Design for Thermal Comfort during Summer & Psychometry Tool for Human Comfort

Syed Faheem¹, Syed Mujeeb Ali², Syed Suleman³, Syed Obaid Ur Rahman⁴, Syed Wali Uddin Irfan⁵

1. Introduction

Heating, ventilation and air conditioning (HVAC) is the technology of indoor and vehicular environmental comfort. Its goal is to provide thermal comfort and acceptable indoor air quality. HVAC system design is a sub discipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics, and heat transfer. Refrigeration is sometimes added to the field's abbreviation as HVAC&R or HVAC&R, or ventilating is dropped as in HACR.

Energy efficiency can be improved more by installing central heating systems which allows more granular application of heat. Zones can be controlled by multiple thermostats. The HVAC industry is a worldwide enterprise, with roles including operation and maintenance, system design and construction, equipment manufacturing and sales, and in education and research. The HVAC industry was historically regulated by the manufacturers of HVAC equipment, but regulating and standards organizations such as HARDI, ASHRAE, SMACNA, ACCA, Uniform Mechanical Code, International Mechanical Code, and AMCA have been established to support the industry and encourage high standards and achievement.

The starting point in carrying out an estimate both for cooling and heating depends on the exterior climate and interior specified conditions. However, before taking up the heat load calculation, it is necessary to find fresh air requirements for each area in detail, as pressurization is a building environment standards. It establishes the general principles of building environment design. It considers the need to provide a healthy indoor environment for the occupants as well as the need to protect the environment for future generations and promote collaboration among the various parties involved in building environmental design for sustainability. ISO16813 is applicable to new construction and the retrofit of existing buildings.

Abstract: Central Air Conditioning is more reliable for easy operation with a lower maintenance cost. The effective design of central air conditioning can provide lower power consumption, capital cost and improve aesthetics of a building. This paper establishes the result of heating load calculation under different climatic conditions by using E-20 for a multi-story building. Heating load items such as people heat gain, lighting heat gain, infiltration and ventilation heat gain and cooling load due to walls and roofs. Using ISHRAE and CARRIER fundamental hand books and here the study of air water vapor mixture (called psychometric) for human comfort in the air conditioning system for the city Hyderabad.

Keyword: Temperature difference, thermal resistance, overall heat transfer coefficient, E-20 performa, ISHRAE Std.

2. Methodology

- Commerical building plan of 11634.5 square feet
- Calculation of floor, roof, wall and windows areas.
- Calculation of temperature difference (ΔT).
- Thermal resistance of wall, roof and windows.
- E-20 ISHRAE Std.
- Overall heat transfer co – efficient.
- Heating load in BTUH.

3. Psychometric condition during summer in Hyderabad

Dry Bulb Temperature- 105°F
Relative Humidity-70-80%

As the above conditions for the citizens of Hyderabad is not comfortable. So, the air should be dehumidified and should bring the temperature at 72°F-76°F, and relative humidity to 50%-60%. For this cooling is required in a space.
Ra is standard value irrespective of thickness of the air gap.

9" COMMON WALL:
- X= thickness of material
- R1, R2, R3...Rn is the resistance of the material
- 'U' Value of R for different material are taken from resistance table of data book.

Note:
1) Ro may vary as per location
2) Ra is standard value irrespective of thickness of the air gap.
3) R1, R2, R3... Rn is the resistance of the material
4) X= thickness of material
5) Value of R for different material are taken from resistance table of data book.

4. Design

For estimating cooling loads, one must consider the unsteady state processes, as the peak cooling load occurs during the day time and the outside conditions also vary significantly throughout the day due to solar radiation. In addition, all internal sources add on to the cooling loads and neglecting them would lead to underestimation of the required cooling capacity and the possibility of not being able to maintain the required indoor conditions. Thus, cooling load calculations are inherently more complicated as it involves solving unsteady equations with unsteady boundary conditions and internal heat sources.

1) Cooling load calculation
   (heat load calculation i.e. heat gain through all the sources)
   - Application for summer
   - Process is directly to cooling and dehumidification (required in wet summer)
   - Cooling and humidification (required in dry summer like in desert areas where there is no water available for evaporation).

