PCM Augumented Composite Wall for Base Transceiver Station (BTS) for Telecom Towers

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PCM AUGUMENTED COMPOSITE WALL FOR BASE TRANSCEIVER STATION (BTS) FOR TELECOM TOWERS

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Abstract-Latent heat storage system is one of the most efficient ways of storing thermal energy. The present work employs a composite wall augmented with PCM for use in (Base transceiver station) BTS for telecom towers. An insulated cabin having dimension 0.5*0.5*0.6 m^3 employing PUF insulated walls with thickness 0.050 m has been made. One inner surface of the wall has been augmented using PCM, which works as a composite wall. High density polyethene (HDPE) bag is used as encapsulation material. Experiment is performed in shelter & solar radiation climatic condition by varying mass of the PCM. The tests are conducted by providing constant heat source inside the cabin till its inside temperature reaches form 25 to 35ºC for 3 condition (1) Composite Wall without PCM (2) Composite wall with 3mm layer of PCM, (3) Composite wall with 5mm layer of PCM. In this study $CaCl_2.6H_2O$ is used as PCM which has melting point is 30ºC and freezing point is 24ºC. First order implicit method is adopted to solve three dimensional composite wall in FLUENT 15.0 Simulation results are validated against experiment.

Keywords: *Latent heat, Base Transceiver Station, Phase change material, encapsulation, Liquid fraction.*

Nomenclature

Q	Heat flux per unit area	W m^{-2}
T	Temperature	ºC
t	Time	Second
ρ	Density	Kg m^{-3}
H	Static enthalpy	KJ Kg^{-1}
c_p	Specific heat	KJ $Kg^{-1}K^{-1}$
h_{sky}^{r}	Irradiative heat transfer co-efficient	W $m^{-2}K^{-1}$
h_i	Inside heat transfer co-efficient	W $m^{-2}K^{-1}$
h_o	Outside heat transfer co-efficient	W $m^{-2}K^{-1}$
X	Thickness of layer	m
K	Thermal conductivity	W m-1K-1
σ	Stefan-boltsmann constant in	W m-2K-4
I	Intensity of radiation	W m-2

I. Introduction

Latent heat storage system with phase change materials (PCMs) has higher energy storage density while requiring smaller masses and volumes of material. [6]

Telecommunications networks are critical infrastructure that needs assured power supply 24x7. India has more than 4 lacks telecom towers which form the backbone of its telecom market. The base stations are on rooftops of buildings in the cities, and at the bases of remotely located towers in rural areas. [15, 16]. Due to an unreliable electrical power grid, tower infrastructure companies use diesel generators, batteries and a variety of power management equipment to back-up the grid and ensure network availability. In excess of 2.6 billion liters of diesel is consumed by diesel generators at telecom towers annually to meet the energy demand-supply gap, emitting 7 million metric tonnes of CO_2. [17, 18].

In review work of Atul Sharma et al. and Adeel Waqas et al. [2,3], explained different applications of PCM in thermal energy storage Systems. M.J. Huang et al. [4] numerical investigated and analyzed the temperature regulation effects resulting by incorporation of PCMs in a building cavity wall. S. Mozhevelov et al. [9] investigate performance of room in which paraffin wax (T_m = 22 to 24°C) is used as an energy storage unit and during this experiment outside atmospheric condition is considered as a desert region. In order to investigate the performance of PCM and PCM plus insulating material for summer & winter climatic condition on room, an experimental setup was constructed by Yeliz k. et al. [8].

An experimental work on the passive cooling in building facades in hot humid climates with the use of composition of paraffin wax (m = 26ºC) and copper foam is explained by Mohd Hafizal et al. [14]. An experimental, mathematical and numerical model is developed by Xiang fei et al. [5] for understanding the behaviour of PCMs on inside & outside of the wall in the room. It is proved that the relative maximum and average errors were both less than 5% from relative error analysis method.

Xing Jin et al. [6] analyzed the effects of different state of PCM location on the thermal performance of building walls. Differential scanning calorimeter (DSC) tests and the cooling experiments were performed to analyzed the performance of PCM. Numerical study of heat transfer from PCM incorporated composite wall is explained by L. Derradji et al. [12]. Enthalpy based numerical formulation was described by an equation of heat transfer. The equation is solved by an implicit method of finite differences. Mustapha Faraji [13] numerically investigated of solar heat storage in PCM incorporated composite wall which is made of two alternative layer of PCM and two layer of cement.

