening because of small fluctuations in the measured indoor temperature at these hours. The average values of the measured load and the calculated (theoretical) cooling load along the day are 1864.4 and 1690.3 W respectively. The underestimate of the calculated value is about 9.3%.

Good agreement between the average theoretical and measured cooling load is obtained from the comparison. This means that the calculated values of the cooling load of the Iraqi tested roof and wall using the RTS method and the procedure in the present paper is satisfied. Also the values of heat gains that are calculated in **Tables 5a. and 5b** can be adopted by engineers as design data for estimation the cooling load in Iraq for similar construction without needing correction formulas.

5. CONCLUSIONS

The following conclusions are found pertinent for the calculations of cooling load:

1. Radiant Time Series Method (RTSM) can be used to estimate the cooling load without correction formula and gives a good agreement with the measured cooling load. The underestimate of the average calculated value not exceeds 9.3% for the case in the present study.
2. The measured load average value is 1864.4 W, whereas the calculated (theoretical) cooling load average value is 1690.3 W along July 8, 2011for the tested space.

3. The roof construction of 15 cm of high density concrete, 1cm of felt and membrane, 5 cm of Styrofoam, 5 cm of sand, 4 cm of cement shtyger, with suspended ceiling has 12 hours' time delay.
4. The wall construction of 30 cm thermo-stone, with 3 cm of cement plaster in the outside and 1.5cm juss plaster and 1 cm gypsum plaster in the inside delays the peak load by 8.5 hours.

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NOMENCLATURE

A Area, m^2
c_p Specific heat of air, kJ/kgK
c_f conduction time factor
E_m Motor efficiency
F_{LM} Motor load factor
F_{ul}, F_{um} lighting, motor using factor
F_{sa} lighting special allowance factor

h specific enthalpy, kJ/kg
hi, ho inside, outside heat transfer coefficient, W/m^2K
I solar radiation, W/m^2
$\dot{m}_a$ air mass flow rate, kg/s
P motor power rating, W
p atmospheric pressure, pa
p_r periodic response factor, W/m^2K
Q heat, W
R gas constant of air, kJ/kg.K
R^b, R^f back, front face reflected of glass
ΔR The difference between the long wave radiation incident on the surface from the sky and surroundings, and the radiation emitted by a black body at the outdoor air temperature W/m^2
r radiant time factor
SHGC solar Heat Gain Coefficient
T temperature, °C
t time, sec
U overall heat transfer coefficient, W/m^2K
υ_a air supply velocity, m/s
$\dot{V}_s$ air supply volume flow rate, m^3/s
$\dot{V}_a$ ventilation air volume flow rate, m^3/s
w_s moisture content, kg_{water}/kg_{air}

Greek Symbols
e emittance of the surface
m absorptivity of the surface
r_a air density, kg/m^3
Q incident angle, degrees
t_v visible transmittance
$Æ^f_k$ front absorptance of layer *k* of glass

Subscripts
a air
b beam
c cross sectional (diffuser area)
d diffuse
e sol-air (Temperature)
f fenestration
fs solar fenestration
fth thermal fenestration
i indoor
o outdoor
r reflected (radiation)
s supply
t total (solar radiation), time (others)

Abbreviations

CL Cooling load, W
CLF Cooling load factor,
CLTD Cooling load temperature difference, ^{o}C
CTS Conduction Time Series
ETD Equivalent temperature difference, ^{o}C
HG Heat gain, W
IAC Indoor solar attenuation coefficient
LCav Average calculated load, W
LMav Average measured load, W
PRF Periodic response factor, W/m^2K
RTS Radiant time series
RTSM Radiant time series method
SCL Solar cooling load, W/m^2
SHGC Solar heat gain coefficient
TETD/TA Total equivalent temperature differential with time averaging, ^{o}C
TFM Transfer function method