   Definition: The room cooling load is a rate at which the heat must be removed from the room air in order to maintain it at desired temperature and humidity.

2) Sources of heat (Qin)
   a) External sources
   - Heat gain through glass due to conduction
   - Heat gain through glass due to radiation
   - Heat gain through skylight (conduction & radiation)
   - Heat gain through wall (sensible)
   - Heat gain through roof (sensible)
   - Heat gain through partition, floor and ceiling due to conduction (sensible heat)
   - Heat gain through ventilation due to convection (sensible & latent heat)
   - Heat gain through infiltration due to convection (sensible & latent heat)

   b) Internal sources
   - Heat gain through lighting (sensible heat)
   - Heat gain through people (sensible and latent heat)
   - Heat gain through appliances

3) Finding ‘U’ Value

\[ U = \frac{1}{\sum R} \]

Where, \( \sum R = R_0 + X_1R_1 + X_2R_2 + X_3R_3 + \ldots + X_nR_n + R_i \)

- Ri = Resistance of inside air film = 0.68 (std value)
- Ro = Resistance of outside air film = 0.25 for summer @ 7.5 m/s wind velocity
- Ro = 0.17 for winter @ 15 m/s wind velocity
- Ra = Resistance of air film gap = 0.91

Note:
1) Ro may vary as per location
2) Ra is standard value irrespective of thickness of the air gap.
3) R1, R2, R3... Rn is the resistance of the material
4) X= thickness of material
5) Value of R for different material are taken from resistance table of data book.

4) ‘U’ Value of Building
   a) 9” COMMON WALL:
   
   \[ \sum R = R_0 + X_1R_1 + X_2R_2 + X_3R_3 + \ldots + X_nR_n + R_i \]
   
   \[ \sum R = 0.25 + (0.5 \times 0.12) + (8 \times 0.2) + (0.5 \times 0.12) + 0.68 = 2.65 \]
   
   \[ U = \frac{1}{\sum R} = 1/2.65 = 0.37 \text{ Btu/(hr-ft}^2\text{-F)} \]

   b) 0.25” GLASS:-
   
   \[ \sum R = R_0 + X_1R_1 + X_3R_3 + \ldots + X_nR_n + R_i \]
   
   \[ \sum R = 0.25 + (0.25 \times 0.12) + (0.25 \times 0.12) + 0.25 = 1.37 \]
   
   \[ U = \frac{1}{\sum R} = 1/1.37 = 0.73 \text{ Btu/(hr-ft}^2\text{-F)} \]
\[ \sum R = 0.25 + (0.25 \times 1.25) + 0.68 = 1.24 \]
\[ U = \frac{1}{\sum R} = \frac{1}{1.24} = 0.8 \text{ Btu/(hr-ft}^2\text{-F)} \]

\( \text{c) 6” ROOF} \)

\[ \sum R = 0.25 + (0.5 \times 0.12) + (5 \times 0.08) + (0.5 \times 0.12) + 0.68 = 1.45 \]
\[ U = \frac{1}{\sum R} = \frac{1}{1.45} = 0.69 \text{ Btu/(hr-ft}^2\text{-F)} \]

\section*{Cooling Load Calculation of A Spaces}

\begin{itemize}
  \item **Input File / Data:** (ISHRAE Std.)
  \begin{enumerate}
    \item Location – Hyderabad
    \item Space - C.E.O. Chamber
    \item Number of people – 7
    \item Bottom of slab (or) section height 9’
    \item Outside dry bulb temperature – 105F
    \item Inside required dry bulb temperature – 76 F
    \item Glass thickness – 0.25”
    \item Glass type – ordinary dark color
    \item Latitude – 17.45 N
    \item Longitude – 78.47 E
    \item Elevation – 1788 ft
    \item Number of walls – 2 (S,W)
    \item Number of partitions – 0
    \item Number of windows – 2 (S,W)
    \item Number of doors – 0
  \end{enumerate}