Numerically analyses is done by I. Behunek et al. [14] on phase change behavior of $CaCl_2.6H_2O$. Analytical solution on melting and solidification of CaCl2.6H2O in 1D model and Numerical model was solved by FEM/FVM in ANSYS software.

In the present work, an insulated cabin made from PUF insulated walls. One inner surface of the wall has been augmented using $CaCl_2.6H_2O$, which works as a composite wall. The feasibility of temperature moderation inside the room using a phase-change material, which is stored in storage units, is studied numerically. Experiment is performed in shelter & solar radiation climatic condition by varying mass of the PCM. Dynamic measurement of wall for three different cases i.e., (1) Wall without PCM (2) wall with 3mm layer of PCM, (3) wall with 5mm layer of PCM is analysed.

In the next section, the physical model is introduced. Then, the numerical approach is described and its verification is presented. Finally, the results are presented and discussed.

II. PHYSICAL MODEL

A. Phase change material.

In this study $CaCl_2.6H_2O$ (T_m = 30ºC) is used as PCM. Thermal analysis of $CaCl_2.6H_2O$ is done on Differential scanning calorimeter (DSC) [14]. White Crystal foam of $CaCl_2.6H_2O$ is shown in figure 1 and properties of PCM is shown in table I.

TABLE I. PROPERTIES OF $CaCl_2.6H_2O$.

Properties		Value (unit)
Melting Point		29ºC
Freezing point		24ºC
Latent heat		190.8 KJ/Kg
Density	Solid	1710 Kg/m^3 (at 25ºC)
	Liquid	1562 Kg/m^3 (at 32ºC)
Thermal conductivity	Solid	1.09 W/m K (at 23ºC)
	Liquid	0.54 W/m K (at 38ºC)
Specific heat	Solid	1.4 KJ/ Kg K (at 24ºC)
	Liquid	2.1 KJ/ Kg K (at 32ºC)

Fig. 1 Crystal foam of $CaCl_2.6H_2O$ in the biker.

B. Preparation of Macro-encapsulation with PCM.

In actual condition it very difficult to hold PCM. For that Macro encapsulation container is used for holding of PCM. Figure 2 shows High density polyethylene (HDPE) bag is used as encapsulation container for holding PCM. HDPE bad has thermal conductivity, Density & Specific heat is 0.48 W/ m K, 959 Kg/m^3, 1.850 KJ /Kg K, respectively. One bag has dimension of 0.130*0.160*0.005 m^3.

PCM filled Macro encapsulated bag is assembled to the wall from the following steps:

1. HDPE bag is filled with PCM and sealed it in such manner that no air bubble is stayed in the bag.
2. That PCM filled bag is mounted to the wall with help of Adhesive material (Vetra Gel) in such way that whole the wall is covered with the PCM material.

PCM filled macro-encapsules

Fig. 2 PCM augmented composite wall.

C. Test Cabin

Figure 3 shows single PUF wall & Insulated cabin. PUF wall is made from Polyurethane foam material. PUF is insulating material which is kept in between two pre painted galvanized sheet. The dimension of the cabin was 0.5*0.5*0.6 m^3 and thickness of wall is 50 mm. Cabin was oriented north-west direction during the experiment. One circular duct has diameter of 0.010 m is provided for supplying cold air inside the cabin with help of 1.5 tonnes L.G window air condition.

Fig. 3, (a) Insulating PUF wall (b) Insulating test cabin

D. Measurements

Temperature is recorded by sensor (PT-100 type of thermocouple) at the following location inside and outside of the cabin:

1. North-west internal wall (T_1)
2. North-west outer wall (T_2)
3. Outside for ambient temperature (T_3)
4. At the center of the cabin (T_4)

The accuracy of the sensor was ± 0.3ºC. Data from the sensors were dynamically recorded using a data acquisition system (Agilent Make 34980A LXI Data Acquisition Switch with LAN). To see the influence of a PCM augmented composite wall on the cabin panel of temperature distribution, experiments carried out in Shelter and solar radiation climatic condition for the following cases:

1. Composite wall without PCM
2. Composite wall with 3 mm PCM layer.
3. Composite wall with 5 mm PCM layer.

In center of cabin there is one electric bulb which work as heat source inside the cabin and rating of bulb is 60 Watt. Experiment is perform for 2 different atmospheric temperatures i.e., (1) T_a=30ºC (2) T_a=40ºC in shelter and radiation condition.