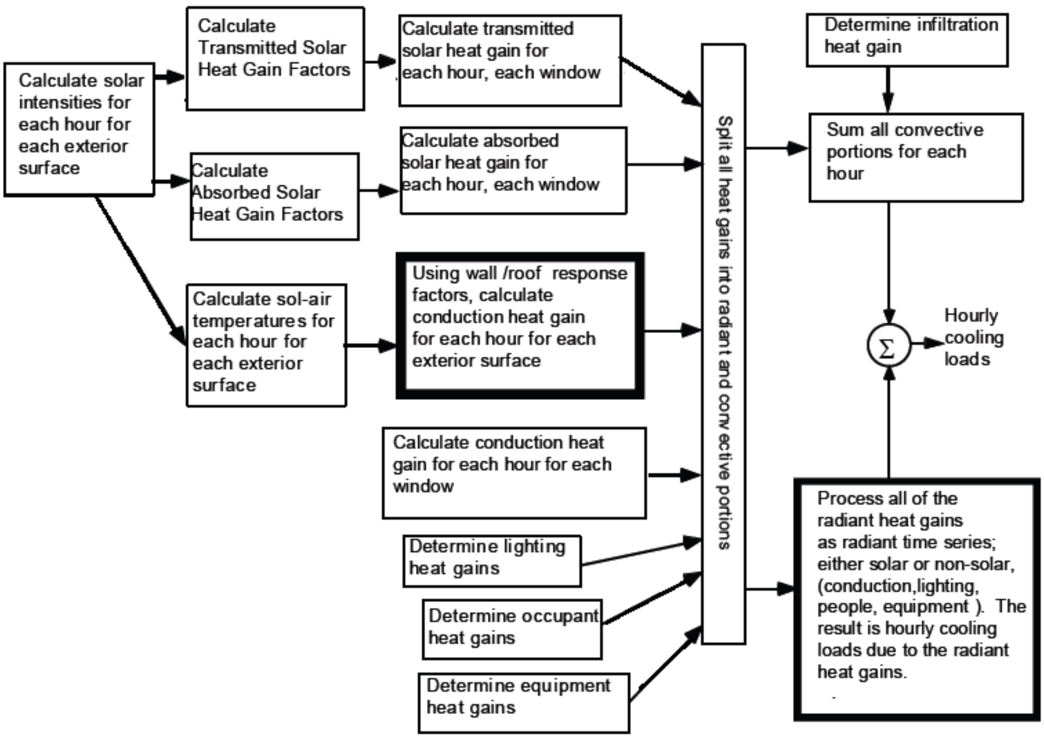

Figure 1. Overview of the (RTS) method.

Table 1. Recommended radiative/convective splits for heat gains components* **, Nigusse, 2007.** and adopted by **, ASHRAE, 2009.**

Heat Gain Type	Recommended Radiative Fraction	Recommended Convective Fraction
Occupants, typical office conditions	0.60	0.40
Lighting	Varies	
Recessed fluorescent luminaire with lens	0.40 to 0.50	0.61 to 0.73
Infiltration	0.00	1.00
Conduction heat gain		
Through walls and floors	0.46	0.54
Through roof	0.60	0.40
Through windows	0.33 (SHGC > 0.5) 0.46 (SHGC < 0.5)	0.67 (SHGC > 0.5) 0.54 (SHGC < 0.5)
Solar heat gain through fenestration		
Without interior shading	1.00	0.00
With interior shading	varies	

* Notes

1. For solar radiation through fenestration with interior shading tables 13A to 13G in Chapter 15 in ASHRAE 2009 can be reviewed.
2. For lighting table 3 and for different equipment, tables 6 to 12 in Chapter 18 in ASHRAE 2009 can be reviewed.

