International Journal of Innovation Engineering and Science Research

Open Access

The effect of using solar chimney on reduced heating load in cold climate of US

Mohammadmehdi Danesh,
PhD student in Architecture, Texas A&M University

ABSTRACT

In a plethora of countries, buildings are adapted to the local climate condition using sustainable architecture techniques and materials, thereby the highest level of climatic comfort is provided. For example, the walls and roofs reflecting sunlight have been used for centuries in the warm regions of the world, while in the cold regions, the maximum use of solar energy has been tended.

The process of modernization has created a high density, thereby demand for fast and affordable constructions in cities has subsequently increased, resulting in reduced attention to environmentally sustainable architecture techniques that, in turn, has led to the financial loss and scarcity of non-renewable energy resources over long periods of time.

Regarding the energy crisis and the necessity of saving non-renewable energy, the reduced need to use heating/cooling systems is assumed to be one of the key goals in advanced building design.

The present study was conducted based on causal research and simulation. Design Builder thermal simulation software was used as the tool to this end. Therefore, a building with/out solar chimney was modeled and analyzed to identify the effect of solar chimney on the amount of energy used for heating.

The interior temperature of the building equipped with solar chimney and without mechanical heating systems was measured to be 22 °C. Given the ambient humidity of 40-60 percent (according to the field measurements), the measured temperature is within the comfort range. In comfort condition, regarding the ambient humidity of 40-60 percent, the comfort temperature is between 70-80 °F (22-26 °C)

Keywords: solar chimney, cold climate, reduced heating load

I. Introduction

In a plethora of countries, buildings are adapted to the local climate condition using sustainable architecture techniques and materials, thereby the highest level of climatic comfort is provided. Increasing demand for housing has created a high density, therefore the need for fast and affordable constructions in cities has subsequently increased as well, resulting in reduced attention to issues like shortage of skilled worker (Escamilla et al., 2018), environmental sustainability, and energy efficiency. This, in turn, has led to the financial loss and scarcity of non-renewable energy resources over long periods of time (IEA, 2013).

The first study on solar chimneys was conducted by Bansal and colleagues in 1993. Using a mathematical model, they proved that solar chimney and correct design of the respective system may increase ventilation (Bansal et al., 2011). Comparing solar chimney and its conventional counterpart, Afonso and Oliveira (2010) confirmed the impact of sun's energy on the increased ventilation. As they suggested, solar chimney may effectively improve ventilation. They have also proved that increased thermal mass may reduce ventilation throughout the day and increase it during the night. Buchair (2011) investigated the optimum cavity width in a solar chimney and observed that in Algeria the optimal width is H /10 (H is the height of the chimney). Charvat et al. (2013) showed that high thermal mass may increase air velocity and consequently ventilation power at night. They also demonstrated that using solar chimney during day may increase air velocity by 25 percent. Punyasompun and colleagues (2009) experimentally and numerically examined the performance of solar chimney in a multi-storey building in Bangkok.They presented two small-scale models of a three-storey building and compared two possible states, i.e. one where each floor has a separate SC channel and one where three floors are connected to a common SC channel. They finally concluded that the latter, i.e. a common SC channel for the whole building, may have a better performance.

Khedari and colleagues considered different types of solar chimneys and concluded that they have effective role in producing airflow. The performance of solar chimney in office buildings equipped with air conditioning were also studied in this research. It was conclusively found that daily electricity consumption of ventilation devices may decrease due to using solar chimney (Khedari et al., 2010).

Sudaporn and Bundit have experimentally investigated the impact of solar chimney with and without a wetted roof on enhanced indoor ventilation. They reported that depending on the ambient temperature and the amount of solar radiation, the outdoor chimney can reduce the indoor temperature by 1–3.5 degrees (Sudaporn&Bundit, 2014).

Today, considering the increasing importance of energy in the world, many studies have been focused on energy-efficient buildings design and construction (Rabah, 2011). Using solar energy to heat homes in the winter has been traditionally known as a solution in all parts of the world (Bodach et al., 2014). Today also using inactive solar systems can play an important role in reducing energy consumption in the world and preserving the environment (Tahersimaet all, 2017). These systems include using, whether directly or indirectly, solar radiation such as greenhouse system, double-glazed system, or solar chimney having been taken into account in this study (Chandel et al., 2015)

This technique has been used in building construction in many countries. For example, more than 100 buildings have been constructed in the western parts of India in Himalayan mountain ranges(Chandel et al., 2012).