For carrying out Experiment, initially experiment is performed without PCM wall inside the cabin and during this process inside temperature is maintained 25ºC with help of A.C for 1 hour. During that period A.C is working as heat sink and Bulb working as heat source. After 1 hour A.C is turn off so there is only heat source inside the cabin and no heat sink. Measured the time for increasing temperature of cabin from 25ºC to 35ºC. Now perform same experiment by replacing without PCM wall with 3mm & 5mm PCM augmented composite wall. In both case when A.C is turn off, PCM is working as heat sink and Electric bulb working as heat source. So it takes more time to increase the temperature of cabin form 25ºC to 35ºC compared to without PCM cabin. During this experiment temperature measure for 4 different place in cabin and melting behaviour PCM is observed.

When cold air supplied inside the cabin, PCM is solidify because of decreased in temperature. After 1 hour, stopped the supply of cold air and turn on heat source. During that period PCM is worked as Heat sink and absorbed the heat. By doing that PCM maintained inside cabin temperature for longer period of time compared to without PCM inside the cabin. When this experiment is performed in shelter condition PCM is mostly absorbed inside heat and in solar radiation condition PCM is absorbed inside as well as outside heat of the cabin.

III. NUMERICAL STUDY

A. Heat transfer equation for the composite wall

The numerical model includes all the processes described above: the transient heat conduction inside the walls, free convection of air, and radiation inside the room, conduction and phase change inside the storage units. The numerical calculations are performed to simulate the melting fraction inside the PCM by using the FLUENT 15.0 software, The energy transport in composite wall may be written using the enthalpy formulation [3],

$$\frac{\partial H}{\partial t} = \nabla(K\nabla T), \qquad (1)$$

In the above equation the total volumetric enthalpy (H) is the sum of the sensible and latent heats of the PCM and is related to the temperature of the PCM as follows,[3]

$$H(T) = \rho_{PCM} C_{PCM}(T_{PCM} - T_m) \ (T_{PCM} < T_m) \qquad (2)$$

Or

$$H(T) = \rho_{PCM} C_{PCM}(T_{PCM} - T_m) + \lambda\rho_{PCM} (T_{PCM} > T_m) \qquad (3)$$

Temperature of PCM is calculated from below equation [3],

$$T_{PCM} = T_m + \frac{H}{\rho_{PCM} C_{PCM}} \ (0 < H) \qquad (4)$$

$$T_{PCM} = T_m \ (0 < H < \rho\lambda) \qquad (5)$$

$$T_{PCM} = T_m + \frac{H - \lambda\rho_{PCM}}{\rho_{PCM} C_{PCM}} (H > \rho\lambda) \qquad (6)$$

Value of Liquid fraction of PCM is between 0 to1. If PCM is in solid phase at that time L.F=0, if it’s in liquid phase at that time L.F=1.

Liquid fraction of PCM is calculated from bellowed equations [3],

$$L.F(H) = 0 \ (H \le 0, \text{ solid phase}) \qquad (7)$$

$$L.F(H) = \frac{H}{\rho_{PCM}\lambda} \ (0 < H < \lambda\rho_{PCM}, \text{ musty region}) \qquad (8)$$

$$L.F(H) = 1 \ (H > \lambda\rho_{PCM}, \text{ liquid region}) \qquad (9)$$

Figure 4 & figure 5 shows the boundary condition are used for PCM augmented wall of the cabin. Outside wall time depend ambient temperature and heat transfer co-efficient are prescribed. The air temperature is taken according to the experimental data which reflect usual evolution of the daily temperature in April.

B. Simulation process

Pressure – based, absolute velocity formulation option was selected under solver part. The simulation process takes place under transient condition. Volume of fluid model under multiphase model & solidification/ melting model is kept on. The solution is also checked at 1, 0.5, 0.1 & 0.01 sec, but the solution was the same after 0.5 sec. The time step size for the solution was set to 0.5 s. In order to satisfy convergence criteria, the number of iterations for every time step was set to 100. The PISO scheme was adopted for pressure correction equation whereas the second order upwind scheme was adopted for momentum & energy equations.