\end{itemize}

\section*{Areas}

\begin{enumerate}
  \item **Orientation : South**
    \begin{enumerate}
      \item Wall area : 13’x12’ = 156 ft\(^2\)
      \item Glass area : 6’x12’ = 74 ft\(^2\)
    \end{enumerate}
  \item **Orientation : West**
    \begin{enumerate}
      \item Wall area : 10’x12’ = 120 ft\(^2\)
      \item Glass area : 9’x12’ = 108 ft\(^2\)
    \end{enumerate}
  \item **Roof Area :** 18’-6” X 20’ = 370 Ft\(^2\)
\end{enumerate}

\section*{Heat Gain Through External Sources}

\begin{itemize}
  \item **Heat Gain Through Glass**
    \begin{enumerate}
      \item Through Conduction :
        \[ Q = U \times A \times \Delta T \]
    \end{enumerate}
\end{itemize}

Where, \( Q \) = Total sensible heat gain
\( A \) = Area of glass in sq.ft
\( \Delta T \) = Temperature difference between outside and inside.

Here , \( U = 0.8 \)
\( A = 74+108 = 180 \text{ ft}^2 \)
\( \Delta T = 105-76 = 29 \text{ F} \)

As a result,
\[ Q = 0.8 \times 182 \times 29 = 4222 \text{ Btu/hr} \]

\begin{itemize}
  \item **b. Through Radiation :**
    \begin{enumerate}
      \item \( Q = U_R \times A \times \Delta H \)
    \end{enumerate}
\end{itemize}

Where, \( U_R \) = solar factor or shade coefficient (depend on the type of glass; light, medium or dark)
\( U_R = 0.75 \) [Data book : Table no. 16]

\begin{itemize}
  \item **FOR SOUTH WINDOW**
    \begin{enumerate}
      \item \( U_R = 0.75 \)
      \item \( A = 74 \text{ ft}^2 \)
    \end{enumerate}
\end{itemize}

\( \Delta H \) requirements :
1) Latitude of the city : 17.49 N
2) Month in which the city faces maximum temperature : May
3) Timings : 8am or 4pm

Using the above parameters from data book table 15 ;
for ‘20\(^o\) North latitude’ in the month of ‘May’ at 8am or 4pm,
\[ \Delta H = 12 \text{ Btu/hr-ft}^2 \]

Thus,
\[ Q = 0.75 \times 74 \times 12 = 666 \text{ Btu/hr} \]

\begin{itemize}
  \item **FOR WEST WINDOW**
    \begin{enumerate}
      \item \( \Delta H = 163 \text{ Btu/hr-ft}^2 \)
      \item \( A = 108 \text{ ft}^2 \)
    \end{enumerate}
\end{itemize}

Therefore,
\[ Q = 0.75 \times 108 \times 163 = 13203 \text{ Btu/hr} \]

\section*{Heat Gain Through Wall}

\[ Q = U \times A \times \Delta T \text{ Btu/hr} \]

\begin{itemize}
  \item a) **FOR SOUTH WALL**
    \begin{enumerate}
      \item \( U = 0.37 \text{ Btu/hr-ft}^2\text{-F} \)
      \item \( A = 156 \text{ ft}^2 \)
      \item \( \Delta T \) = Equivalent temperature + correction factor
    \end{enumerate}
  \item **Equivalent temperature requirements :**
    \begin{enumerate}
      \item Weight or thickness of the wall :100 lb/sft or 9”
      \item Timing : midday + 2 hours(storage effect)
    \end{enumerate}

For Hyderabad, midday is found at 2pm.
Therefore, the timing = 2+2 = 4pm
Using above parameter,

**From [Data book, table – 19]**

We get,
Equivalent temperature = 16°F

- **Correction factor requirements:**

  1) Range = Maximum outside DB – Minimum outside DB
  
  = 10.5°C (from ASHRAE Climatic Data Software) shown below
  
  = 18.9°F ~ 19°F

  2) Temperature Difference
  
  = T_o – T_i
  
  = 105 – 76
  
  = 29°F

Using above parameters, From [Data Book, Table – 20A] We get,

Correction factor = 14°F

Therefore, ∆T = 16+14 = 30°F

As a result,

\[ Q = 0.37 \times 156 \times 30 = 1731.6 \text{ Btu/hr} \]

