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# Progress of High-Performance Building Design with Cooling Load Variation from Solar Heat in HVAC Equipment Energy and Power and Operation

**Michael B. Zhou**

Independent Advisory Engineer, New York, NY 11375, USA; mbzengineerpc@yahoo.com

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**Abstract:** Energy performance is the one of building performance related to the multiple disciplines. It is somewhat distinguishable to the LEED of Green Building Certificate Institute. The LEED uses the model design, e.g., adopting optimal pattern and parameter including the energy issue. The high-performance design of building related to the energy applies the ASHRAE standard, code and guideline to calculate and predict their consumed and numerical quantity of the engineering power and energy need. The purpose of this paper is to study and apply the solar irradiation system and radiation, and to get the optimal energy kw-hr (Btu) for the de-carbonizations, reduction of GHG (Green House Gas) and decrease of the carbon footprint in construction with power KW (Btu/hr) capacity in the HVAC equipment and facilities of the building design. One strategy of seeking the goal is to look for the popular and practical design method for variable cooling load impacted by solar energy. As great efforts, the Radiant Time Series Method (RTS) based on the Excel codes has been found. The paper summarizes the logical procedure from the varied HVAC and building design codes and resources, create the Excel computing codes, populate the case data, and assess the computing outcome for the better building performance.

**Keywords:** Building; HVAC; Cooling Load; Energy; Power; Solar Radiation; RTS; Heat Gain

## 1. Introduction

Some LEED certified buildings did not have a good energy savings. In one study of 953 New York City office buildings, it is found that 21 LEED certified building collectively with less energy saving compared to non-LEED buildings although some gold buildings outperformed other office building by 20%. In 2009, some studies showed average 28 to 35% of LEED-certified buildings used more energy. The USGBC has noted that "Buildings have a poor track record for performance as predicted during design" [1].

High performance building design in energy is a consideration of the predicted instantly energy change and balance with the exterior condition and requirement to save energy [2]. Especially, the cooling system and equipment in the summer with the major electrical consumption must care the solar irradiation change during the daily 24 hours to get the good energy performance design and changeable operation analysis. It also deals with the indoor air quality.

Therefore, New York City currently emphasizes, implements, and progresses the energy performance as emission as ton $CO_2$ e/ft$^2$/year converted from energy consumption of building with the energy limit in year 2024 as 0.00758-ton $CO_2$ e/ft$^2$/year and 2030 as 0.00269-ton $CO_2$ e/ft$^2$/year for building above 25,000 ft$^2$ [3].

## 2. Targeting Solar Energy Impact to Cooling System as an Initiative of High Building Performance

Solar radiation has important effects on both the heat gain and the heat loss of a building. This effect depends to a great extent on both the location of the sun in the sky and clearness of the atmosphere as well as on the nature and orientation of the building. In making energy studies and in the design of the building HVAC, mostly the maximum radiation or the average radiation value striking on a surface at some specified time is adopted. However, the intensity of solar striking on surface is changeable during the 24 hours for heat gain and calculation of the general cooling load with the change of solar radiation is far away to the real condition.

This paper will imitate a medium size tall office building and discuss cooling system and load. This is because the solar energy is one of the changeable heat gains inside building and transient cooling load rate might be required to remove the instantaneous heat from the space at the rate to maintaining space's temperature and humidity at the design values. This strong transient effect is created by hourly variation of solar radiation for heat gain.

Regularly, there are two methods applied to calculate the cooling load, Heat Balance Method and Radiant Time Series Method (RTS). The complicated Heat Balance Method is implemented in a computer program for design cooling load calculations, in which all of the heat balance equations on the building exterior structure must be solved simultaneously by solar heat conduction, absorption, convection, and thermal radiation. RTS is to simplify the scheme without exterior heat balance. Instead of modeling convection to the outdoor air, radiation to the ground and sky, and solar radiation separately, they are modeled as a single heat transfer between an equivalent temperature known as solar-air temperature and the surface temperature [4] for design formula unlikely LEED parameter model design [5].

In the RTS method, there is no interior surface heat balance. Instead, it assumed that surface radiates and convents to the zone air temperature. The conduction transfer functions are replaced with time periodic response factor. There is no zone heat balance. The storage and release of the energy are approximated with predetermined zone responses [6].

After all parameters, temperature-independent quantities, and surface temperatures are determined, 24 hours' cooling load for the building system from window, wall, roof, and others from solar radiation plus other heat gains can be profiled within 24 hours for 24 hours facility power KW (Btu/Hr) need and for heat extraction from the cooling equipment. As result, the system can be obtained for the optimal energy consumption KW–Hour (Btu) and reduction of the GHG emission and get flexible operation for energy savings for new building design and existing building energy estimate precisely. This method is more practical for general needs of building engineering design and evaluation of system energy operation, energy efficiency and savings for existing building.

This high-performance building design is to apply the ASHRAE RTS design standards, codes and principles for cooling load and refrigeration load and the intermittent practical samples in the codes and the relevant practiced referenced text books with the more detailed procedures and samples and the other paper [7]. Further, it integrates and combines a complete practical engineering design for the partial HVAC and energy disciplines of a tall office project.

## 3. The Design Methodology of Cooling Load

As explained, the Radiant Time Series Method makes some confused computation and complicated cooling load simplified. The method may be organized and conducted with the following steps and the formulas used in the calculation are adopted in the reference book and handbook [4] (pp. 254–255), [6] (pp. 29.25–29.37).

(1) Determination of exterior boundary conditions, incident solar radiation, sol-air temperatures ($t_0$), and solar altitude angle sin β and incident angle (cos θ).
(2) Calculation of transmitted heat gains for window.
(3) Calculation of absorbed heat gains for window.
(4) Calculation of heat conduction gains for window, wall and roof.
(5) Internal heat gain and infiltration heat gain.
(6) Determination of radiative portion of heat gain split from heat conduction and solar transmission and absorption with RTS response factors.

(7) Determination of cooling loads due to the radiative portion of heat gains from heat conduction and solar transmission and absorption.
(8) Summation of cooling loads due to convective portion and radiative portion of heat gain from heat conduction and solar transmission and absorption.
(9) Cooling load distribution for the three sections and each section with four stories and coil design.
The followings are design condition, procedure and frame for this exploring.

## 4. Basis of Study of Cooling Load for High Performance Building

### 4.1. Building Structure

The function of the building is planned as a general and complex office building to meet the requirements of diversity, small, and medium-sized firm. Therefore, the internal partition and structure of the building from 1st to 12th floor are assumed as same except the cellar where the boilers, refrigerators, pumps, fans, electrical and telephone closet, electrical switchgear, elevator machines, meters, and others are roomed as auxiliary service area.

Area size of each floor:

$$150 \times 70 = 10{,}500 \text{ sf} \tag{1}$$

Overall area of the building

$$10{,}500 \times (12 \text{ stories} + 1 \text{ cellar}) = 136{,}500 \text{ sf} \tag{2}$$

Height for each floor: 12 feet (3ft between ceiling tile and floor slab)
Height for the cellar: 15 feet.
For 1st to 12th floor, 01 and 02 as Manager Office and 03 to 08 as Operation Offices are arranged (**Appendix A**, **Figures A1** and **A2**).

In the cellar, mechanical room, telephone closet, meter room, emergency generator room, electrical switchgear room, fuel tank room, refrigerator room [8] (pp. 41.1–41.12), boiler room [9] (pp. 10.1–10.16) and fan room [9] (pp. 18.1–18.8), which serve to 1st to 4th floor and cellar, are positioned. Two fan rooms are also furnished on 5th and 9th floor to serve to rest of the part's area, 5th to 8th floor and 9th to 12th floor.

### 4.2. Design Condition – Main Weather Conditions and Design Parameter for Cooling Load

The weather condition is based on July 21 in the summer near New York La Guardia Air Port from Handbook 1-Fundamentals [6] (p. 27.17).

- Outdoor: 1%–89F DB, 73 MWB, rh 48%.
- Indoor: 76 F DB, rh 55%, but still take 72 DB and not consider other allowance and compensation due to the delay effect of solar radiation.

The Other Design Condition
The zone or per section with the geometry previously described is constructed with the following features:

1. The south, north, east, and west wall and roof are all exposed to the outside.
2. Date: July 21 and solar saving time.
3. 90 occupants with 6 sections in south or north (south rooms in four floors as one section), 104 customers and staffs in corridor, stair, cellar with 4 sections, who are there from A.M. to 5 P.M. doing moderately active office work.
4. 1 W/ft$^2$ heat gain from computers and other office equipment from 8 A.M. to 5 P.M.
5. 0.2 W/ft$^2$ heat gain from computers and other office equipment from 5 P.M. to 8 A.M.
6. 1.5 W/ft$^2$ heat gain from suspended fluorescent (unvented) lights from 8 A.M.to5 P.M.
7. 0.3 W/ft$^2$ heat gain from suspended fluorescent (unvented) lights from 5 P.M. to 8 A.M [4] (p. 256).