In the following, the way of using solar chimney system is presented. Firstly, a building, here a school, was chosen as a sample in the cold region to be simulated by Design Builder energy analysis software and then results were subsequently analyzed.

Just like other strategy used in education, the division of labor has much importance in the industry with respect to productivity (Escamilla et al., 2018), Building industry also needs new strategy to reduce energy consumption in this sector.

II. Research method

The present study was conducted based on causal research and simulation. The best and also the most convincing way to create a causal relationship is a precise experiment where the impact of latent variables is controlled as well. Accordingly, a simulation was conducted using thermal software to identify the temperature effect of solar chimney system embedded in the southern part of an educational building in addition to observe other climatic principles in the project.

The validity of the Design Builder software has been proved in previous research.By using Virtual Simulation Game, energy consumption could be simulated. By visiting the main page of the software web page, it can be seen that the results presented by the software simulations have been validated and totally recognized by the United Kingdom's decision-making bodies through entering the climate characteristics of different areas (Design Builder 2015)

To achieve the research purpose and asses the effect of solar chimney on increased efficiency of modern buildings, the plan of a school in the cold city of Bojnourd was considered as the sample.However, this mean has some flaw such as technical difficulty like low speed and limit options.

III. New methods of increasing energy efficiency in the world

In addition to the all requirements of indigenous architecture, today there are other new techniques to better adapt buildings to the climate conditions, decrease non-renewable energy consumption, and reduce environmental pollutants production (Tahersima et all, 2017). In cold climates, these

techniques called inactive heating systems may emphasize the storage of solar radiation in different ways. Some of these methods include: (1) absorption of direct sunlight, as illustrated in Fig. 4; (2) absorption of indirect sunlight, as illustrated in Fig. 5; (3) greenhouse, as illustrated in Fig. 6; and (4) solar chimney system, as illustrated in Fig. 7 (Holloway, 2011).
This study was focused on solar chimney and its effects.