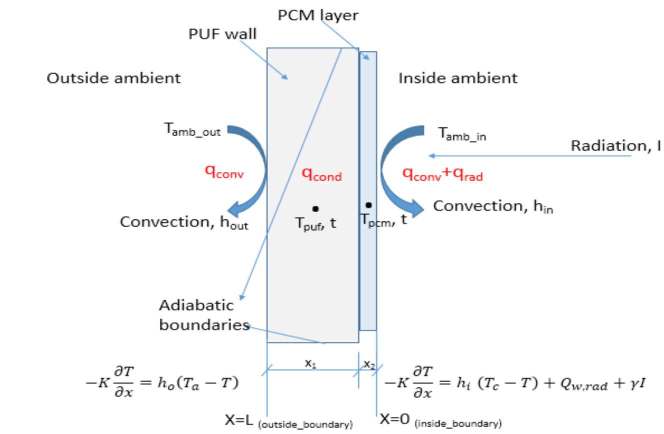

Fig. 4 Heat transfer mechanism in composite wall of Cabin When it is worked as BTS in shelter atmospheric condition

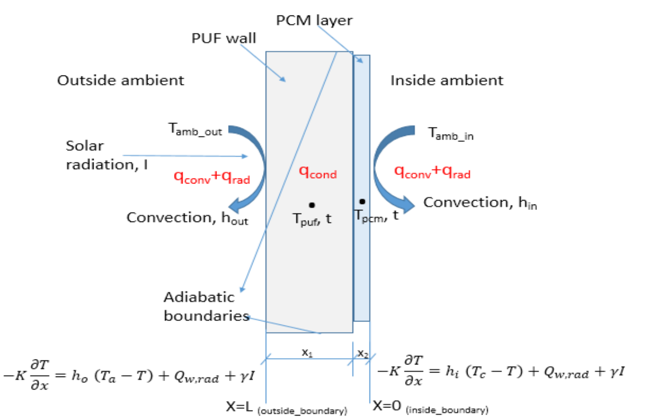

Fig. 5 Heat transfer mechanism in composite wall of Cabin When it is worked as BTS in solar radiation atmospheric condition

IV. RESULT & DISCUSSION

A. Empty cabin measurement

In order to compare the measurements inside the test cabin for the two cases described above, the outdoor temperature distribution for each case must be similar. Therefore, outdoor temperature measurements during the test period in April 2015 was analyzed. Solar radiation values for the chosen days are taken from the ISRRE (Institute of Studies and Research in Renewable Energy, Gujarat) for Calculation purpose. Data got from the ISRRE shows that there no variation in the outside temperature so outside temperature tacking constant with respect to time.

Experiment is performed on insulated cabin with and without PCM on 14/4/2015 to 19/4/2015. For parametric study Cabin considered with 3 mm inner side PCM Layer, 5mm inner side PCM layer & without PCM layer in shelter (solar radiation does not exposed to cabin) and solar radiation (solar radiation is exposed to cabin) climatic condition. Comparison melting fraction of PCM, energy storage in PCM and its effect on reduction of room temperature in various condition were observed

B. Shelter condition measurement

Test cabin was run with and without PCM on 14th & 15th April 2015 during day. Comparison of room inside temperature and PCM Temperature was measured for following two different sets.

Table II shows the change in the inside temperature of cabin & Temperature of PCM when outside atmospheric temperature (T_a) is 30^{o}C and 40^{o}C, respectively. For maintaining room inside temperature from 25 to 35 ^{o}C in without PCM, with 3 mm PCM, with 5 mm cabin tacks 11 min, 16 min, 15 min, respectively when T_a = 30^{o}C and it tacks 10 min, 15 min, and 15 min for the same when T_a = 40^{o}C. When PCM inside the cabin, cabin tacks average 6 min more for maintaining room inside compared to without PCM. Cabin with 3 mm PCM Layer Composite wall maintained inside temperature for longer period time compared to wall with 5 mm PCM. So it is observed that cabin has a 3 mm PCM augmented composite wall gives best performance compared to 5 mm PCM wall in shelter atmospheric condition.

C. Solar radiation measurement

Test cabin was run with and without PCM on 18th & 19th April 2015 during day and data were collected in solar radiation climatic condition. Comparison of room inside temperature and PCM Temperature was measured for following two different sets.

Table II temperature variation of PCM when cabin is performed experiment in two different solar radiation atmospheric condition i.e., (1) T_a = 30^{o}C & (2) T_a = 40^{o}C. For maintaining room inside temperature cabin tacks 09 min, 12 min, 14 min in without PCM, with 3 mm PCM, with 5 mm respectively when T_a = 30^{o}C and it tacks 08 min, 12 min, 14 min for the same when T_a = 40^{o}C. So time required for maintaining room Temperature is average 2 min more in 5mm PCM case compared to 3 mm PCM in both the atmospheric condition so it is more suitable to use of 5 mm PCM layer wall instead of 3 mm PCM layer.