# 5. Design Procedure

## 5.1. Local Solar Time

Because of the earth's rotation about its own axis, a fixed location on the earth goes through a 24-hour cycle in the relation to the sun. The earth is divided into 360 deg of circulation arc by longitudinal lines passing the poles. Thus, 15 deg of longitude corresponds to 1/24 of a day or 1 hour of time as local solar time. Clocks are usually set for the same reading throughout a zone covering approximately 15 deg of longitude as local civil time. The time for the project is Eastern Standard Time, EST 75 deg as local civil time that has to be converted to local solar time for the calculation.

The local solar time (LST) can be calculated from the local civil time as

$$\text{LST} = \text{LCT} + (\text{equation of time}) \tag{3}$$

Solar Data for 21st Day of each Month in the reference textbook, on July 21 show Equation of time, −6.2 min; Declination, 20.6-degrees; A solar flux, 346.6 Btu/hr-ft$^2$; B Dimensionless, 0.186; C Dimensionless, 0.138.

For local solar time corresponding to EST saving time on July 21 in the project area around 74 deg W longitude and N latitude 41-degrees; the general formula to compute solar time is [6] (p. 29.15):

$$\begin{aligned} \text{LST} = (\text{LCT} - 1\text{hour}) \times 60\text{min/hr} + (60\text{min}/15\text{deg}) \times (75 - 74)\text{ deg} \\ -6.2\ (\text{Equation of Time}) = (\text{LCT} - 1) \times 60 - 2.2 \end{aligned} \tag{4}$$

## 5.2. Solar Angle

It is convenient in HVAC computations to define the sun's position in the sky in terms of solar altitude β and the solar azimuth ø, which depend on the fundamental quantity l, h, and d.

Referring to **Figure 1** for Latitude, hour angle, and sun's declination and **Figure 2** for the solar altitude ψ ($\Theta_z$) and azimuth angle ø as the definition of these parameters, the solar altitude β is the angle between the sun's ray and the projection of that ray on a horizontal surface. It can be shown by analytic geometry (**Figure 2**) that the following relationship is true [4] (pp. 166–168), [6] (p. 29.14):

$$\sin\beta = \cos l \times \cos h \times \cos d + \sin l \times \sin d \tag{5}$$

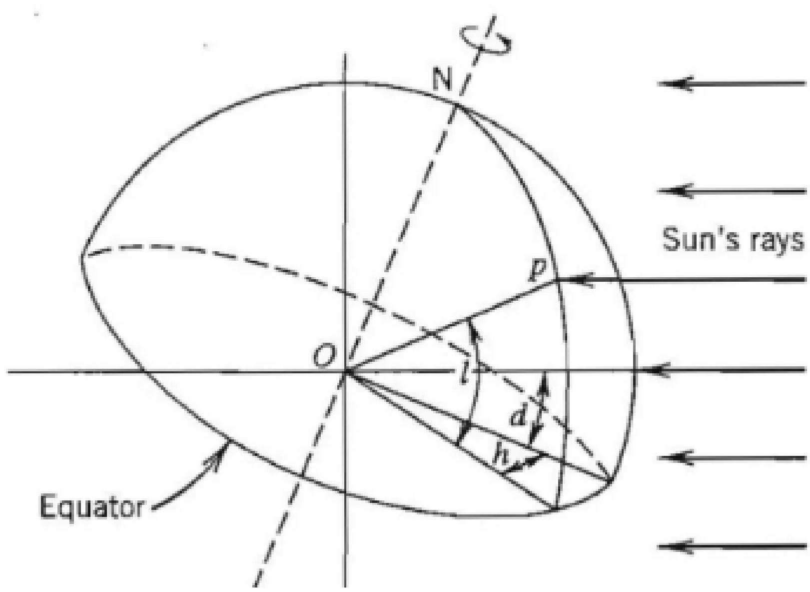


**Figure 1.** Latitude, hour angle, and sun's declination.

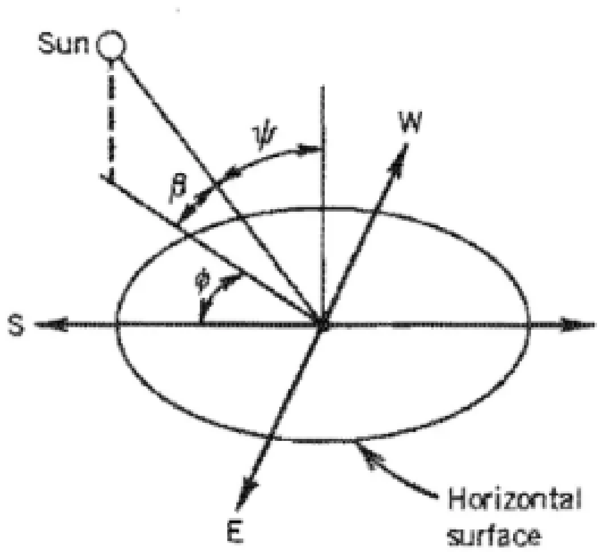


**Figure 2.** Solar altitude ϕ and azimuth ø.

In **Figure 1**, l is latitude angle, h stands for hour angle, and d represents sun's declination angle. The solar azimuth angle ø is the angle in the horizontal plane measured between south and projection of the sun's rays on that plane from **Figure 2.** By analytic geometry, it can be given as

$$\cos ø = (\sin \beta \sin l - \sin d)/(\cos \beta \cos l) \quad (6)$$

For a vertical surface—wall and window, the angle measured in the horizontal plan between the projection of sun's rays on that plane and a normal to the vertical surface is called the wall solar azimuth γ, **Figure 3** illustrates this quantity.

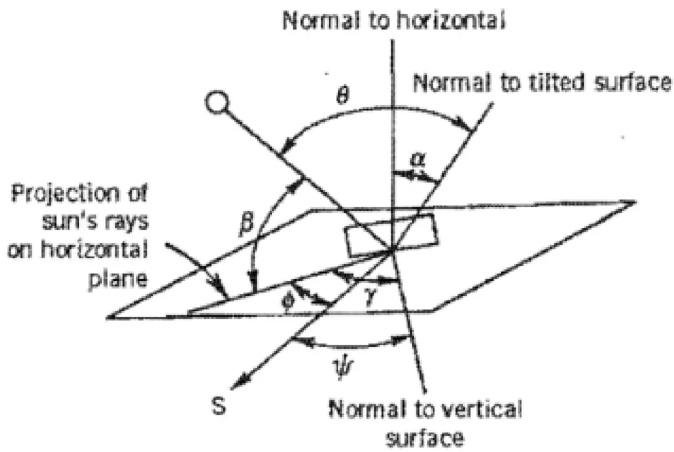


**Figure 3.** Wall solar azimuth, wall azimuth, and angle of tilt for any arbitrary titled surface.

If ψ is wall azimuth measured east or west from south, then obviously:

$$\gamma = ø + / - \psi \quad (7)$$

The angle of incidence cos $\theta$ is the angle between sun's rays and normal to the surface, as shown in **Figure 3**. The angle of tilt α for an arbitrary surface is the angle between the normal to surface and normal to the horizontal surface. It may be found that [4] (pp. 166–168):

$$\cos\theta = \cos\beta\cos\gamma\sin\alpha + \sin\beta\cos\alpha \tag{8}$$

Then, for a vertical surface wall and window:

$$\cos\theta = \cos\beta\cos\gamma. \tag{9}$$

For horizontal surface—roof for the key data of computation, cos $\theta$ = sin $\beta$, θ is the angle of incidence, β is to sun's altitude angle. Note:

$$\gamma = (\o + \psi) \tag{10}$$

The following rules aid in the computation of the wall solar angle γ:

- For the morning hours with walls facing east of south and afternoon hours with walls facing west of south

$$\gamma = |\o - \psi| \tag{11}$$

- For afternoon hours with the walls facing east of south and morning hours with walls facing west of south

$$\gamma = |\o + \psi| \tag{12}$$

where wall on south ψ = 0; west ψ = $90^0$; north ψ = $180^0$; east = ψ = $-90^0$ from Handbook ([6], pp. 30.13–30.16).