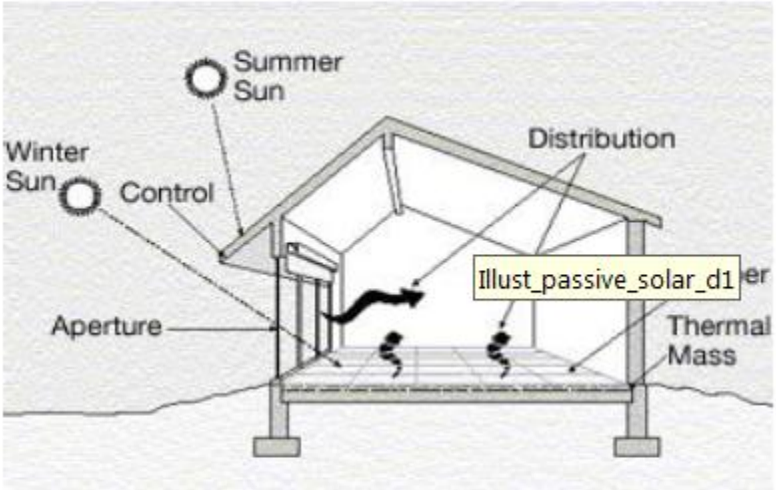

Fig. 1: Internal gain of solar radiation

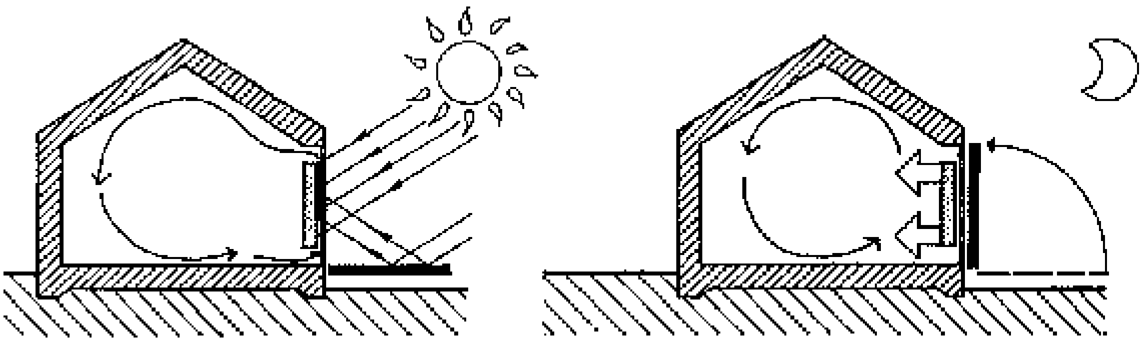

Fig. 2: Using of indirect solar radiation

The greenhouse method is in fact the same traditional solution of covering south-facing balconies with glass or nylon (Fateh, 2010). In this technique, the greenhouse environment absorbs heat during the day, while during the night, absorbed waves with longer wavelength as the result of sequential reflections fail to exit due to the existing glass walls. In other words, the greenhouse acts like a heat-saving source at night (Tahersimaet all, 2018).
Greenhouse can be either freestanding or attached to another structure to grow plants (Holloway, 2011).
In the sample plan, in addition to being used for plant cultivation and maintenance, the greenhouse added to the space flexibility with an appropriate attachment.

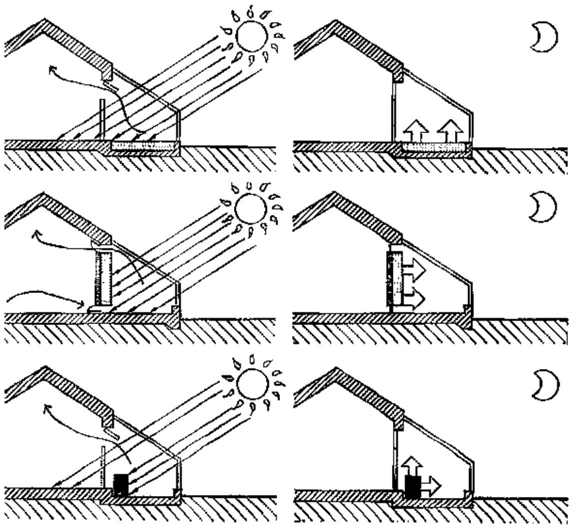

Fig. 3: Greenhouse strategy to warm the user space

Solar chimney is a system contributing to the air ventilation owing to chimney function. A simple solar chimney can be made out of a black tube (to absorb more solar energy) with suitable diameter a few meters above roof level(Tahersima, 2017). A thermal mass helping to retain heat for some time after sunset is used within these chimneys. Apart from being installed on the roof, this chimney can be installed on either the wall facing the Equatoror a separate surface higher than the roof level.
The solar chimney has a dual cooling-heating function. That is to say, when the vent in the upper level of the building is open, natural ventilation can be created by allowing warm air to escape to the outside, conversely, when the vent is closed, warm air captured in the chimney can be drawn into the building (Holloway,2011).

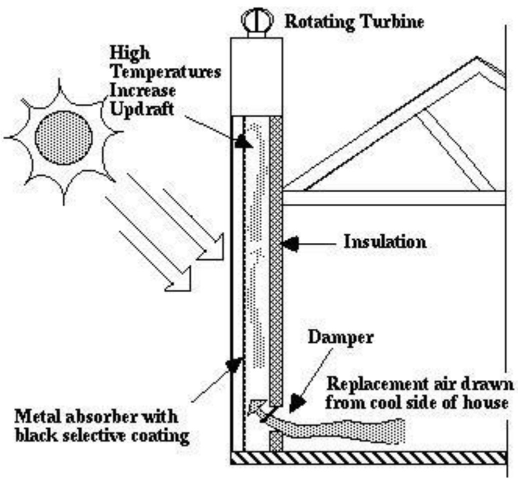

Fig. 4. solar chimney strategy to warm the user space

IV. Utilization of solar chimney system in cold climate

A residential complex plan in a cold climate has been considered to achieve the research purpose and investigate the effect of solar chimney on enhanced energy efficiency of buildings. The chosen sample is located in Shiraz, Fars province. It should be noted that in this research only a part of the complex facing southern has been modeled and studied. Fig. 8 shows the position of the solar chimney in the sample building.

4.1. Plan features in energy productivity

As shown in Fig. 8, East-West elongation of the building may result in the maximum use of southern sunlight in the winter (MozafariTorshizi&TaghizadehKurdi, 2005).