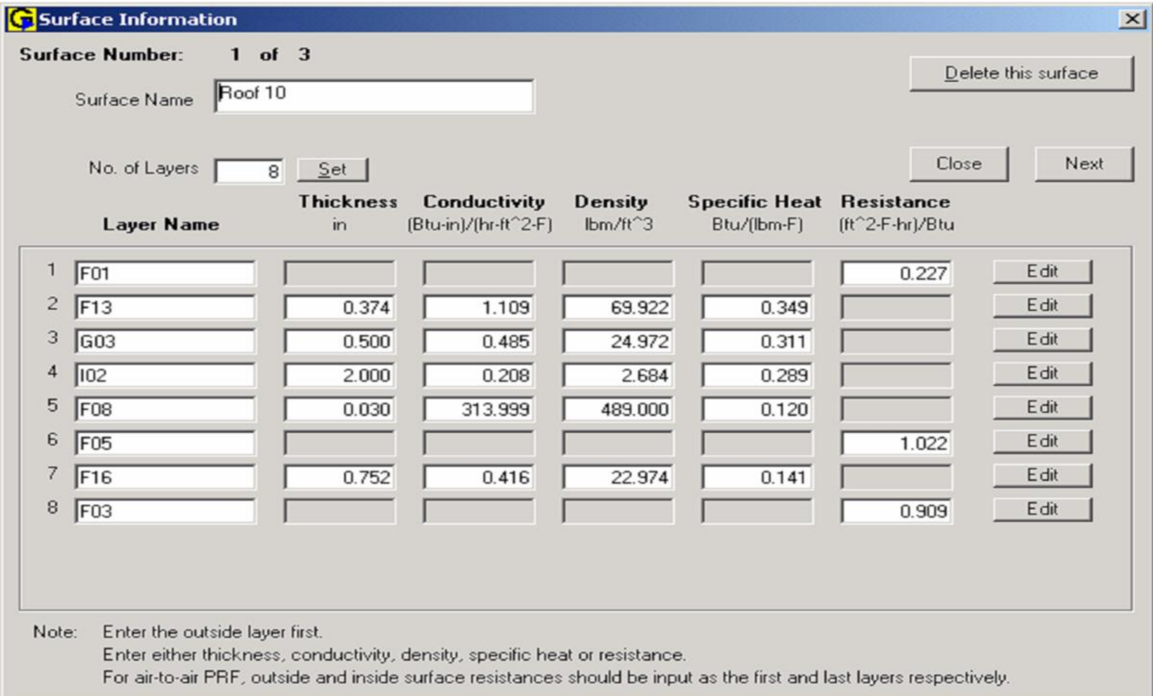

Figure 2. The dialog box of PRF/RTF generator program.