## 5.3. Hourly Outdoor Temperature

The hourly outdoor temperature is usually assumed to vary in an approximately sinusoidal fashion between the outdoor design temperature and a minimum temperature, equal to the daily range subtracted from the outdoor design temperature. The hourly outdoor temperature is given by [4] (pp. 217–218):

$$t_0 = t_{\text{design db}} - DR(X) = 89 - 14.6 * (X) \tag{13}$$

X: percentage of the daily range hourly is selected from the reference textbook. The hourly outdoor temperature can be evaluated from the above formula. The solar altitude angle $\beta$ can be formulated as below,

sinβ = coslcosdcosh + sinlsind = cos41cos20.6cosh + sin41sin20.6

$h_{1\text{-}12}$= (720 − (i − 1)*60 − 2.2) min/4deg/min*0.01745rad/deg,

$h_{13\text{-}24}$= ((i − 1)*60 − 720 − 2.2))min/4deg/min*0.01745rad/deg,

first equal sign: 1:00–12:00 and second equal sign 13:00–24:00.

And the Excel code for computation is:

sinβ = 0.7065*COS(((720 − (i − 1)*60 − 2.2)/4)*0.01745) + 0.2307

sinβ = 0.7065*COS((((i − 1)*60 − 720 − 2.2)/4)*0.01745) + 0.2307,

first equal sign: sinβ from 1:00–12:00; second equal sign: 13:00–24:00.

## 5.4. Radiation Portion of Conduction and Solar Heat Gain

Each heat gain must be split for each hour into radioative and convective portions from solar radiation and heat conduction. The radioative-convective splits are as follows [6] (p. 29.27):

(1) Wall, window conduction – 63% radiative; 37% convective.
(2) Roof conduction – 84% radiative; 16% convective.
(3) People –70% radiative; 30% convective.
(4) Lighting – 67% radiative; 33% convective.

(5) Equipment – 20% radiative; 80% convective.
(6) Transmitted solar heat gain –100% radioative; 0 convective.
(7) Absorbed solar heat gain – 63% radioative; 37% convective.
(8) Infiltration – 0 radiative; 100% convective.

These splits are applied in the final summation with the radioative portion of each heat gain from conduction, and solar transmission and absorption, plus convection portion. For compactness, the wall and roof conduction heat gains have combined.

Cooling Load due to Radiative Portion of Heat Gains from Conduction and Solar Transmission and Absorption is calculated by instant heat load and response factor of Radiant Time Series The radiative heat gains are converted to cooling loads by virtue of hourly response factor as [4] (pp. 261–263)

$$dq/d_{\theta,\,CL} = r_0 dq/d_\theta + r_1 dq/d_{\theta-}\delta\text{-----} + r_{23} dq/d_{\theta-23} \tag{14}$$

Where:

- $dq/d_{\theta,\,CL}$ = cooling load at the current hour, Btu/hr.
- $dq/d_{\theta-n}$ = heat gain n hours ago, Btu/hr.
- $r_n$ = nth radiant time factor from reference book [4] (pp. 261–263) as Non-solar medium weight zone construction MW2 for wall/roof, people, lights, equipment, window conduction, and Solar MW1zone for TSHG and ASHG by the Radiant Time Series impact to the specified time.

Note: Two types of radiant time factor are utilized in this design. One is solar radiant time factors for solar radiant heat gain through windows and second non solar for uniform surfaces, floor, wall, etc.; typical US light and medium sample zone as MW1 and UK medium sample zone as MW2 with $r_0 - r_{23}$ and respective radiant time factors in the textbook.

## 5.5. Hourly Cooling Loads Following Step 1 to Step 8 in Section 3

The design cooling loads are determined by combining the cooling loads due to the radioactive portion and the convective portion of heat gains from solar transmission and absorption and heat conductance from each parts as = 0.37*( dq/dt (Btu/hr.), convective from conductance heat gain subtotal wall )+ 0.16*(dq/dt (Btu/hr.), convective from conductance heat gain on roof) + (dq/dt, Btu/hr., cooling load due to radiative from wall and roof), including people, lights, equipment, window conduction, TSGH, ASGH, and infiltration with respective percentage. The results are shown in as below **Table 1** and **Figure 4.** The peak load, 1,909,250 Btu/hr., occurs at 5 P.M. A cursory review of the loads reveals that they are dominated by the walls and roof conduction loads, and lighting and solar transmitted heat gains.

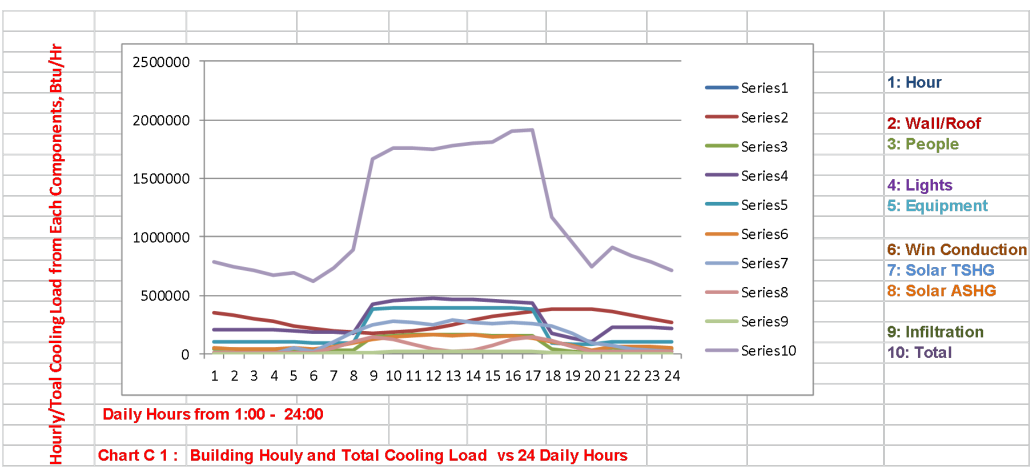


**Figure 4.** Building hourly and total cooling load vs. 24 daily hours.

**Table 1.** Hourly cooling loads for building (cooling % heat gain from convective portion + radiactive portion).

| **Table C - 9** | | | **Hourly Cooling Loads for the Building** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Cooling** | **Load, Btu/hr** | | | | | |
| Convective<br>Radiative | 37%/16%<br>63%/84% | 30%<br>70% | 33%<br>67% | 80%<br>20% | 37% | <br>100% | 37%<br>63% | 100%<br>0% | |
| **Hour** | **Wall/Roof** | **People** | **Lights** | **Equipment** | **Conduction** | **TSHG** | **ASHG** | **Infiltration** | **Total** |
| 1 | 357,083 | 39,486 | 211,418 | 102,389 | 48,960 | 11,622 | 16,118 | 1,587 | 788,662 |
| 2 | 329,288 | 37,974 | 208,294 | 101,768 | 46,159 | 7,577 | 15,438 | 1,317 | 747,815 |
| 3 | 302,900 | 36,569 | 205,392 | 101,190 | 43,699 | 4,965 | 14,831 | 1,103 | 710,649 |
| 4 | 278,403 | 35,246 | 202,659 | 100,646 | 41,554 | 3,274 | 14,273 | 941 | 676,995 |
| 5 | 242,340 | 33,988 | 196,380 | 99,397 | 53,387 | 51,847 | 14,837 | 4,062 | 696,239 |
| 6 | 221,144 | 32,786 | 190,638 | 98,254 | 41,143 | 23,232 | 14,131 | 1,199 | 622,526 |
| 7 | 200,397 | 31,633 | 185,265 | 97,185 | 63,532 | 99,612 | 49,439 | 6,263 | 733,326 |
| 8 | 185,545 | 30,524 | 180,173 | 96,171 | 93,221 | 185,261 | 109,266 | 11,777 | 891,939 |
| 9 | 179,273 | 141,006 | 427,890 | 386,732 | 121,405 | 247,248 | 145,514 | 16,465 | 1,665,534 |
| 10 | 183,113 | 156,314 | 456,983 | 392,522 | 144,829 | 277,814 | 128,709 | 19,860 | 1,760,145 |
| 11 | 198,052 | 164,329 | 471,116 | 395,335 | 158,808 | 266,737 | 80,449 | 21,847 | 1,756,673 |
| 12 | 222,671 | 169,419 | 479,298 | 396,963 | 161,678 | 251,278 | 40,590 | 22,383 | 1,744,278 |
| 13 | 250,589 | 166,042 | 470,077 | 395,128 | 154,636 | 291,319 | 26,584 | 21,727 | 1,776,102 |
| 14 | 286,438 | 162,783 | 461,181 | 393,357 | 162,568 | 273,517 | 34,915 | 23,389 | 1,798,148 |
| 15 | 318,269 | 159,638 | 452,596 | 391,649 | 140,924 | 255,041 | 71,674 | 23,794 | 1,813,587 |
| 16 | 345,704 | 156,602 | 444,312 | 390,000 | 151,552 | 266,312 | 122,445 | 22,479 | 1,899,408 |
| 17 | 367,810 | 153,672 | 436,318 | 388,409 | 132,983 | 263,561 | 147,057 | 19,439 | 1,909,250 |
| 18 | 382,287 | 39,295 | 176,027 | 95,346 | 103,569 | 238,087 | 119,317 | 14,795 | 1,168,723 |
| 19 | 387,485 | 20,230 | 134,830 | 87,148 | 68,846 | 176,627 | 65,297 | 9,042 | 949,503 |
| 20 | 381,473 | 8,588 | 109,034 | 82,014 | 35,883 | 94,975 | 25,578 | 3,819 | 741,365 |
| 21 | 363,687 | 48,252 | 229,529 | 105,993 | 65,489 | 75,542 | 23,402 | 3,148 | 915,043 |
| 22 | 336,739 | 45,316 | 223,464 | 104,787 | 59,794 | 43,763 | 19,311 | 2,609 | 835,782 |
| 23 | 303,294 | 43,045 | 227,731 | 108,351 | 58,448 | 27,749 | 17,914 | 2,177 | 788,710 |
| 24 | 266,996 | 41,150 | 214,857 | 103,074 | 51,931 | 17,906 | 16,914 | 1,856 | 714,684 |