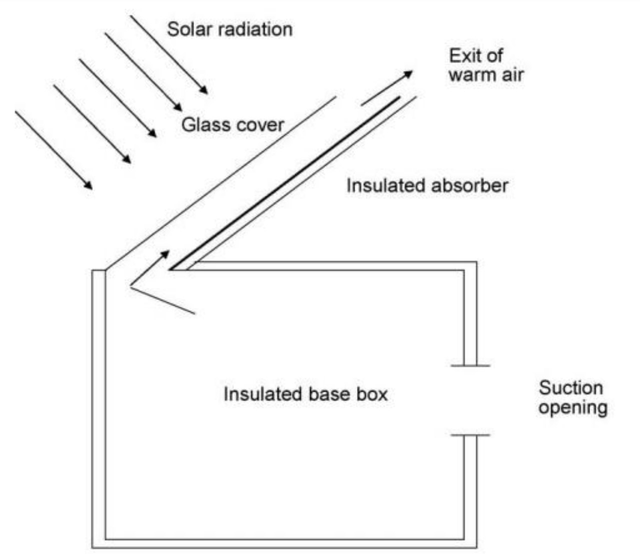

Fig. 5: The building, which use solar chimney to warm user space, is used for simulation (Mathur et al, 2006)

In the Southwest-facing wall of the building, a solar chimney system is used to save solar energy. Closed wooden shutters in summer may keep out sunlight. Installing solar panel on the sloped roof of the building may provide electrical energy required for the building by saving solar energy.Storing fragile material like glasses, Glass has been used in construction since approximately 2000 years ago.

The solar chimney is heated up in the winter with solar radiation, and transmits heat through the lower and upper vents to the interior. Vertical wooden shutters will also help the reflection of radiation and its entry into the building. In the winter nights, the absorbed heat will be trapped if shutters are closedhence the space acts as a source of heat. The interior materials of this space are mainly chosen fromhigh thermal capacity materialslikemud mortar with cement hardness that is mainly used for the inner liner of the solar chimney,

V. Modeling and analyzing the research sample using Design Builder's Energy Analysis Software

In this section, the results yielded from sample modeling with the features described in Design Builder software are presented.

As demonstrated in Figs 9 and 10, the indoor temperature is estimated to be 22 °Cwithout using mechanical heating systems.

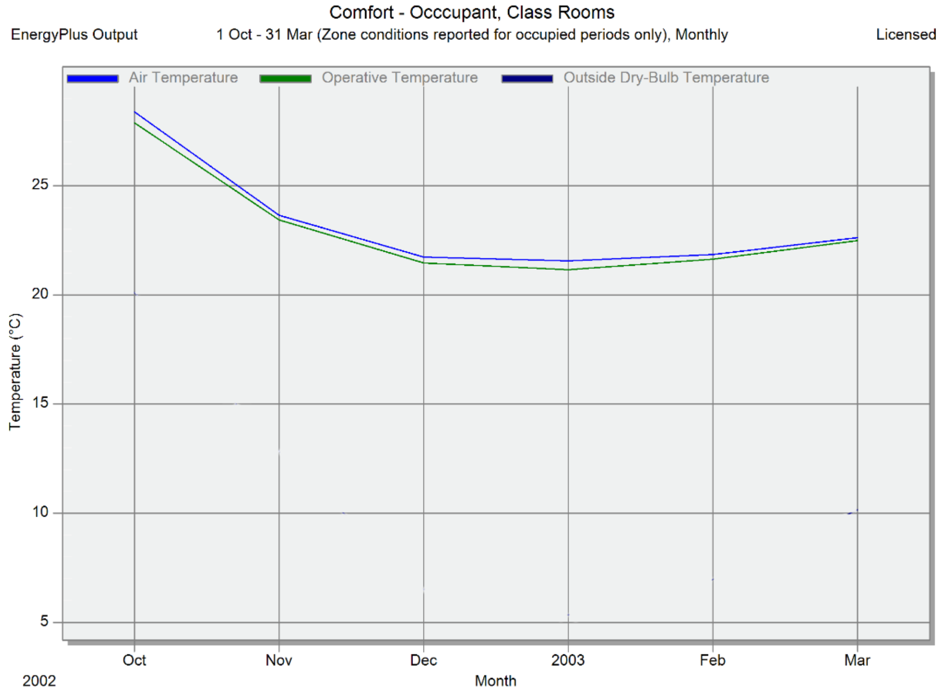

Fig. 6: The temperature of outside the building

Fig. 10 shows the flow of warm air generated by the applied system. As seen, average indoor temperatureis 22 ° C.

As seen in Fig. 11, given the fact that humidity of the environment is between 40-60 percent (based on the field measurements), this temperature is within the comfort range. In comfort conditions, with an ambient humidity of 40-60 percent, the comfort temperature will be between 70-80 °F (22 to 26 °C).