**b) FOR WEST WALL**

U = 0.37 Btu/hr-ft²°F

A = 120 ft²

\[ \Delta T = \text{Equivalent temperature + Correction factor} \]

= 12+14 = 26°F

Thus,

\[ Q = 0.37 \times 120 \times 26 = 1114.4 \text{ Btu/hr} \]

**Heat Gain Through Roof**

Thickness of the roof = 6"

\[ Q = U \times A \times \Delta T \text{ Btu/hr} \]

Where,

U = 0.1 Btu/hr-ft²°F

A = 370 ft²

\[ \Delta T = \text{Equivalent temperature + correction factor} \]

(Correction factor = 14)

**Equivalent temperature requirements:**

1) Weight of the roof : 40 lb/sft

2) Timing: midday + 2 hours

2pm + 2 = 4pm

Using above parameters, we get, from [Data Book, table – 20] we get,

Equivalent temperature = 38°F

\[ \Delta T = \text{Equivalent temperature + correction factor} \]

\[ \Delta T = 38 + 14 = 52°F \]

Thus,

\[ Q = 0.1 \times 370 \times 52 = 1924 \text{ Btu/hr} \]

**Heat Gain Through Ventilation**

1. **Sensible Heat Gain :**

\[ Q_s = 1.08 \times \text{CFM} \times \Delta T \text{ Btu/hr} \]

Where,

1.08 = specific heat of air

CFM = Ventilation flow rate in cubic feet per minute

\[ \Delta T = T_o – T_i = 105 – 76 = 29°F \]

To find CFM we use two methods

1) Person method

2) Area method

- **Person method:**

CFM = number of people x CFM per person

[Data Book, Table – 45] we get,

CFM per person = 25

Therefore according to the people method

\[ \text{CFM} = 7 \times 25 = 175 \]

- **Area method:**

CFM = Floor area x CFM per sq.ft

[Data Book, Table – 45] from above table, we get,

CFM per sq.ft = 0.25

Therefore according to the area method

\[ \text{CFM} = 370 \times 0.25 = 92.5 \]

We should select the maximum value among two.

Thus,

\[ Q_s = 1.08 \times 175 \times 29 = 5481 \]

2. **Latent heat gain:**

\[ Q_L = 0.68 \times \text{CFM} \times \Delta W \text{ Btu/hr} \]

Where,

0.68 = specific heat of moiseter

CFM = 175

\[ \Delta W = W_o – W_i = \text{Humidity Ratio} \]

Now considering the psychometric chart, we have the following details,

DB = 105 F & WB = 72 F

Therefore, \( W_o = 65 \text{ gain/lb} \)

And also, DB = 76 F and RH = 50% which provides the details for \( W_i = 67 \text{ gain/lb} \)

Therefore,

\[ Q_L = 0.68 \times \text{CFM} \times (W_o – W_i) \]

\[ Q_L = 0.68 \times 175 \times (-2) = -238 \text{ Btu/hr} \]
Note: the –ve sign indicates loss in latent heat because of decrease in humidity.

- **Heat Gain Through Infiltration**

  The infiltration occurs when the outside air enters through the opening due to the wind pressure. Infiltration of air through crack around windows and through area from doors results in both sensible and latent heat gained to rooms.

1. **Sensible heat gain**

   $Q_s = 1.08 \times CFM \times \Delta T \text{ Btu/hr}$

2. **Crack Method to find CFM for infiltration**

   The crack method assumes that a reasonably accurate estimate of the rate of infiltration perfect of crack opening.