## 6. Cooling Load Distribution and Cooling Coil Load

The peak cooling load occurred at 17:00, 1,909,250 Btu/hr. is equal to 1,957,081 due to solar delay effect half differential between 15:00 to 17:00 as 0.02505 = 1,909,250 Btu/hr ×1.02505 (delay factor) = 1,957,081 Btu/hr/(3.412Btu/W) = 573.587 KW × 0.2844 Tons/KW = 163.13 Tons of Refrigeration.

The cooling loads are distributed to each section of south, north, and corridors/stairs according to the individual heat gains based on the peak time 17:00 and delay effective time two hours before peak one, 15:00 as a key step to turn and exhibit the high-performance building design into equipment and operation. The distributions for cooling coils are based on the even percentage of three sections and the calculations are given by the proportion of main heat gains for wall/roof, TSHG and ASHG for three parts with overall 937,354 Btu/hr. by South 31.42%, North 41.66%, East and West (Stair, Hallway, Elevator) 26.92% as shown on **Appendix A**, **Tables A1–A3** [10].

The distributions for cooling coils are based on the even percentage of three sections and the calculations are given in **Table 2**.

South section:

$$1{,}957{,}081 \times 0.3142 \times 114/150 = 467{,}383\text{Btu/hr} = 138.982\text{KW (38.96 Tons)} \quad (15)$$

North section:

$$1{,}957{,}081 \times 0.4166 \times 114/150 = 619{,}770\text{Btu/hr} = 181.623\text{ KW (51.65 Tons)} \quad (16)$$

$$\text{Corridors/Stairs:} = 1{,}957{,}081 - 467{,}383 - 619{,}770 = 869{,}997\text{ Btu/hr.} = 254.981\text{KW (72.52 Tons)} \quad (17)$$

The distributions of cooling load for each section of three parts are referred to the heating loads that are so close for the three sections for each part and are evenly among them based on the overall hear gain 937,354 Btu/hrs. and percentage per part South, North, East/West Corridor (**Appendix A**, **Table A3** and **Table 3**) [10].

**Table 2.** Cooling load distribution, air supply, coil load and Indoor air quality (IAQ) [11–15].

| Cooling Load Distribution, Air Supply, Coil Load, ASHRAE Standard and IAQ Check | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Adjustment of Cooling Load: | 1,957,081.72 | | Btu/hr | | | |
| | | South | | North | | Corridor/Stair/Elev | Subtotal |
| Cooling Coil Load Btu/h (power) | | 467,383.94 | 0.29 | 619,700.37 | 0.41 | 869,997.41 | 1,957,081.72 |
| Cooling Coil Load W (power) | | 136,982.40 | | 181,623.79 | | 254,981.66 | 573,587.84 |
| Cooling Coil Load Tons | | 38.96 | | 51.65 | | 72.52 | 163.13 |
| SHF | | 0.90 | | 0.92 | | 0.93 | |
| i3 | Btu/lb dry air | 29.80 | | 29.80 | | 29.80 | |
| i2 | Btu/lb dry air | 26.70 | | 26.60 | | 26.80 | |
| v2 | ft^3/lb dry air | 13.40 | | 13.41 | | 13.42 | |
| dm/dt m2 | lbma/hr | 56,062.79 | | 70,177.12 | | 103,599.71 | |
| Q2 | cfm | 12,520.69 | | 15,684.59 | | 23,171.80 | |
| Qo | cfm | 1,800.00 | | 1,800.00 | | 2,080.00 | |
| dm/dt m0 | lbma/hr | 7,552.45 | | 7,552.45 | | 8,727.27 | |
| dm/dt m4 | lbma/hr | 48,510.34 | | 62,624.67 | | 94,872.44 | |
| line ratio 31/30 | line on Chart 1a | 0.13 | | 0.11 | | 0.08 | |
| t1 | F | 78db | | 77db | | 77.5db | |
| rh1 | % | 0.53 | | 0.54 | | 0.53 | |
| i1 | Btu/lb dry air | 31.00 | | 30.80 | | 30.90 | |
| dqc/dt | Btu/hr | 241,069.99 | | 294,743.91 | | 424,758.82 | |
| dqc/dt | Ton | 20.09 | | 24.57 | | 35.40 | |
| SHF-Coil | | 0.78 | | 0.82 | | 0.87 | |
| dqcs/dt | Btu/hr | 188,034.60 | | 241,690.01 | | 369,540.17 | |
| dqcl/dt | Btu/hr | 53,035.40 | | 53,053.90 | | 55,218.65 | |
| Check standard: cfm/ft^2 = 0.75/2.0; NAQQS PM 2.5 50 ug/m^3 a a; effective outdoor air <=1 | | | | | | | |
| Air move | cfm/ ft^2 | 0.99 | 12,600.00 | 1.24 | | 1.84 | |
| Recirculation rate R | | 0.87 | | 0.89 | | 0.92 | |
| Effective outdoor air rate | | 0.95 | | 0.96 | | 0.97 | |
| PM C under Produced C=100 ug/m ^3 | 47.95 | PM 10 150 ug/m3-24 h a | 39.26 | | 27.47 | | |

**Table 3.** Cooling load distribution by percentage of heating load.

| Table C-11 | Each Cooling Coil Heat Distribution | | Btu/hr. | Cooling Load | Cooling Load |
|---|---|---|---|---|---|
| | 9–12 Floor | 5–8 Floor | 1–4 Floor | Btu/Hr/Part | Btu/Hr/Section |
| South | 101,633.02 | 96,004.75 | 97,566.52 | 146,852.03 | 48,950.68 |
| South % | 34.49% | 32.58% | 33.11% | 100.1800% | 33.33% |
| North | 134,013.59 | 126,238.45 | 130,458.12 | 619,700.37 | 206,566.79 |
| North % | 34.30% | 32.31% | 33.39% | 100.0000% | 33.00% |
| Corridor | 86,691.37 | 81,214.80 | 84,470.46 | 869,997.41 | 289,999.14 |
| Corridor % | 34.3500% | 32.18% | 33.47% | 100.000% | 33.33% |

## 7. Cooling Coil Load and Air Supply

The calculation of cooling load and air supply, and the single line sketch of cooling and dehumidifying system are similar to those for heating load. Although indoor temperature 72 F db is used for cooling load calculation, the given space is still on the basis and to be maintained on and at 76 F db, rh 55%.

The calculation of south section from 9th to12th floor is taken as sample.

The sensible load for this section is 145,989 Btu/hr., the latent heat is 200Btu/hr.*90 persons as 18,000 Btu/hr. Regularly, it is customized to first select unit on the basis of block sensible cooling load, then choose latent capacity to quality the cooling coil.

The condition of the case is:

$$\text{SHF} = 145{,}989/(200 * 90 \text{ latent heat} + 145{,}989) = 0.89, \quad (18)$$

Total heat gain for the section is 163,989 Btu/hr., the outdoor air requirement of occupants is 1,800 cfm, outdoor air has a temperature and relative of 89 F db and rh 48%, 73 F wb [4] (pp.254–255, pp. 561–562), [10] (pp. 30–44).

