1. Introduction

India's teledensity crossing 1.04 billion out of which about 1.01 billion are mobile based connections. Information and communication sector (ICT) is responsible for 2% of global CO$_2$ emission. The growth of mobile connections directly indicated the increase of BTS (Base Transceiver Station), increase of energy consumption and increased CO$_2$ emission. The BTS operates round the clock. For maintaining the temperature of the BTS equipment, an air conditioner is installed. The atmospheric temperature varies during various seasons and night hours. For energy conservation in the BTS room free cooling fans are installed. These free cooling fans are switched ON and the air conditioner switched OFF when the atmospheric temperature is below set point. These fans consumes about 25% of the power consumed by the air conditioner. Thus there is 75% saving in energy. The BTS shelter absorbs heat from the atmosphere, which is additional load for the air conditioner. There is scope for further optimization in
Energy Conservation for Base Transceiver Station Cooling System with Energy Plus Software

this system, if the variation of the heat absorbed by the BTS shelter is considered as a separate variable.

In order to get the shelter envelope thermal load, the shelter is modeled by using Energy Plus. The shelter envelope heat in Watts is received for every 15 minutes. This is given to the fuzzy controller in the Simulink to calculate the total load. The load is fed as thermal current to the RC model. To compensate this load and maintain the shelter temperature the controller selects air conditioner or the free cooling fans and feed the cool air. This cool air treated as thermal current in opposite direction. As a result the shelter temperature is maintained within the specified range. For communication between the Matlab and Energy Plus, Building control virtual test bed (BCVTB) software environment is used, which is acting as interface to make the simulation close to real time. For the case study, a BTS shelter in Chennai city (India) is selected.

2 Mace Sorretino et al. optimized air conditioning system with free cooling system. 3 Fatima Amara et al. reviewed the simulation various thermal model of building energy consumption. 4 Peder Bacher et al. studied for identifying suitable model for heat dynamics of buildings. 5 Fayaz bakhsh et al. studied the effect of change of building parameter and compressor cycles. 6 Jingran Ma et al. studied with economic model predictive control with pre cooling in HVAC system. 7 Xiu feng Pang et al. simulated energy plus with real time building management system compared actual performance of building with expected performance. 8 AL Sharife et al. studied for optimizing BTS energy consumption using solar/diesel hybrid power. 9 Husamettin Bulut et al. analyzed free cooling potential in HVAC system for Istanbul. 10 Turkey Boubekeur Dokkar et al. studied Chimney and underground pipe for optimizing energy in BTS shelter.

2. Free Cooling Potential

The BTS cooling shelter with system is room shown Figure 1. An air conditioner feeds the cool air to the room. The free cooling controller controls the room temperature between 27°C - 32°C. When the atmospheric temperature goes below 27°C, then the air conditioner is switched OFF and free cooling fans starts working. The free cooling potential for the Chennai region for January and May is shown in Figure 2. The values in the graph are obtained using ASHRE equation (A) taking 1200CFM and $T_1$ (the room temperature) as 27°C (80.6°F) and $T_2$ (atmosphere temperature) varying.

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$$\frac{BTu}{Hr} = 1.1 \times CFM \times (T1 - T2)$$

3. BTS Shelter RC Model

Vo(t) - Room temperature °C, Vi(t) - Outside temperature °C, R- Lumped building Equivalent Resistance C-lumped Building Equivalent Capacitance W Hr./°C, P-Air Conditioner /Free cooling capacity in W IL - Equipment Load W, $i_e$ - Shelter(envelope) thermal
load $W$

![Shelter RC Model](image)

Figure 3. Shelter RC Model.

For Co-simulation of Simulink, BCVTB and Energy Plus, the Simulink allows only discrete mode. Hence the discrete model of the RC network is shown in (12) is derived.

\[ v_L(t) = v_0(t) + R i_L(t) \]  \hspace{1cm} (1)
\[ i_L(t) = C \frac{dv_0(t)}{dt} = i_b(t) - (p(t) - i_L(t)) \]  \hspace{1cm} (2)
\[ i_b(t) = \frac{C}{R} \frac{dv_0(t)}{dt} + (p(t) - i_L(t)) \]  \hspace{1cm} (3)
\[ I_b(s) = sCV_0(s) + (P(s) - I_L(s)) \]  \hspace{1cm} (4)