   - **For windows**
     
     $CFM = \text{crack in ft(Perimeter)} \times \text{CFM/ft}$

     Where perimeter of glass = $(6x2)+(12x2)+(9x2)+(12x2) = 78 \text{ ft}$

     $CFM = 78 \times 0.37 = 28.86$

   - **For doors**
     
     $CFM = \text{crack in ft}^2(\text{Area}) \times \text{CFM/ft}^2$

     Since there is no exposed door in this space so door CFM would not be considered, if there is door CFM then total CFM will be sum of the windows and doors CFM. Now the total CFM is

     $Q_s = 1.08 \times 28.86 \times 29 = 903.86 \text{ Btu/hr}$

3. **Latent Heat Gain**

   $QL = 0.68 \times CFM \times \Delta W \text{ Btu/hr}$

- **Heat Gain Through Internal Sources**

  1. **Heat Gain Through Lighting**

     $W = \text{Wattage}$

     $B.F = \text{ballast factor}$

     $1 W= 3.4 \text{ Btu/hr}$

     Ballast factor depends on the type of light, since we are using fluorescent light so the ballast factor is 1.25.

     Using the thumb rule, for office application, we have

     $W = 2 \times \text{floor area} = 2 \times 370 = 740 \text{ watts}$

     As a result,

     $Q_l = 740 \times 1.25 \times 3.4 = 3145 \text{ Btu/hr}$

  2. **Heat Gain Through People**

     - **Sensible Heat Gain**

       $Q_s = q_s \times n \text{ Btu/hr}$

     - **Latent Heat Gain**

       $QL = q_l \times n \text{ Btu/hr}$

   

   From the above, for office worker at room temperature 75 F, $q_s = 245 \text{ Btu/hr}$ therefore,

   $Q_l = 245 \times 7 = 1715 \text{ Btu/hr}$

- **Heat Gain Through Appliances**

   Where, $W = \text{Wattage}$

   **WATTAGE PER APPLIANCE:**

   1. **Wattage for computer**

      Number of computer : 5

      CPU : 49 Watts

      Monitor : 28 Watts

      Total : $49 + 28 = 77$ watts

      Therefore, as per requirement, $5 \times 77 = 385$ watts

   2. **Wattage for printer**

      Number of printer : 1

      Wattage : 130 watts

      Therefore, as per requirement, $1 \times 130 = 130$ watts.

      Total Wattage Acquired = $385 + 130 = 515$ Watts.

   Heat gain through appliances:

   $Q = W \times 3.4 \text{ Btu/hr}$

   **S.No** | **Sources** | **Sensible heat gain (Btu/hr)** | **Latent heat gain (Btu/hr)**
---|---|---|---
01 | Glass | 18091 | 
02 | Walls | 2886 | 
03 | Roof | 1924 | 
04 | Ventilation | 5481 | -238 |
05 | Infiltration | 904 | -39 |
06 | Lighting | 3145 | 
07 | People | 1715 | 1407 |
08 | Appliances | 1751 | 
09 | Sub Total | 35897 | 1130 |
10 | Safety factor | 10% = 3589.7 | 5% = 56.5 |
11 | Total | 39487 | 1187 |
Grand Total = total sensible heat gained + total latent heat gained

= 39487 + 1187

= 40674 Btu/hr

Therefore,

Ton of refrigeration = 40674/12000 = 3.3 ~ 3.5 T.R

**PERFORM OF E-20 OF A SPACE**

**COOLING LOAD CALCULATIONS**

<table>
<thead>
<tr>
<th>20 N LATITUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROJECT DETAILS</strong></td>
</tr>
<tr>
<td><strong>Project Name:</strong> MINI PROJECT</td>
</tr>
<tr>
<td><strong>Date:</strong></td>
</tr>
<tr>
<td>Space:</td>
</tr>
<tr>
<td>Space Area:</td>
</tr>
<tr>
<td><strong>Total Height:</strong></td>
</tr>
<tr>
<td><strong>Volume:</strong> 4440 Cub. Ft.</td>
</tr>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td>Solar Gain - Glass</td>
</tr>
<tr>
<td>Glass NE</td>
</tr>
<tr>
<td>Glass W</td>
</tr>
<tr>
<td>Glass SW</td>
</tr>
<tr>
<td>Glass NW</td>
</tr>
<tr>
<td>Skylight</td>
</tr>
<tr>
<td>Solar &amp; Trans Gain Through - walls &amp; roof</td>
</tr>
<tr>
<td>Wall N</td>
</tr>
<tr>
<td>Wall NE</td>
</tr>
<tr>
<td>Wall E</td>
</tr>
<tr>
<td>Wall S</td>
</tr>
<tr>
<td>Roof</td>
</tr>
<tr>
<td>Trans. Gain - except walls &amp; roof</td>
</tr>
<tr>
<td>Partition</td>
</tr>
<tr>
<td>Skylight</td>
</tr>
<tr>
<td>Skylight</td>
</tr>
<tr>
<td>Skylight</td>
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<tr>
<td>Outside Air</td>
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<tr>
<td>Ventilation</td>
</tr>
<tr>
<td>Internal Heat</td>
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<tr>
<td>Equipment</td>
</tr>
<tr>
<td>Effective Room Latent Heat Subtotal</td>
</tr>
<tr>
<td>Effective Room Latent Heat (SRH)</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Outdoor Heat Gain</td>
</tr>
<tr>
<td>Effective Room Latent Heat (SRH)</td>
</tr>
<tr>
<td>Safety Factor</td>
</tr>
<tr>
<td>Effective Room Latent Heat</td>
</tr>
</tbody>
</table>