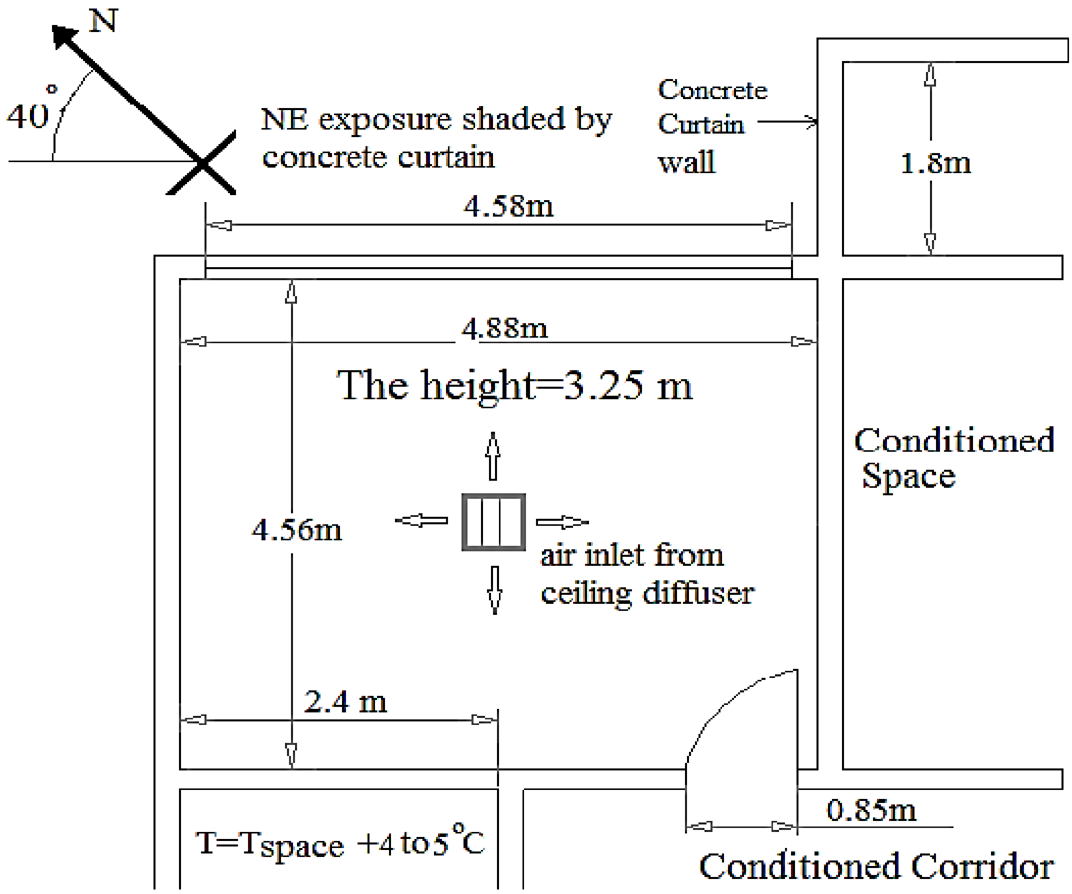

Figure 3. Schematic floor plan of tested space.

Table 2. Space construction components.

Part	Area (m^2)	U-value W/m^2K	Details
Roof	22.25	0.371	4 cm of cement shtyger+5 cm of sand+1cm of felt and membrane +5 cm of sty-rubber+15 cm of high density concrete+air gap+acoustic tiles in suspended ceiling
NE exterior wall	8.32	0.5747	3 cm of cement plaster +30 cm thermo-stone+1.5cm juss plaster+1 cm gypsum plaster
NW exterior wall	15.05	0.5747	3 cm of cement plaster+30 cm thermo-stone+1.5cm juss plaster+1 cm gypsum plaster
Window	7.8		5.75 m^2 of glazing area + 2.035 m^2 of aluminum frame area in NE(shaded) direction
SW partition	7.8	2.45	1 cm gypsum plaster +1.5cm juss plaster +20 cm hollow block +1.5cm juss plaster +1 cm gypsum plaster
floor	22.25	0.99	20 cm of high density concrete+3cm cement mortar+2.5cm mozaek tile

Table 3. Thermal properties of the building materials*.

Material	Thermal conductivity W/mK	density kg/m^3	Specific heat kJ/kgK	Thermal resistance m^2K/W
Outside air film				0.044
Inside horizontal surface air film (ceiling)				0.163
Inside vertical surface air film				0.12
Inside horizontal surface air film (floor)				0.11
Ceiling air space				0.176
Thermo-stone blocks	0.21	760	0.8	
High-density concrete	1.49	2300	0.84	
Styrofoam	0.03	30	2.03	
Concrete roofing tile (shtyger)	0.85	2220	0.837	
Sand (under roofing)	0.25	1450	0.84	
Cement plaster	1.08	2050	0.84	
Juss	0.72	1858	0.84	
Gypsum	0.57	1200	0.84	
Acoustic tile	0.061	481	0.84	
felt	0.35	1400	1.67	
Asphalt	0.041	1121	1.25	

***** These thermal properties of the building materials are based on more than one source to insure an actual case, some of them are:

1- Center of building research issues /Baghdad University 1977.
2- The specific heats of the materials are taken according to the ASHRAE issues for the similar building materials that used in present study.
3- Previous studies of Iraqi building materials.

Table 4. PRFs of the test space roof and wall constructions as obtained by (PRF/RTF) generator program.

Hours	Concrete roof	Thermo-stone wall	Hours	Concrete roof	Thermo-stone wall
0	0.0138	0.0136	12	0.0171	0.0359
1	0.0134	0.0124	13	0.0170	0.0342
2	0.0132	0.0119	14	0.0168	0.0322
3	0.0134	0.0132	15	0.0166	0.0300
4	0.0140	0.0169	16	0.0163	0.0278
5	0.0148	0.0221	17	0.0160	0.0257
6	0.0156	0.0275	18	0.0157	0.0236
7	0.0162	0.0321	19	0.0154	0.0216
8	0.0166	0.0353	20	0.0151	0.0197
9	0.0169	0.0371	21	0.0148	0.0180
10	0.0171	0.0376	22	0.0144	0.0164
11	0.0171	0.0371	23	0.0141	0.0149

Table 5a. Heat gain of roof of tested space in W/m^2 with corresponding outdoor temperature on July 21.