The cooling process is similar to the heating process as **Figure 5**. Check the state 2 of air entering the space lines on the line defined by the SHF on Psychometric Chart 1a, **Appendix B**, **Figure A3**. Therefore, the state 3 is located as shown on the **Appendix B**, **Figure A3**, and a line is drawn through the point parallel to the SHF = 0.89 line on the protractor. State 2 may be any point on that line, and is determined by operating characteristics of the equipment. Assume that dry bulb temperature of entering air $t_2$ is = 64 $^0$F less than the space temperature $t_3$ = 76 $^0$ Fdb and state 2 is determined. The air quantity required may now be found from an energy process balance on the space as shown in **Figure 5** [4] (pp. 254–255, pp. 561–562), [10] (pp. 30–44).

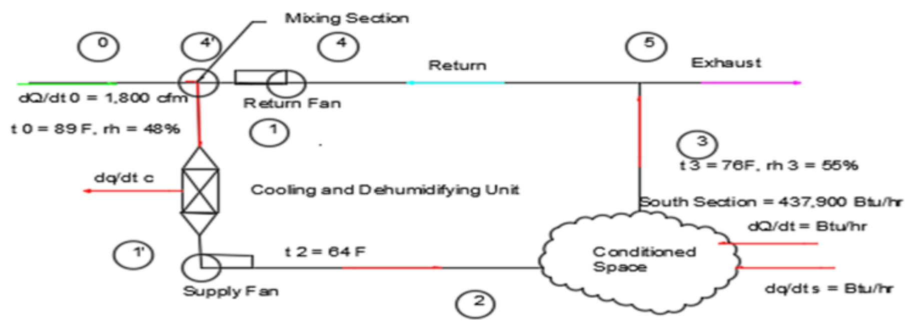


**Figure 5.** Cooling refrigeration coil system and process [4] (pp. 254–255, pp. 561–562), [10].

$$\dot{m}_{air2}, i_2 + dq/dt = \dot{m}_{air\,3}, i_3, \text{and}\ \dot{m}_{air\,2} = \dot{m}_{air\,3} \quad (19)$$

$$\dot{m}_{air\,2} = dq/dt/(i_3 - i_2) \quad (20)$$

From **Appendix B**, **Figure A3** and **Table 2**, $i_3$ = 29.8 Btu/lbma, $i_2$ = 26.7 Btu/lbma, and

$$\dot{m}_{air\,2} = \dot{m}_{air\,3} = (467{,}274/3 + 200 * 90)/(29.8 - 26.7) = 56{,}051\ \text{lbma/hr} \quad (21)$$

$v_2$ = 13.4 ft3/lbma and the air volume flow rate required is

$$Q_2 = \dot{m}_{,\,air\,2} v_2 = 56{,}051\ \text{lbm/hr.} * 13.4\ \text{cf/lbm/60 min} = 12{,}518\ \text{cfm.} \quad (22)$$

Before attention is directed to the cooling and dehumidifying process, state 1 must be determined. A mass balance on the mixing section yields [4] (pp. 560–562), [10].

$$\dot{m}_{air\,0} = 7{,}552\ \text{lbma/hr.}\dot{m}_{air\,4} = 56,051 - 7{,}552 = 48{,}499\ \text{lbma/hr.} \quad (23)$$

By using the graphical techniques and referring to **Appendix B**, **Figure A3**, we see that $\dot{m}\ a_0$ = 0.1428 $ma_1$. State 1 is located at 78 F db and 66.2 F wb. A line constructed from state 1 to state 2 on the Chart 1a then represents the process taking place in the conditioning equipment. An energy balance gives

$$dq/dt,_{coil} = \dot{m}_{air\,1}(i_1 - i_2 = 56{,}051 * (31 - 26.7) = 241{,}019\ \text{Btu/hr.} = 20.08\ \text{tons} \quad (24)$$

The sensible heat factor (SHF) for the cooling coil is found to be 0.78 using the protractor of **Appendix B**, **Figure A3**, then [10],

$$dQ/dt,\ \text{cooling coil sensitive} = 0.78 * 241{,}019 = 187{,}995\ \text{Btu/hr. dq/dt} \quad (25)$$

$$\text{cooling coil latent} = 241{,}019 - 1787{,}995 = 53{,}024\ \text{Btu/hr} \quad (26)$$

The sum of dq/dt, $_{\text{cooling coil sensitive}}$ and dq/dt, $_{\text{coiling coil lantent}}$ is known as the coil refrigeration load because outdoor air cooling load is different from the space cooling load (**Table 2**).

## 8. Indoor Air Quality for Building Environmental Performance

The check of the Indoor Air Quality as the air movement and recirculation, effectiveness of outdoors air used, and concentration of particulate matter are all satisfied with the requirements.

The computation, procedures, and results with Excel spreadsheets for the sections of south, north, and corridors/stairs have been given in **Table 2**.

The following equation can be used to obtain the required constant outdoor-air rates for constant-air-volume systems as well as recirculation rates and results shown in **Table 2**, where,

$dQ_0/dt$ = volumetric flow, f= filter
C = contaminate concentrations, o = outdoor
E = efficiency or effectiveness, r = return
F = flow reduction factor, s = supply
N = contaminate generation rate, v = ventilation
R = recirculation flow factor.

Therefore, concentration level of particular in the space is calculated as

$$C_s = (N + (E_v dQ_o/dt(1 - E_f C_0))/((E_v(dQ_o/dt + RdQ_r/dtE_f)). \quad (27)$$

In addition, the environmental air quality as the high building performance includes the check of rates of air move and compliance of air NAQQS standard that have been concluded in **Table 2**.

**Appendix A** and **Appendix B** have provided the Excel computing codes and building and system heat gain to review the impacted results of transient solar radiation on the building envelop during the daily 24 hours period.

## 9. Operation Analysis for Assessment of High Building Performance

Based on the hourly cooling loads and coil load distribution, the design of cooling facility and energy operation is presented as below. With the solar radiation variation, two 75-ton double screw compressor chillers and one 30 ton double screw compressor chiller are proposed to reduce the energy footprint KW and demand charges and reduction the GHG emission and the Btu (w–hr.)/year by the consumption of electrical energy due to it falling dramatically between the 20:00 to 6:00 next day. Moreover, it can let the all chillers to flexibly get full load closely and high load factor with high electrical energy efficiency for the HVAC system and equipment design and operation. Based on the daily 24- hour cooling load distribution, the operation strategy of energy saving with the refrigerators to decrease carbonization and its footage is as below and **Table 4**.

1:00 – 5:00, 1 × 75 ton chiller
6:00 – 8:00, 1× 75 ton chiller and 1 × 30 ton chiller
8:00 – 17:00, 2 × 75 ton chiller and 1 × 30 ton chiller
17:00 – 19:00, 1 × 75 ton chiller and 1 × 30 ton chiller 19:00 – 24:00, 1 × 75 ton chiller

**Table 4.** Energy performance/GHG reduction and operation analysis [16,17].

| | Construction Energy Footage for Chillers and Energy Operation Analysis | | | |
|---|---|---|---|---|
| Daily Time | Unit | Quantity | Subtotal Hrs | Chillers' Ton to KW during Operation Hrs. |
| 1:00–6:00 | KW-Hrs | 54,000 | 6Hrs × 5M | 1 × 75 TON × 0.8KW/TON |
| 6:00–8:00 | KW-Hrs | 25,200 | 2Hrs × 5M | (1 × 75 TON+ 1 X 30 TON) × 0.8KW/TON |
| 8:00–17:00 | KW-Hrs | 194,400 | 9Hrs × 5M | (2 × 75 TON+ 1 X 30 TON) × 0.8KW/TON |
| 17:00–19:00 | KW-Hrs | 25,200 | 2Hrs × 5M | (1 × 75 TON+ 1 X 30 TON) × 0.8KW/TON |
| 19:00–24:00 | KW-Hrs | 45,000 | 5Hrs × 5M | 1 × 75 TON* × 0.8KW/TON |
| Total KW-Hrs/Year | KW-Hrs | 343,800 | | |
| | MMW-Hrs | 343.80 | | |
| Equivlalent $CO_2$ | Kgs $CO_2$ | 88,831.04 | | US Average 22.5 KWh/sf/yr<br>1 KWh = 0.000258 Ton CO 2 e/0.00021233, |
| | Tons $CO_2$ | 88.83 | | NYC Convert Factor 2010/NYC; LL 97 Convert Factor 2019 |
| | tCO2e /sf/yr | 0.0019 | | 22.5KWh /sf/yr 0.0058 tCO2 e/sf/yr 0.005 tCO2 e/sf/yr |
| NYC 2024 Standard | tCO2e /sf/yr | 0.0076 | | 343800KWh/yr = 88.704t CO2/yr = 0.00065/0.348<br>= 0.00186 tCO2/sf/yr |
| NYC 2030 Standard | tCO2e /sf/yr | 0.0027 | NYC Convert Factor, 2010/2019 Data | =72.99tCO2/yr=0.000534/0.348=0.00153 tCO2e/sf/yr |