Substituting (4) in (1) we get
\[ V_0(s) = V_0(s) + R(s)CV_0(s) + R(P(s) - I_L(s)) \]  \hspace{1cm} (5)
\[ V_1(s) - R(P(s) - I_L(s)) = V_0(s)(1 + RsC) \]  \hspace{1cm} (6)
\[ \frac{V_0(s)}{V_1(s) - R(P(s) - I_L(s))} = \frac{1}{1 + RsC} \]  \hspace{1cm} (7)

The peak thermal load absorbed by the shelter is calculated for Energy plus simulation. The peak occurs during May about 632.15W. The Equipment load is fixed and taken as 3000W.
\[ I_b + I_L = 632.15 + 3000 = 3632 \text{W} \]  \hspace{1cm} (8)

\[ \frac{dv_0(t)}{dt} = \frac{10^{\circ}C}{HR} \]

To find the lumped capacitance using (2) with $p(t)=0$
\[ i_b(t) = \frac{C}{R} \frac{dv_0(t)}{dt} - I_L(t) \]
\[ C \frac{dv_0(t)}{dt} = 3632 \hspace{1cm} C = 363.2 \text{WH} \]  \hspace{1cm} (9)

To Find lumped Resistance of the shelter $R$ with air conditioner load $p(t)=0$, $i_L(t)=3000W$, $i_b(t)=632W$ with $V_0(t)=27^{\circ}C$ and $V_i(t)=40^{\circ}C$

\[ 3632 = \frac{40 - 27}{R} + I_L \]

\[ R = 0.021 \frac{C}{W} \]

Substituting the value of $R$ & $C$ in (7) we get
\[ \frac{V_0(z)}{V_1(z) - R(P(z) - I_L(z))} = \frac{1}{(7.627s + 1)} \]  \hspace{1cm} (10)

The equivalent Z domain equation (11) is obtained by converting continuous domain (10) to discrete domain in Matlab.
\[ \frac{V_0(z)}{V_1(z) - R(P(z) - I_L(z))} = \frac{0.01303}{(z - 0.987)} \]  \hspace{1cm} (11)

The room temperature equation in discrete model is
\[ \frac{V_0(z)}{V_1(z) - R(P(z) - I_L(z))} = \frac{0.01303}{(z - 0.987)}(V_i(z) - R(P(z) - I_L(z))) \]  \hspace{1cm} (12)

4. Fuzzy Logic Controller Design

A fuzzy controller has been designed using Simulink with design parameters shown in the table IA & IB. The shelter temperature has been classified into three groups. The Simulink diagram fuzzy variable range are shown in Figure 4, 5, 6.

![Free Cooling /Air conditioner Selector](image)

Figure 4. Free Cooling /Air conditioner Selector.

![Fuzzy variable for Room temperature](image)

Figure 5. Fuzzy variable for Room temperature.

![Fuzzy variable for atmospheric temperature](image)

Figure 6. Fuzzy variable for atmospheric temperature.
The temperature range is adopted for facilitating the simulation in discrete modeling and keep the fuzzy controller in the control mode during starting. For deciding the free cooling mode the atmospheric temperature has been classified as TOO_LOW_FC, FREE_COOLING and UNFAVORABLE. This is shown in table IB. The Rule table is shown in table IC. There are two outputs for the fuzzy controller. One is for the air conditioner and the other is for the free cooling fans. The Free cooling fans control range is shown table ID. The table IE shows the air conditioner control range for ON and OFF.

5. Equivalent Models
5.1 RC Model Without Free Cooling (NOFCAC)

This free cooling controller is common for RC model with free cooling system and EP model with free cooling system. Fig. 7 shows the RC model circuit without the free cooling system. The shelter temperature permitted range is 27°C to 32°C. In this case no free cooling system is considered. Only air conditioner is used. The Simulink relay block acts as an air conditioner. The air conditioner gets ON when the temperature reaches 32°C and gets Switches OFF when the temperature reaches 27°C. The air conditioner when ON, feeds the cooling capacity of 5250 W. When OFF feeds 0W to the RC model. This is not an efficient system.

5.2 RC model with free cooling (RCACFC)

The Figure 8 shows the RC model in which the variable P is the free cooling input or air conditioning input. The fuzzy logic controller gives signal to the selector depending upon the atmospheric temperature and room temperature. The selector select the free cooling or AC unit. This model does not consider the variation in the heat absorbed by the shelter envelope. But considers the atmospheric temperature variations (12). The free cooling /AC selector shown in Fig.4 gives the output to the room RC model. The free cooling capacity is worked out using (A) and fed as equivalent watts. In case of air conditioning mode the air conditioner feeds 5250W.