Hours	0	1	2	3	4	5	6	7	8	9	10	11
T_{out} (°C)	34.41	34.06	33.9	33.66	33.41	34.61	36.18	38	39.95	41.9	43.93	46.29
Heat gain (W/m^2)	10.68	10.67	10.64	10.58	10.5	10.41	10.31	10.19	10.07	9.95	9.84	9.76
Hours	12	13	14	15	16	17	18	19	20	21	22	23
T_{out} (°C)	47.49	48.24	49	48.24	47.49	46.29	44.73	42.9	40.95	39	37.18	35.61
Heat gain (W/m^2)	9.71	9.7	9.73	9.8	9.91	10.04	10.18	10.32	10.45	10.55	10.63	10.67

Table 5b. Heat gain of thermo-stone wall in W/m^2 with corresponding outdoor temperature on July 21.

Hours	T.out °C	NE (shaded)	NW	Hours	T.out °C	NE (shaded)	NW
0	34.41	12.60	14.38	12	47.49	9.87	10.75
1	34.06	12.66	14.47	13	48.24	9.79	10.59
2	33.90	12.61	14.42	14	49.00	9.82	10.53
3	33.66	12.48	14.24	15	48.24	9.94	10.58
4	33.41	12.26	13.96	16	47.49	10.14	10.75
5	34.61	11.99	13.59	17	46.29	10.43	11.04
6	36.18	11.66	13.16	18	44.73	10.76	11.45
7	38.00	11.31	12.70	19	42.90	11.14	11.97
8	39.95	10.94	12.23	20	40.95	11.52	12.57
9	41.90	10.59	11.77	21	39.00	11.89	13.17
10	43.93	10.28	11.36	22	37.18	12.21	13.71
11	46.29	10.04	11.01	23	35.61	12.45	14.12

Table 6. Glass specifications of tested space **, ASHRAE, 2009.**

Clear glass 6mm thickness double pane with 0.5" air space, aluminum frame with thermal break							
Center glazing τ_v	U_f W/m^{2}K		Total Window SHGC at Normal incidence		Total Window τ_v at Normal Incidence		
	Fixed	Operable	Fixed	Operable		Fixed	Operable
0.78	3.18	3.31	0.64	0.64		0.7	0.69
Center-of-Glazing Properties							
Properties	Incident angle						
	0.0 (normal)	40	50	60	70	80	Hemis., diffuse
SHGC	0.70	0.67	0.64	0.58	0.45	0.23	0.60
τ	0.61	0.58	0.55	0.48	0.36	0.17	0.51
R^f	0.11	0.12	0.15	0.20	0.33	0.57	0.18
R^b	0.11	0.12	0.15	0.20	0.33	0.57	0.18
$Æ^f_1$	0.17	0.18	0.19	0.20	0.21	0.20	0.19
$Æ^f_2$	0.11	0.12	0.12	0.12	0.10	0.07	0.11

Table 7. Non-solar RTS values for the tested space (Table 19 in chapter 18 of ASHRAE Handbook of **, Fundamentals, 2009** for heavy weight construction, no carpet, and glass to wall percentage is 10%).

Hours	0	1	2	3	4	5	6	7	8	9	10	11
RTS%	22	10	6	5	5	4	4	4	4	3	3	3
Hours	12	13	14	15	16	17	18	19	20	21	22	23
RTS%	3	3	3	2	2	2	2	2	2	2	2	2