Figure 6 & figure 7 shows the comparison of melting fraction of PCM when cabin is worked under shelter and solar radiation climatic condition. At t = 16 min melting fraction is 0.612 & 0.428 in shelter and solar radiation climatic condition respectively. Melting fraction is more in case of solar radiation condition because PCM is absorbed heat from outside as well as from inside of the cabin.

TABLE II OBSERVATION DONE WHEN CABIN IS WORKED AS BTS IN SHELTER CONDITION

Outside climatic condition	Outside Temperature	Time (min) required to maintain inside temperature.		
		Without PCM layer	With 3 mm PCM layer	With 5 mm PCM layer
Shelter	T_a = 30°C	11 min	15 min	16 min
	T_a = 40°C	10 min	15 min	15 min
Solar radiation	T_a = 30°C	9 min	12 min	14 min
	T_a = 40°C	8 min	12 min	14 min

D. validation of results

Figure 8 shows experimental and simulated result of Liquid fraction (at t = 16 min) is 0.401 & 0.428 in Shelter climatic condition while it is 0.586 & 0.612 in solar radiation climatic condition. Average percentage of difference between experimental and simulated result is 6% and 4% of liquid fraction values in shelter and solar radiation condition respectively. Figure 9 shows experimental and simulated result of stored energy at t = 16 min. Average percentage of difference between experimental and simulated result is 5.3 % and 1.7 % of stored energy values in shelter and solar radiation condition respectively.

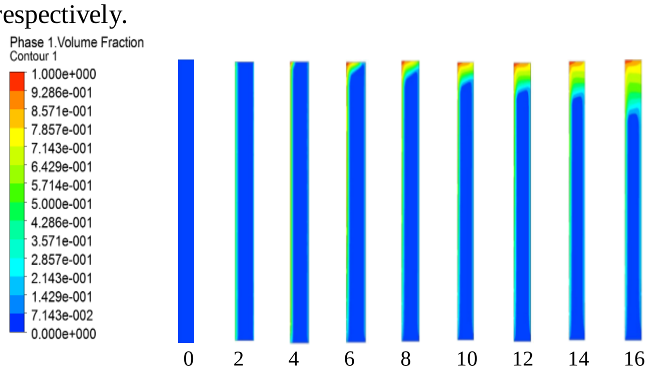

Fig. 6 Contour of Volume fraction (Liquid fraction) of PCM in shelter climatic condition.

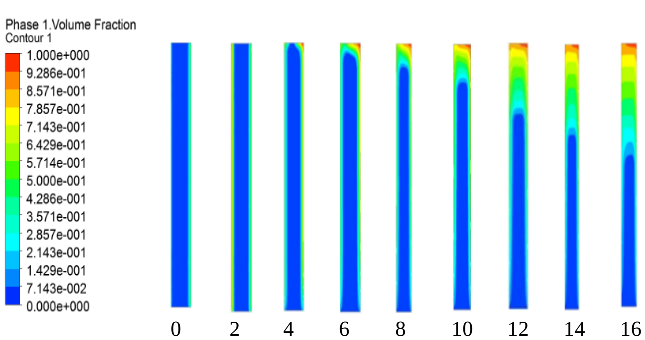

Fig. 7 Contour of Volume fraction (Liquid fraction) of PCM in solar radiation climatic condition.

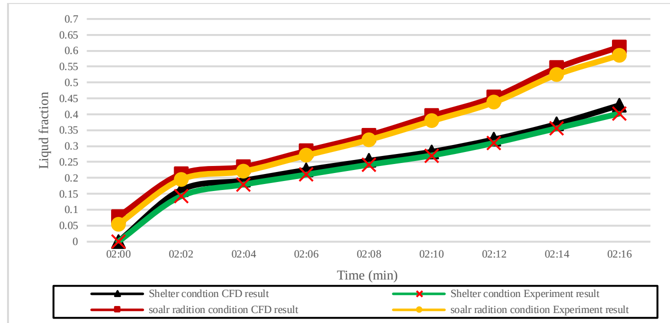

Fig. 8 Validation of experimental result with simulation result for liquid fraction of PCM when Cabin is considered as BTS

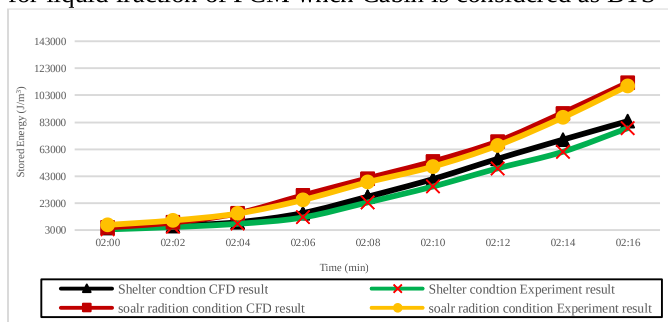

Fig. 9 Validation of experimental result with simulation result for stored energy in PCM when Cabin is considered as BTS.