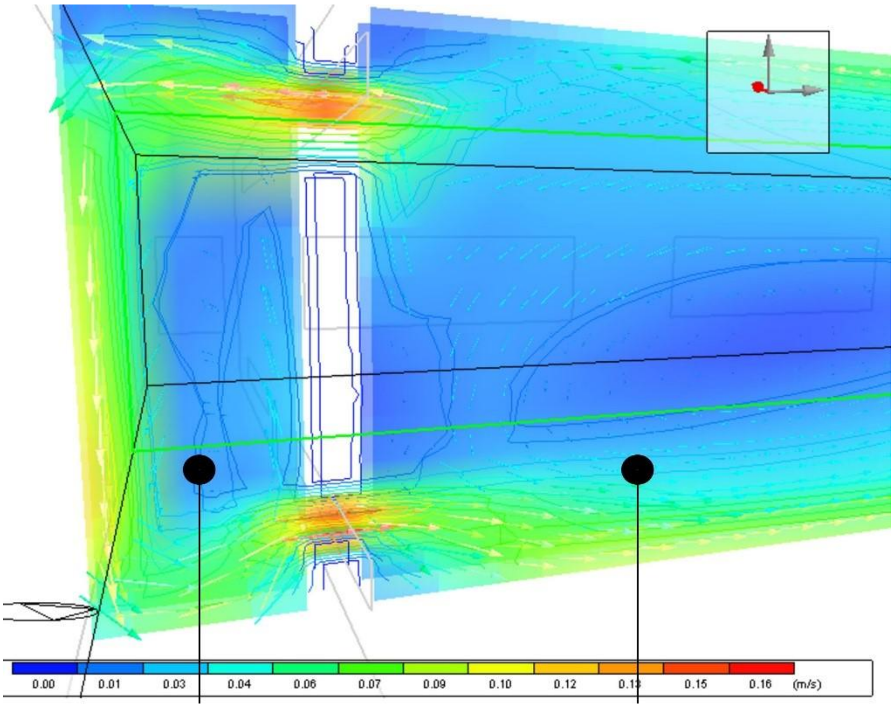

Fig. 7: Air flow in the user's space

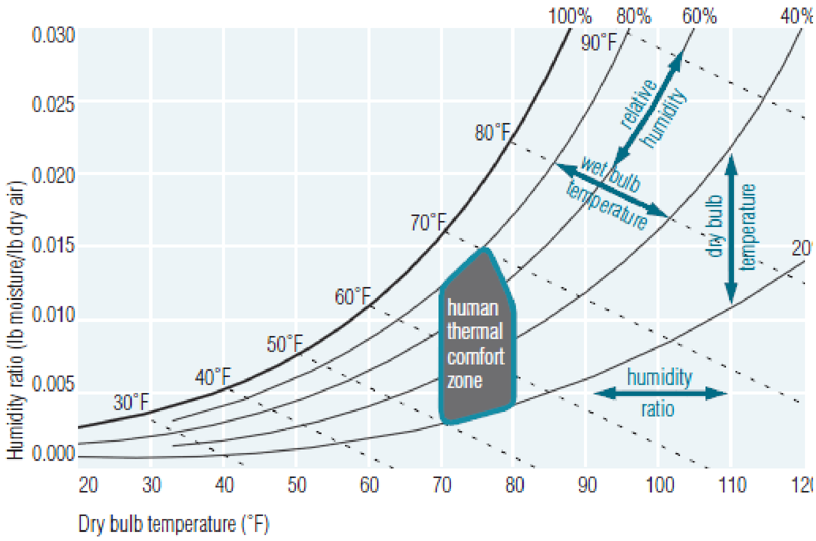

Fig. 8: Thermal comfort graph

VI. Discussion and conclusions

By using climate-friendly design techniques in the cold climate zones and also using solar chimney as one of the inactive solar systems, average indoor temperatureof the chosen sample substantially increased. Applying this technique has raised the indoor temperature of classes without using mechanical heating system. As seen in simulation of the sample, indoor temperaturereached 22 °C in winter. Regarding the humidity of the region estimated to be 40-60 percent, the mentioned temperature is in comfort range. However, according to field studies conducted on a winter day, when the ambient temperature ranged from 8-15 °C, the indoor temperature of the classes in the respective sample was measured to be 8-11 °C (Fateh, 2010). Accordingly, carful design and considerable attention to environmental sustainability in small- and large-scale architectural projects can be a major step towards saving non-renewable sources of energy and reducing environmental damages and air pollutants production without spending a lot of money. This issue is currently a matter of great importance in the design of architectural projects in the world.