## 10. Findings

1. From **Table 1** and **Figure 4**, Hourly Cooling Load in the building, the loads related to solar temperature and radiation, wall and roof, window solar heat conduction, TSHG and ASHG weight 47.74% of overall Btu/hr@17:00. Meanwhile, it distributes itself effects to the building unevenly and unpredictable generally on the daily. The 24-hr. solar radiation analysis to the HVAC process and equipment is very important for the high-performance building design.
2. From **Table 1** and **Figure 4**, it is understood that the lighting is a biggest part of the heat gain. Although planned lighting with1.5 w/sf during working hours is larger than current popular T8 usage with 0.8 w/sf, it still has potential energy measure for T5 to save the energy consumption, and or by automatically turn-off the lights with the sensor controlling the person appearance in the office space.
3. Compared with other conventional cooling load design to use average temperature difference as $89^0$ F − $72^0$ F = $17^0$ F vs. average out temperature 80.78 $^0$ F − $72^0$ F = 8.22 $^0$ F in the RTS (radiant time series), it can be projected that the heat gain and cooling load in the RTS is approximately 15% less than the general preliminarily-planned heat gain.
4. Compared with the other Excel spread sheet for the purpose of design for some small building case, it used partial solar data effects with CLTD (Climate Temperature Difference) related to the latitude with north, east, south and west for some case under some codes for north wall [13], SHGF for window related to north, east, south, west under some codes for south window. However, the Excel computing for the design evaluation is not transient and without roof heat gain and solar ASGH and partial application of ASHRAE solar data and formulas. It will be not enough cooling power to supply during peak hours for medium office building. It is suitable for small building estimates of the energy evaluation.

## 11. Conclusions

1. Based on **Table 1**, the heat gain 1,957,081 Btu/hr. at the 17:00 is taken to be distributed to the cooling coils to remove heat gain with the cooling loads to three sections in the three parts 1–4 floors, 5–8 floors and 9 – 12 floors: South, North, and Corridor with the 163-ton (power, Btu/hr.) chiller. However, the cooling coil and the flow rate of the air fan are selected by the even number between 15:00 and 17:00 for the cooling load delay.
2. It is definitely impossible to figure out daily each hour cooling load for the new building and operation energy need to get the optimal energy performance for the existing without solar radiative analysis. It cannot be completed by the only use the automatic temperature control.
3. According to the 2023 NYC Sustainable Plan, it has planned the initiative to maximize access to indoor cooling, whereas it made the GHG emission limit under the building goal to reduce carbon footprint of the existing building and new construction [2]. The electrical consume for the building cooling system and equipment has projected a very major portion of the whole year, around 58% (Heating and Cooling in Office Building) × 60% (Cooling) = 34.8% [14]. Accounting the solar transient radiation on the building envelope and surrounding environment, the cooling load distribution with the impact of solar energy could be identified more clearly. It would help to solve the dilemma issue: access cooling and reducing of footprint KW (Btu/hr.) and reduction of HVAC system energy kw-hour (Btu).
4. Excel computing and analysis for the cooling load is a good, convenient, and available measure with the individual codes' writing. Under the parameter designation with the cell of Excel, it can change the solar flux number Btu/hr−$ft^2$, equation time, and other solar data such as C (clearness of weather) under the each $21^{st}$ day of each month in the year. Moreover, it can modify and predict cooling load for each day adjusting the solar data between the two months, then split it across 30 days, roughly. It is very good for the energy operation analyses with the daily weather status to adjust clear day factor C for operation of facility components daily, then to support all calculation of heat gains. The sample codes for the solar radiation with south wall @13:00, cos θ with north wall @13:00, solar TSHG with east window @9:00 are present in **Appendix B**, **Figure A3**.
5. The other strategic ways are to use and conform resilient solar transient radiation in the high energy performance for the building design, such as to adopt VFD (Variable Frequency Diver) for chiller water pump and fan in the north wall and north window sections [15], VAV (variable air volume) in the section zone, solar panel

with available solar gain on the roof and optimal incident **cos θ** on the north and south wall for solar panel, available solar heat gain load for heat storage with solar-water exchange on the roof.

6. Use premium efficiency motor with energy efficiency 95.4% for water pump of coiling coil and fresh inlet and exhaust fan.
7. Control chilled water temperature based on the solar temperature and $t_0$, outside temperature predicted by the numerical quantities with update of Excel spread sheets daily.
8. RTS cooling load analysis and design including evaluation with the Excel spread sheet can establish the consolidated basis for the HVAC system and equipment design and energy management under the high performance for medium office building and six story resident building by simplicity of the computing codes with light impact of external shading to sun's rays. It is based on the ASHRAE standards, code and design guideline, and local building code, and forms the detailed steps to project the energy performance data and comply with the sustainable policy. Meanwhile, it makes easy for the small and medium building owners or engineering consultants to design new HVAC construction and manage energy operation and management for current building energy consumption and reduce GHG emission to attain under the local government limit of carbon gas emission.
9. Current RTS design uses typical sample radiant time factors from the sample zone developed from a computer program that are some different with the factors from the ASHARE methods, which can be as an alternative way. For actual design load calculations, radiant time factor should be generated for the specific zone (structure materials of construction) in question. Therefore, some design error of the calculated cooling load should appear and be no too big [6] (pp. 262–264).
10. Under the high-performance building design in the HVAC system and the energy code of the implementation, as in the 5 months as the operation time procedure for chillers as mentioned before, the projected final designed performance result in the HVAC and energy is electrical consumption and converted to the ton $CO_2$ e/sf/year = 0.0015 - 0.0019 < NYC 2024 limit 0.00758, and 2030 limit as 0.00269, and US average as 0.005 – 0.0058 $tCO_{2/}$e/sf/yr (**Table 4**).

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## Institutional Review Board Statement

Not applicable.

## Informed Consent Statement

Not applicable.

## Data Availability Statement

All data supporting reported results can be found from the references including links to publicly archived datasets analyzed or generated during the study.

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## Conflicts of Interest

The author declares that there is no conflict of interest.