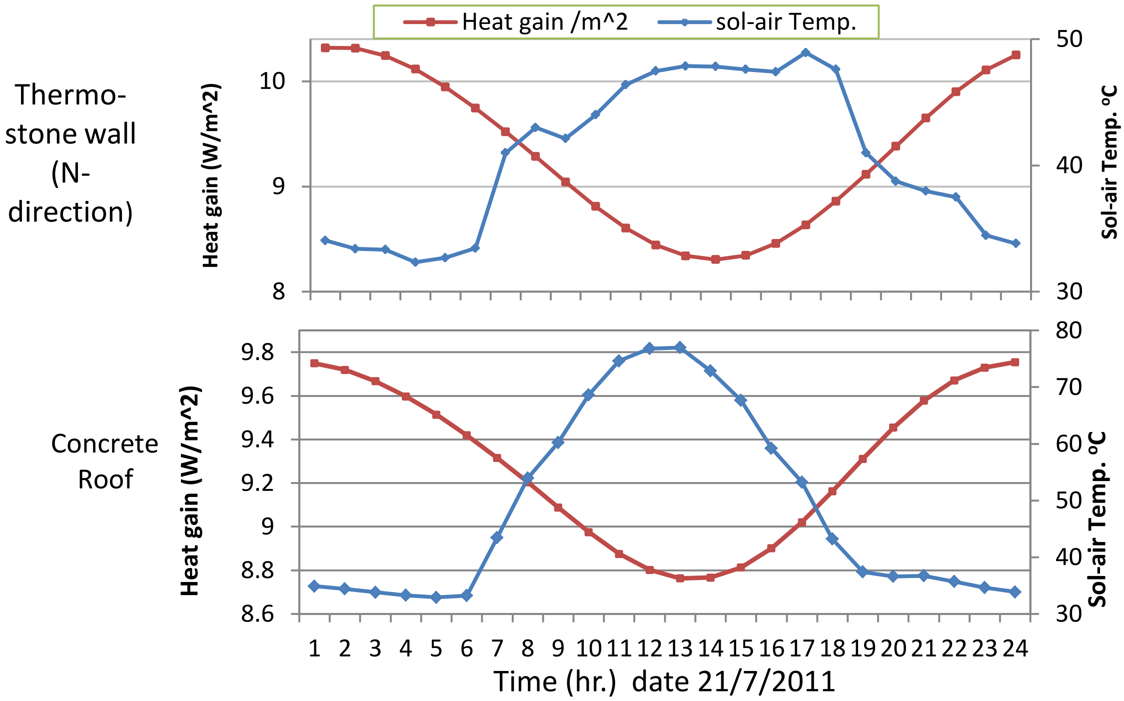

Figure 4. Conduction time delay of Thermo-stone wall and concrete roof of tested space.