References

[1] IEA, international energy agency: Energy efficient building envelopes,2013

[2] Bansal, NK & Mathur, R& Bhandari, MS (2011), A study of solar chimney assisted wind tower system for natural ventilation in buildings, Building and Environment, Vol 28, No 3, 373- 377.

[3] Tahersima, M., Ley, T., & Tikalsky, P. (2017). Hydration Heat in a mass concrete and a thin slab with limestone blended cement. Int. J. Mater. Sci. Eng., 5(2), 79-86.

[4] Afonso.C , Oliveira.A (2010), Solar chimneys: simulation and experiment, Energy and Buildings, Vol 32, pp 71_79. ASHRAE Handbook_Fundamentals)SI( )2009(, chapter 16, 16.28 [3] Chopra AK.

[5] Bouchair A. (2011), Solar chimney for promoting cooling ventilation in southern Algeria, Build ServEng Res Technol, 15:81_93.

[6] Charvat P, Jicah M, Stetina J. (2013), Solar chimneys for ventilation and passive cooling, Denver ,USA: World Renewable Energy Congress

[7] Tahersima, M., & Tikalsky, P. (2017). Finite element modeling of hydration heat in a concrete slab-on-grade floor with limestone blended cement. Construction and Building Materials, 154, 44-50.

[8] Punyasompun.S, Hirunlabh.J, Khedari.J, Zeghmat.B (2009), Investigation on the application of solar chimney for multi-storey buildings،Renewable Energy, Vol 34, pp 2545_2561.

[9] Tahersima, M., Tikalsky, P., & Revankar, R. (2018). An experimental study on using a mass radiant floor with geothermal system as thermal battery of the building. Building and Environment.
[10] Escamilla, E. F., Ostadalimakhmalbaf, M., Pariafsai, F., Ranka, N., Danesh, M., & Naderi Alizadeh, M. (2018). Impact of Using iPad Tablets in a Construction Communication Graphics Class: Evaluation Based on System Usability Scale. Journal of Educational Technology Systems, 47(1), 32-49. doi:10.1177/0047239518773744
[11] Khedari, Joseph& Boonsri, Boonlert & Hirunlabh, Jongjit (2010), Ventilation impact of a solar chimney on indoor temperature fluctuation and air change in a school building, Energy and Building, Vol 32, pp 89_93.
[12] Sudaporn, Chungloo, Bundit, Limmeechokchai (2014), Utilization of cool ceiling with roof solar chimney in Thailand: The experimental and numerical analysis, Renowable Energy, 34, pp 623_633.
[13] Tahersima, M. (2017). Modeling Heat Transfer in Mass Concrete Floors with Radiant Heat from Ground Source Systems (Doctoral dissertation, Oklahoma State University).
[14] Rabah.K, (2011): Development of energy-efficient passive solar building design in Nicosia Cyprus,Renewable Energy,907-937,
[15] Bodach.S ,Lang.W, (2014), Climate responsive building design strategies of vernacular architecture in Nepal, Energy and Buildings 81,227-242,
[16] Escamilla, E. F., Ostadalimakhmalbaf, M., Pariafsai, F., Gragera, C., & Naderi Alizadeh, M. (2018). Enrollment, Retention, and Graduation patterns of Higher-Education Construction Science Students at Texas A&M University: A Comparative Study. The Professional Constructor Journal of the American Institute of Constructors, 43(1), 48-61.
[17] Chandel.SS ,Sarkar.A, (2015) Performance assessment of a passive solar building for thermal comfort and energy saving in a hilly terrain of India, Energy and Buildings 86 ,873–885
[18] Chandel.SS, Aggarwal.RK, (2012), Performance evaluation of a passive solar building in Western Himalayas, Renewable Energy 33 ,2166–2173,
[20] Design Builder, Design Builder SBEM Approval, Available in: WWW.DesignBuilder.CO.UK , access date:2015
[21] Holloway.D.R, (2011), SUN TEMPERED ARCHITECTURE A Simple Design Methodology For Passive Solar Houses with a Brief History of Solar Energy Utilization in the Built Environment,
[22] SKAT, (2007), Climate Responsive Building - Appropriate Building Construction in Tropical and Subtropical Regions ,
[23] SDEG,Sempra Energy Company, design brief,Design for your Climate,2013
[24] Mathur, J., & Mathur, S. (2006). Summer-performance of inclined roof solar chimney for natural ventilation. Energy and Buildings, 38(10), 1156-1163.