5.3 EP model with free cooling (EPACFC)

In this, the shelter model is defined as .idf file to the energy plus software with the specification of the shelter. The Energy Plus has been interfaced with BCVTB and Matlab. The Energy plus model of the shelter is viewed using Open studio as shown in Fig.10. Fig 11A, 11B shows the simulation, dataflow models and Fig.12 shows the Ptolemy model.

Table 2. BTS Shelter Parameters

| Sr. no. | Parameter          | Value                                                                 |
|---------|-------------------|-----------------------------------------------------------------------|
| 1       | Location          | CHENNAI                                                               |
| 2       | Latitude          | 13.00[DEG]                                                            |
| 3       | Longitude         | 80.18[DEG]                                                            |
| 4       | Elevation         | 16.00[M]                                                              |
| 5       | Gross wall area   | 61[m2]                                                                |
| 6       | Area of shelter   | 17.5[m2]                                                              |
| 7       | Volume            | 52.5[m3]                                                              |
| 8       | Inner sheet material | Galvanized percolated steel 0.8mm thick, conductivity -50.2 W/m-K, density-7850kg/m3, specific heat 450 J/kg-K |
| 9       | Outer sheet material | Galvanized percolated steel 0.6mm thick, conductivity -50.2 W/m-K, density-7850kg/m3, specific heat 450 J/kg-K |
| 10      | Insulation layer  | PU foam 80mm thick conductivity -0.023 W/m-K ,density-40kg/m3, specific heat 1400 J/kg-K |
Energy Conservation for Base Transceiver Station Cooling System with Energy Plus Software

The BTS shelter usually constructed with sandwich insulated panels. The outer and inner material are galvanised precoated sheetsteel covering inside 80mm thick PU foam insulating material. The BTS shelter specified in Table II is modelled in the energy plus software. In the energy plus material, global geometry rule, wall exterior, output schedule, HVAC templates, infiltration etc configured in the .idf file. The Energy Plus automatically incorporates many other factors by default and take parameter from weather data file. The weather data file for Chennai region is configured in the BCVTB. After incorporating all the factor energy plus gives many output in which the sensible cooling load for the shelter is separately taken using External Interface. In the external interface the room temperature set point is set as 27°C for very time step of simulations. For this set point the Energy Plus gives the sensible cooling load of the shelter in watts \( I_b \) for every time step.

\[
V_0(z) = \frac{0.01303}{(z-0.987)} \left( V_0d + I_b R - R(P(z) - I_L(z)) \right)
\]

(13)

\( V_{0d} \) is the shelter design temperature taken as 27°C. Fig. 9 shows the EP (Energy Plus) model. In this model the P indicates the air conditioner or the free cooling output. The equation (13) is used in this EPACFC model. The fuzzy controller selects the cooling unit depending upon the room temperature and atmospheric temperature. But in this model the Shelter heat absorption due to external heat is considered as a separate variable \( I_b \). This Sensible cooling load is received \( I_b \) from the Energy Plus for the room temperature of 27°C. This has been set in the .idf file as set point. The peak value of shelter heat occurs during May about 632W and zero Watts during the month of January. This model is more efficient than the previous models. By considering the variations of \( I_b \), the air conditioner and the free cooling load is optimized. Thus there is energy saving in this model over the other model discussed in Section 5. A and 5. B.

6. Simulation and Discussions

6.1 Peak Winter days Simulations

The Peak winter days for the Chennai region is falls during December 31 to Jan 03. During this period the shelter heat absorption goes to zero on 01 - JANNUARY. Accordingly the simulation are carried out by setting the period in the Energy Plus. For three models the simulation has been carried out. The contribution of free cooling fans during these peak winter days are more in both RC and EP models. Fig.13 Shows room temperature. The energy consumed by various models as shown in Fig.14. The energy consumption are calculated for 1.5TR split air conditioner having cooling capacity 5250W and power consumption with (Energy Efficiency Ratio as 3.3)1590W. The free cooling fans consumption taken as 200W X 2=400W. As seen in the model without free cooling consumes maximum energy 75.17KWH. Whereas the other model consumes 54.02KWH and 53.82KWH. This shows the importance of the free cooling fans.

| Sr.no. | NAME               | DESCRIPTION                         |
|-------|--------------------|-------------------------------------|
| 1     | EPRT               | Room temperature with EP model with free cooling |
| 2     | RCRT               | Room temperature with RC model with free cooling |
| 3     | NOFCRT             | Room temperature with RC model without free cooling |
| 4     | OT                 | Outdoor temperature                 |

Table 3. Legend for Graphs (Temperature)

![Figure 13. Room Temperature for Peak winter simulation.](image)
6.1 Peak Summer Days Simulations

The Fig. 15 shows the room temperature for the peak summer days. In this model the contribution of free cooling system is zero. The air conditioner is operated for most of the time. It is because there is no favorable atmospheric temperature. Fig. 16 shows the energy consumed by various model.