The U-Values must not exceed Municipality Values.

Roof area should be added if roof is exposed to sun.

**TONNES OF REFRIGERATION**

1.375422387

**SQUIFFER TONNAGES OF REF.**

99.03169062

**Final Result**

2268.525

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### COOLING LOAD CALCULATIONS

#### Project Details
- **Space:** OVERALL BUILDING
- **Volume:** 13964 Cu.Ft.

#### Design Conditions - Hyderabad
- **DBT (°F):** 105
- **VBT (°F):** 85
- **RH (%):** 65
- **HR (Gallons/Hr):** 2

#### Cooling Load Calculation

<table>
<thead>
<tr>
<th>Solar Gain - Glass</th>
<th>WALL NE</th>
<th>N 235 Sqft</th>
<th>24</th>
<th>0.612</th>
<th>129096.24</th>
<th>29</th>
<th>1.08</th>
<th>846947.4</th>
<th>2908.625</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLASS NW</td>
<td>444 Sqft</td>
<td>25</td>
<td>0.37</td>
<td>4928</td>
<td>28</td>
<td>1.08</td>
<td>73814</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>GLASS SW</td>
<td>230 Sqft</td>
<td>25</td>
<td>0.37</td>
<td>3570</td>
<td>29</td>
<td>1.08</td>
<td>6330</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>LATENT</td>
<td>2308.625</td>
<td>29</td>
<td>1.08</td>
<td>91098</td>
<td>29</td>
<td>1.08</td>
<td>6330</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>PARTITION-02</td>
<td>2908.625</td>
<td>29</td>
<td>1.08</td>
<td>91098</td>
<td>29</td>
<td>1.08</td>
<td>6330</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>SUN GAIN - Walls &amp; Roof</td>
<td>40527.8625</td>
<td>29</td>
<td>1.08</td>
<td>91098</td>
<td>29</td>
<td>1.08</td>
<td>6330</td>
<td>25</td>
<td>29</td>
</tr>
</tbody>
</table>

#### GRAND TOTAL HEAT
- **Total:** 767000.4
- **Subtotal:** 648484.5
- **Notes:** The U-Values may not exceed Municipality Values. Roof area should be added if roof is exposed to sun.

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The heating load calculation of the project is calculated.
The BTU per hour for space 101 is 44825.
12000 BTU per hour is equal to 1 ton of refrigeration.
Therefore, the calculated tonnage for the room no. 101 is (44825/12000) = 3.51 Tr.

The BTU per hour for overall space is 846947.
12000 BTU per hour is equal to 1 ton of refrigeration.
Therefore, the calculated tonnage for the overall space is (846947/12000) = 70.57 Tr.

#### 5. Conclusion

Using E-20 as per ISHRAE standards we provide effective comfort solution for the commercial building during summer, for that building heat absorption to be 846000BTUH.

Building Infiltration – 9288 BTUH

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At point 1
Dry bulb temperature is 105 F
Wet bulb temperature is 72 F

At point 2
Dry bulb temperature is 76 F
Relative humidity is 50%

References