## Appendix A

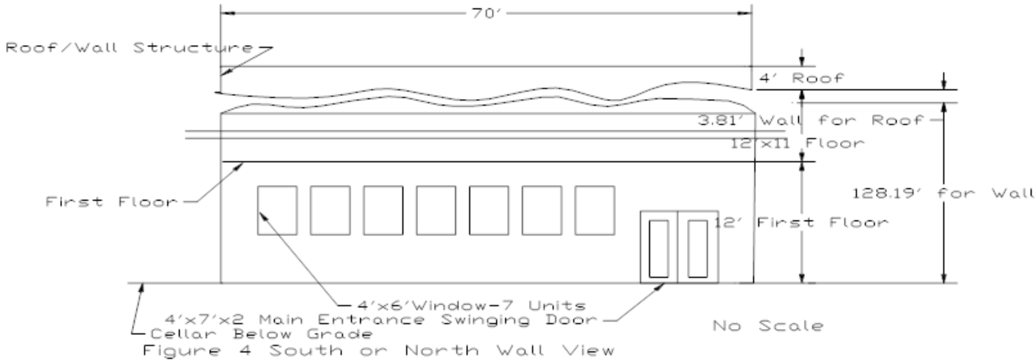


**Figure A1.** Building vertical plan.

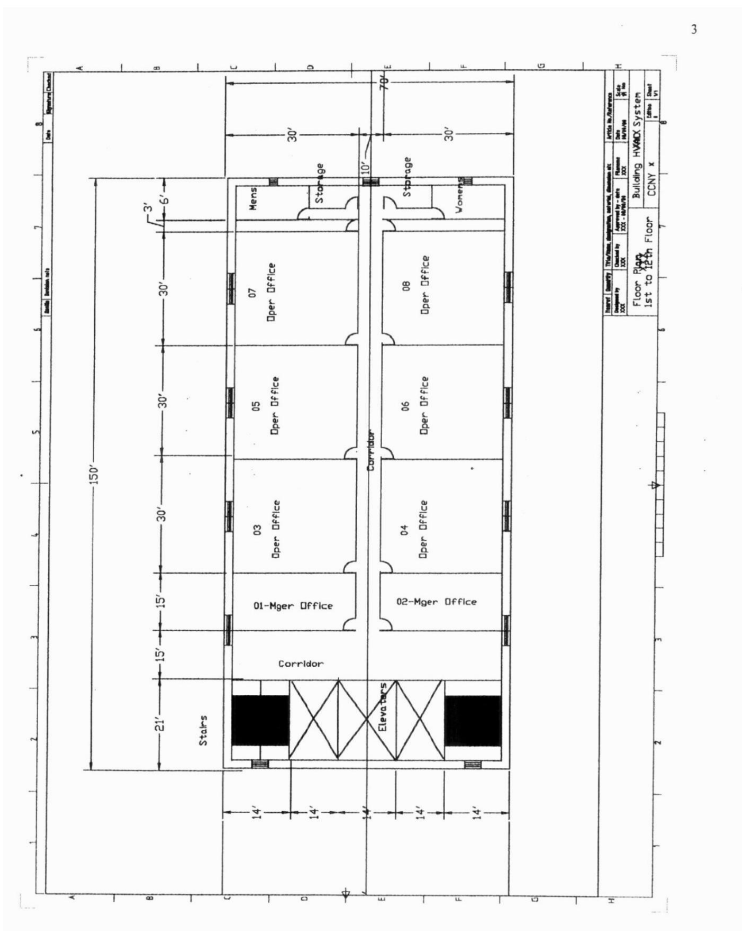


**Figure A2.** Building floor plan layout.

**Table A1.** Solar heat gain for the windows in the building.

| Table | C-4 | | Solar Heat Gain for the Windows in the Building | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S.Window qTSHG | W.Window qTSHG | N.Window qTSHG | E.Window qTSHG | Windows TSGH | S.Window qASHG | W.Window qASHG | N.Window qASHG | E.Window qASHG | Window qASHG |
| **Hour** | **Btu/hr** | **Btu/hr** | **Btu/hr** | **Btu/hr** | **Btu/hr** | **Btu/hr** | **Btu/hr** | **Btu/hr** | **Btu/hr** | **Bti/hr** |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 1,137.95 | 76,690.31 | 18,759.11 | 96,587.37 | 102.14 | 0.00 | 1,458.16 | 349.53 | 1,909.82 |
| 6 | 949.22 | 68.39 | 4,547.03 | 1,141.27 | 6,705.91 | 6.14 | 1,292.65 | 83.81 | 21.99 | 1,404.58 |
| 7 | 24,661.08 | 1,830.81 | 113,146.50 | 29,356.60 | 168,994.98 | 164.33 | 61,578.78 | 2,048.00 | 527.58 | 64,318.70 |
| 8 | 21,555.19 | 3,821.56 | 202,534.83 | 54,609.49 | 282,521.07 | 343.02 | 160,447.66 | 4,216.24 | 1,046.52 | 166,053.44 |
| 9 | 25,883.21 | 5,659.14 | 233,946.01 | 65,715.23 | 331,203.58 | 759.27 | 213,751.79 | 5,294.91 | 1,459.13 | 221,265.10 |
| 10 | 68,344.61 | 7,223.92 | 194,965.51 | 59,646.90 | 330,180.94 | 2,529.06 | 174,708.49 | 4,638.66 | 1,355.99 | 183,232.21 |
| 11 | 131,363.97 | 8,415.18 | 96,703.26 | 35,570.75 | 272,053.15 | 4,031.20 | 87,277.48 | 3,381.91 | 1,042.24 | 95,732.83 |
| 12 | 182,933.81 | 9,154.93 | 37,055.79 | 11,036.05 | 240,180.59 | 4,961.40 | 23,115.19 | 821.74 | 352.30 | 29,250.63 |
| 13 | 201,419.44 | 9,394.25 | 98,394.09 | 17,876.01 | 327,083.79 | 5,276.80 | 2,276.76 | 843.22 | 1,962.66 | 10,359.44 |
| 14 | 182,181.44 | 9,117.27 | 36,903.39 | 36,893.76 | 265,095.87 | 4,940.99 | 350.86 | 818.36 | 23,020.12 | 29,130.32 |
| 15 | 132,358.80 | 8,342.37 | 95,866.58 | 0.00 | 236,567.75 | 3,996.32 | 1,004.67 | 3,352.64 | 86,522.35 | 94,875.99 |
| 16 | 73,088.04 | 7,120.75 | 192,181.10 | 0.00 | 272,389.89 | 2,492.94 | 1,312.61 | 4,572.42 | 172,213.38 | 180,591.35 |
| 17 | 27,552.77 | 5,532.32 | 228,703.18 | 0.00 | 261,788.27 | 742.25 | 1,416.58 | 5,176.25 | 208,961.52 | 216,296.61 |
| 18 | 14,921.04 | 3,679.16 | 194,987.85 | 0.00 | 213,588.05 | 1,248.59 | 1,007.54 | 4,059.13 | 154,468.95 | 160,784.21 |
| 19 | 6,826.10 | 1,683.15 | 104,020.87 | 0.00 | 112,530.12 | 6,299.96 | 483.05 | 1,882.82 | 56,612.26 | 65,278.10 |
| 20 | 88.49 | 21.82 | 1,450.76 | 0.00 | 1,561.06 | 386.72 | 7.00 | 26.74 | 412.43 | 832.89 |
| 21 | 1,818.77 | 448.46 | 30,223.59 | 0.00 | 32,490.82 | 0.00 | 138.55 | 574.66 | 3,065.17 | 3,778.38 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table A2.** Conduction heat gain for the each wall and roof.