6.2 January and May Month Simulations

Simulation has been carried out for the month of January and May. Which are the peak winter and summer months in the Chennai region.

6.3 Full year Simulations

In order to assess the overall power consumed by the three models full year simulation has been carried out.

As seen from Fig. 17 the model NOFCAC consumes more power than the other two. The EPACFC model gives the lowest energy consumption. The free cooling contribution is slightly higher in the EPACFC model over the RCACFC model. The air conditioner energy consumption also less in the EPACFC over the RCACFC model.

From Fig 17, the EPACFC model consumes 6671 KWH the RCACFC model consumes 6855 KWH. Without free cooling system, NOFCAC model energy consumption
is 7794KWH. The free cooling contribution in EPACFC model is 1076KWH. In case of RCACFC model it is 1064.7KWh. It is due to the accurate calculation of shelter envelope thermal load by Energy Plus. The RC model works based on temperature difference only. During peak winter EPACFC model gives slightly lesser savings over the RC model based control. It is due to the low temperature prevailing in the atmosphere than the room temperature set point. The RC model responses the same. Also when the temperature goes below certain level from the set point the heat absorption by the envelope from atmosphere becomes zero. The energy plus gives zero energy absorption. But the RCFCAC allows the reduction of atmospheric temperature.

During the full year comparison the energy savings of the EPACFC model is 2.69% above than the RCFCAC. The average temperature during simulations are well within specified limit of 27°C to 32°C. The NOFCAC model consumes more energy in comparison to the other two models. Simulation is also carried out for changing the weather file for selected cities. The energy consumption of air conditioner and free cooling system is given the Fig. 18.

6.4 Simulation with Variable Capacity Air Conditioner

All the above simulations are carried out with air conditioner out put as 5250W when ON and 0W when OFF. In order to study the effect of variable capacity air conditioner the simulation has by varying the value of P during the air conditioner mode. For the EPFCAC model shown in Fig. 9 in this, the air conditioner out put P is varied using (14) and for RCFCAC model (15) is used in Simulink.

\[ P = \frac{\partial V_c(t)}{\partial t} + I_L \]  \hspace{1cm} (14)

\[ P = \frac{V_c(t) - V_e(t)}{R} + I_L(t) - \frac{C V_e(t)}{\partial t} \]  \hspace{1cm} (15)

7. Conclusion

The free cooling system is one of the method for conservation of energy in BTS shelter for reducing the air conditioner energy consumption. In this paper we modeled the BTS shelter cooling system as RC circuit from the basic principle. The shelter absorbs heat from atmosphere and which is varying throughout the year. With simple RC model, the heat transfer from atmosphere to inside the room normally considered as linear variation of temperature difference. The Energy Plus model proposed in this paper considers the heat absorbed by the shelter as heat in Watts. Energy plus computes the shelter heat considering various factors such as atmospheric temperature, wind speed, wind direction, construction material, heat absorbed by the surfaces and infiltration etc. The shelter thermal load along with the equipment load used by the fuzzy logic controller, which controls the air conditioner and the free cooling fans. Thus the Energy Plus model based control proposed in this paper has energy saving of 2.69% and 1.37% respectively for fixed and variable capacity air conditioner over the model derived from the basic principles. The over all energy saving is increased from 12.04% to 14.41% by using the EPFCAC control model proposed in this paper with free cooling for Chennai region. A comparison is made for the free cooling control system with same configuration of BTS in select cities. Bangalore region gives more free cooling saving and lesser energy consumption among the selected cities. The EP modeled data based control is having advantages over the temperature based control which can avoid over cooling in the room due to the changing environment. As there are lakhs of mobile shelters available in India, this contribution will be helpful for optimization of energy and reduction of carbon foot print. The proposed model in this paper can be implemented by storing the simulated data of thermal energy of the shelter envelope in the memory of controller as numbered data. Every 15 minutes the controller can read the shelter envelope thermal load from memory and can incorporate controlling the capacity of the air conditioner. The other implementation approach would be by interpolation method. Design and testing of controller will be taken up as future work.

8. References

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