CONCLUSIONS

The influence of using a PCM in an insulated cabin in actual Shelter & solar radiation atmospheric conditions was tested. Temperature can be maintained for longer period of time by using PCM inside the cabin. Composite wall with 3 mm PCM layer performed well When Cabin is in Shelter climatic condition. While cabin in solar radiation condition 5 mm PCM layer composite wall gives best results.

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REFERENCES

1. Mohammed M. Farid, Amar M. Khudhair, Siddique Ali K. Razack, Said Al-Hallaj, “A review on phase change energy storage: materials and applications” (Energy Conversion and Management 45 (2004) 1597–1615).
2. Atul Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, “Review on thermal energy storage with phase change materials and applications”. (Renewable and Sustainable Energy Reviews 13 (2009) 318–345).
3. AdeelWaqas, Zia Ud Din, “Phase change material (PCM) storage for free cooling of buildings—A

review" (Renewable and Sustainable Energy Reviews 18 (2013) 607–625).

4. M.J. Huang_, P.C. Eames, N.J. Hewitt, "The application of a validated numerical model to predict the energy conservation potential of using phase change materials in the fabric of a building" (Solar Energy Materials & Solar Cells 90 (2006) 1951–1960).
5. Xiang fei Kong, Shilei Lu, Yiran Li, Jingyu Huang, Shangbao Liu, "Numerical study on the thermal performance of building wall and roof incorporating phase change material panel for passive cooling application" (Energy and Buildings 81 (2014) 404–415).
6. Xing Jin, Shuanglong Zhang, XiaodongXu, Xiaosong Zhan, "Effects of PCM state on its phase change performance and the thermal performance of building walls" (Building and Environment 81 (2014) 334 to 339).
7. Mohd Hafizal Mohd Isa, Xudong Zhaoand Hiroshi Yoshino, " Preliminary Study of Passive Cooling Strategy Using a Combination of PCM and Copper Foam to Increase Thermal Heat Storage in Building Façade" (Sustainability 2010, 2, 2365-2381)
8. Yeliz Konuklu, Halime Ö. Paksoy, "Phase Change Material SandwichPanels for Managing Solar Gainin Buildings" (Journal of Solar Energy Engineering, November 2009, Vol. 131 / 041012).
9. S. Mozhevelov, G. Ziskind, R. Letan, "Temperature Moderation in a Real-Size Room by PCM-Based Units" (Journal of Solar Energy Engineering MAY 2006, Vol. 128).
10. Maciej Jaworski, "Thermal performance of building element containing phase change material (PCM) integrated with ventilation system - An experimental study" (Applied Thermal Engineering 70 (2014) 665 to 674).
11. Ajeet Kumar RAI, Ashish KUMAR, " A review on phase change materials & their applications" (IJARET, Volume 3, Issue 2, July-December (2012), pp. 214-225)
12. L. Derradji, Hamid, B. Zeghmati, M. Amara, A. Bouttout, " study of heat transfer from a wall incorporating a phase change material" (EPJ Web of Conferences, 44 02001 (2013))
13. Mustapha Faraji, "Numerical computation of solar heat storage in phase change material/concrete wall" (international journal of energy and environment Volume 5, Issue 3, 2014 pp.353-360)
14. I. Behunek, T. Bachorec, and P. Fiala, "Properties and Numerical Simulation of $CaCl_2.6H_2O$ Phase Change" (piers online, vol. 2, no. 6, 2006).
15. Report on, "Green solution for telecom tower: part-1" (March 2013).
16. Report on, "Power system considerations for cell tower applications", by Wissam Balshe, (2011).
17. Report on, "Energy statics in 2013"
18. Report on, "Powering Cellular Base Stations" by Ashok Jhunjhunwala, Bhaskar Ramamurthi, Sriram Narayanmurthy, Janani Rangarajan, Sneha Raj.