| | Table C-5 | | Conduction Heat Gain for the Each Wall and Roof | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Heat Gain, Btu/hr | | | | | |
| **Hour** | **S.Wall** | **W.Wall** | **N.Wall** | **E.Wall** | **Sub@wall** | **Roof** | **S.Window** | **W.Window** | **N.Window** | **E.Window** | **Sub@wind** |
| 1 | 107,883.88 | 48,549.95 | 124,807.22 | 23,145.17 | 304,386.23 | 24,784.35 | 5,404.10 | 1,332.52 | 5,404.10 | 1,332.52 | 13,473.24 |
| 2 | 93,770.92 | 43,021.69 | 109,131.64 | 20,471.50 | 266,395.75 | 16,599.51 | 4,486.66 | 1,106.30 | 4,486.66 | 1,106.30 | 11,185.92 |
| 3 | 80,904.35 | 37,622.79 | 94,419.19 | 18,086.27 | 231,032.59 | 10,109.52 | 3,757.74 | 926.57 | 3,757.74 | 926.57 | 9,368.60 |
| 4 | 69,411.70 | 32,583.01 | 81,047.71 | 15,950.52 | 198,992.93 | 4,941.03 | 3,204.76 | 790.21 | 3,204.76 | 790.21 | 7,989.95 |
| 5 | 50,056.13 | 28,011.85 | 69,154.74 | 14,035.83 | 161,258.55 | 1,382.98 | 1,766.24 | 776.12 | 25,288.20 | 6,199.44 | 34,030.01 |
| 6 | 50,462.01 | 23,951.68 | 59,080.60 | 12,474.13 | 145,968.42 | 1,636.62 | 3,453.78 | 810.69 | 4,784.01 | 1,185.27 | 10,233.74 |
| 7 | 42,794.49 | 20,413.62 | 51,810.95 | 11,724.70 | 126,743.76 | 784.47 | 9,695.74 | -351.61 | 37,945.90 | 9,644.29 | 56,934.32 |
| 8 | 36,384.28 | 17,355.17 | 46,761.84 | 11,576.32 | 112,077.62 | 5,792.55 | 25,228.56 | -1,992.17 | 69,909.94 | 18,094.74 | 111,241.07 |
| 9 | 31,804.47 | 14,567.43 | 45,226.44 | 12,707.79 | 104,306.13 | 19,174.38 | 47,900.57 | -2,717.74 | 90,651.71 | 23,864.93 | 159,699.47 |
| 10 | 30,262.56 | 11,775.31 | 49,689.66 | 16,369.91 | 108,097.44 | 38,845.50 | 73,646.38 | -1,524.86 | 97,402.45 | 26,064.00 | 195,587.98 |
| 11 | 33,291.95 | 8,925.38 | 60,652.41 | 22,911.42 | 125,781.17 | 62,212.14 | 97,811.11 | 2,144.59 | 90,934.36 | 24,705.53 | 215,595.59 |
| 12 | 42,106.32 | 6,370.38 | 76,329.47 | 31,592.48 | 156,398.65 | 86,795.46 | 115,339.41 | 7,989.40 | 74,286.93 | 20,441.28 | 218,057.02 |
| 13 | 57,046.44 | 4,849.65 | 93,523.49 | 40,952.75 | 196,372.32 | 101,282.08 | 122,514.54 | 14,611.17 | 53,830.10 | 14,892.43 | 205,848.25 |
| 14 | 77,260.69 | 5,268.71 | 108,778.72 | 49,335.74 | 240,643.86 | 130,045.10 | 118,605.35 | 21,279.47 | 77,721.67 | 8,878.81 | 226,485.30 |
| 15 | 100,714.17 | 8,358.32 | 120,037.52 | 55,365.43 | 284,475.44 | 144,570.75 | 104,238.88 | 26,285.38 | 97,421.62 | 3,919.67 | 188,274.04 |
| 16 | 124,557.25 | 14,433.14 | 129,060.55 | 58,218.82 | 326,269.76 | 152,362.75 | 82,480.33 | 28,129.41 | 105,897.31 | 934.63 | 217,441.67 |
| 17 | 145,677.71 | 23,205.91 | 138,693.32 | 57,757.20 | 365,334.13 | 152,550.90 | 58,211.64 | 26,137.49 | 100,005.46 | 150.58 | 184,505.17 |
| 18 | 161,321.63 | 33,693.92 | 149,785.70 | 54,509.77 | 399,311.01 | 144,947.12 | 36,060.19 | 20,323.67 | 79,078.61 | 985.14 | 136,447.61 |
| 19 | 169,676.13 | 44,335.08 | 160,957.08 | 49,470.29 | 424,438.58 | 129,935.84 | 20,094.22 | 11,624.76 | 46,071.29 | 2,434.37 | 80,224.65 |
| 20 | 170,225.32 | 53,278.55 | 169,356.70 | 43,768.16 | 436,628.72 | 108,664.28 | 12,777.50 | 3,269.27 | 13,248.86 | 3,140.72 | 32,436.35 |
| 21 | 163,811.38 | 58,824.03 | 171,823.41 | 38,324.05 | 432,782.88 | 84,590.53 | 10,720.23 | 2,643.34 | 10,720.23 | 2,643.34 | 26,727.15 |
| 22 | 152,352.71 | 60,153.59 | 166,660.02 | 33,598.90 | 412,765.22 | 64,946.07 | 8,885.35 | 2,190.91 | 8,885.35 | 2,190.91 | 22,152.52 |
| 23 | 138,106.61 | 58,016.07 | 155,348.01 | 29,598.16 | 381,068.85 | 48,560.32 | 7,414.93 | 1,828.34 | 7,414.93 | 1,828.34 | 18,486.54 |
| 24 | 122,891.43 | 53,785.13 | 140,671.79 | 26,159.18 | 343,507.52 | 35,136.96 | 6,321.54 | 1,558.74 | 6,321.54 | 1,558.74 | 15,760.56 |

**Table A3.** Cooling coil load distribution percentage to each part south, north, and e/w corridor.

| | **S** | **W** | **N** | **E** | **E/W** | **SUBTOTAL** |
|---|---|---|---|---|---|---|
| 15:00 | 341,308.17 | 43,990.74 | 316,678.36 | 145,807.46 | 189798.2 | 847,784.73 |
| 16:00 | 282,618.56 | 50,995.92 | 431,711.37 | 231,366.83 | 28,2362.74 | 996,692.68 |
| 17:00 | 232,184.37 | 56,292.30 | 472,578.20 | 266,869.30 | 323,161.61 | 1,027,924.18 |
| | 286,746.2696 | 50,141.5236 | 394,628.2809 | 206,338.3788 | 256,479.9 | 937,85445 |
| | 40.26% | | 37.35% | | 22.39% | 100.00% |
| | 22.59% | | 45.97% | | 31.44% | |
| EVEN | 31.42% | | 41.66% | | 26.91% | 1.0000 |

**Appendix B. Excel Sample Codes**

**1.** Btu/hr.– ft$^2$, Solar Irradiation, South Wall @13:00
= (305.61)*0.33*0.433 + (305.61)*(COS (ASIN (0.937273))*COS (ACOS (((00.937273)*0.6559 – 0.3517)/ (COS(ASIN(0.937273))*0.7547)) + 0)) + (305.61)*(0.55 + 0.437*COS(ASIN(0.937273))*COS(ACOS(((0.937273)* 0.6559 – 0.3517) / (COS(ASIN(0.937273))*0.7547)) + 0)) + 0.313*((COS(ASIN(0.937273))* COS(ACOS(((0.937273)*0.6559 – 0.3517)/(COS(ASIN(00.937273))*0.7547)) + 0))^2)

**2.** COSθ, North Wall @13:00
=COS (ASIN (0.937273))*COS (ACOS (((0.937273)*0.6559 – 0.3517) / (COS (ASIN (0.937273))*0.7547)) + 180)

**3.** TSHG, South Window @9:00, Btu/hr.
= (184.10*0.04675*((– 0.00885)*1 + 2.71235*0.04675 – 0.62062*(0.04675^2) – 7.07329*(0.04675^3) + 9.75995*(0.04675^4) – 3.89922*(0.04675^5)) + 2*0.138*184.10*(0.55 + 0.437*0.04675 + 0.313*(0.04675^2)) *(– 0.00885/2 + 2.71235/3 – 0.62062/4 – 7.07329/5 + 9.75995/6 – 3.89922/7))*0.88*2336

**4.** Step 8. Cooling Load of Convective/Radiative Heat Gain with Radiant Time Factor @ 15:00 for Wall and Roof
=0.2550941*BS23 + 0.1139586*BS22 + 0.0695853*BS21 + 0.0513341*BS20 + 0.0425855*BS43 + 0.0377131*BS42 + 0.0346113*BS41 + 0.0324116*BS40 + 0.0307118*BS39 + 0.0293093*BS38 + 0.0280908*BS37 + 0.026996*BS36 + 0.025984*BS35 + 0.0250392*BS34 + 0.0241403*BS33 + 0.0232829*BS32 + 0.022462*BS31 + 0.021674*BS30 + 0.0209139*BS29 + 0.0201816*BS28 + 0.0194781*BS27 + 0.0188*BS26 + 0.0181458*BS25 + 0.0175139*BS24

**Note:** BS 23 is Table C – 7, Radiative Portion of Conduction and Solar Heat Gain for Wall and Roof in the Btu/hr. @ 15:00; BS 22 @14:00, BS21@1300; ---1:00 ---to BS 24@16:00 hour time.

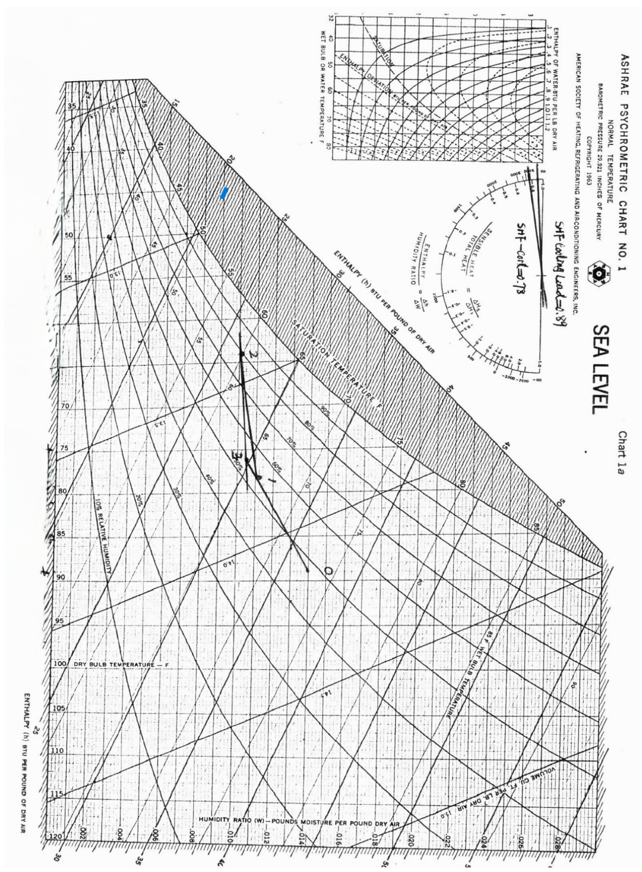


**Figure A3.** Evaluate air flow rate of system and cooling coil refrigeration load by psychometric chart.

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