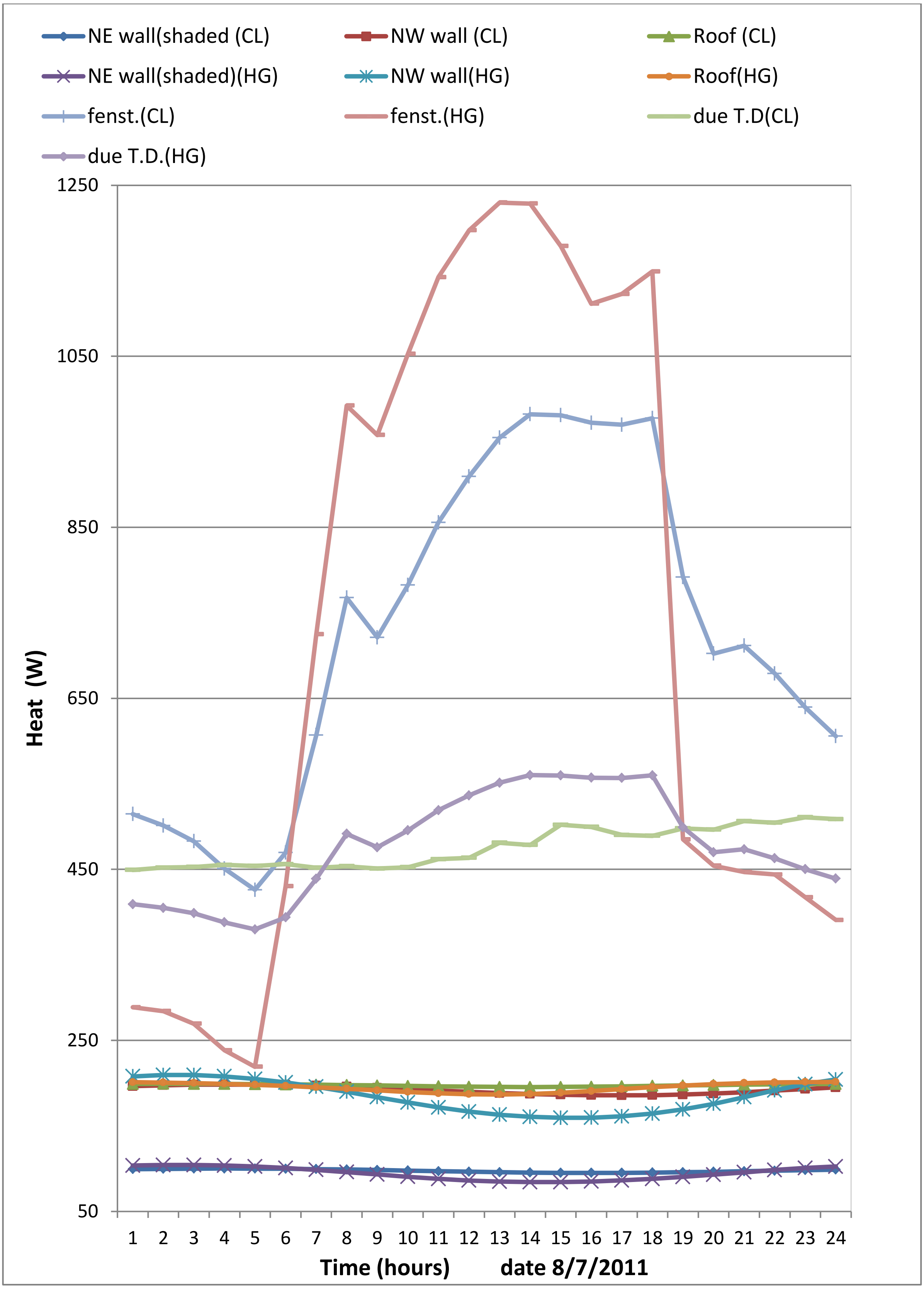

Figure 5. Theoretical components of cooling load and heat gain of tested space.

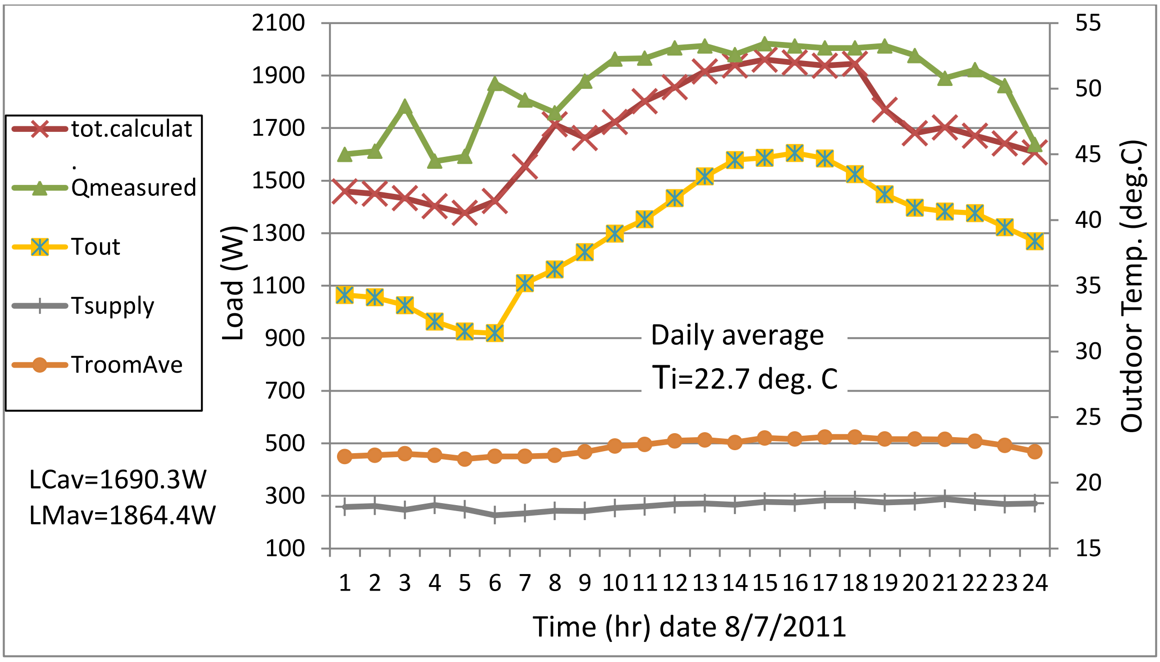

Figure 6. The comparison between the calculated and measured cooling loads for the test space.