

COMPARATIVE THERMAL PERFORMANCE OF STATIC SUNSHADE AND BRICK CAVITY WALL FOR ENERGY EFFICIENT BUILDING ENVELOPE IN COMPOSITE CLIMATE

by

**Meghana CHARDE, Sourabh BHATI, Ayushman KHETERPAL,
and Rajiv GUPTA***

Department of Civil Engineering, Birla Institute of Technology and Science, Pilani, Rajasthan, India

Original scientific paper
DOI: 10.2298/TSCI1403925C

Energy efficient building technologies can reduce energy consumption in buildings. In present paper effect of designed static sunshade, brick cavity wall with brick projections and their combined effect on indoor air temperature has been analyzed by constructing three test rooms each of habitable dimensions (3.0 m × 4.0 m × 3.0 m) and studying hourly temperatures on typical days for one month in summer and winter each. The three rooms have also been simulated using a software and the results have been compared with the experimental results. Designed static sunshade increased indoor air temperature in winter while proposed brick cavity wall with brick projections lowered it in summer. Combined effect of building elements lowered indoor air temperature in summer and increased it in winter as compared to outdoor air temperature. It is thus useful for energy conservation in buildings in composite climate.

Key words: *energy efficient buildings, brick cavity wall, static sunshade, temperature*

Introduction

Buildings are major consumers of energy throughout their lifecycle [1]. Energy efficient building design can help to conserve energy through appropriate materials, insulation and architectural design. The thermal environment in a building depends upon the heat flow through building envelope, distribution pattern of air and relative humidity. Thermal design of buildings is influenced by various parameters, such as site planning, plan form and orientation, design techniques of various building elements like wall, roof, building materials, size and location of openings, finishes and energy use for heating and cooling. Indoor thermal conditions up to a certain extent can be improved by appropriate selection and design of these parameters to minimize solar heat gain in summer and maximize it in winter [2]. Solar contribution to the total cooling and heating load inside the building can be altered significantly through proper design of static sunshade and wall.

Windows are an important source of heat gain in a building. Shading devices must be designed in relation to the fenestration to maximize shading in summer to minimize heat gain and let direct sun indoors in winter to maximize heat gain [3]. Mathematical methods [4] and shading mask graphical approach [5, 6] for design and evaluation of shading devices have been reported in literature. A practical tool [7] was developed to size optimum shading devices, while design principles of external inclined louvers for solar control were given by Chan-

* Corresponding author; e-mail: rajiv@pilani.bits-pilani.ac.in

dra [8]. ParaSol Version 3.0 [9], RADTHERM 6.0 [3], computer tool WINSHADE [10], and simulation program TRNSHD [11] have been used to design and evaluate shading devices.

A number of research studies related to thermal performance and energy efficiency of walls have focused on difference in heat transfer behaviour of walls due to difference in construction technology in various climate zones [12, 13]. Ventilated walls and facades if well designed, can help to reduce considerably the summer thermal loads due to direct solar radiation [14]. Experimental investigations [15], analytical methods [16], numerical computations [17] reported in literature have evaluated heat transfer behavior of cavity walls. Various studies have been reported on the thermal performance of wall insulation [18-20]. It has been shown by numerical computations that incoming heat flux can be reduced by providing air cavity in walls [21] and application of a layer of cow dung slurry in wall cavity [22]. Cavity wall and loft insulation were found to reduce space heating fuel consumption by 45-49% theoretically, while on monitoring in actual dwellings, the reduction was only 10-17% [23]. In the fort city of Jaisalmer, deeply carved patterns on front facades help to control heat flux entering the buildings. These patterns increase convective heat loss due to increased surface area and reduce heat gain, while in the evening with cooler ambient conditions, this increased surface area helps in cooling faster [24]. Various experimental, analytical and simulation studies reported in literature suggest that performance of cavity walls is better as compared to solid brick walls. Many studies have been reported on energy efficiency of walls, static sunshade design and their evaluation. But there has been no comparative experimental and simulation study on rooms of habitable dimensions that compare the effect of single building element or combined effect of different building elements on indoor air temperature.

In the composite climate zone in India, the need is to design a room that would keep the indoor air temperature more in winter and less in summer as compared to outdoor air temperature. The aim of passive solar building design is to maximise solar heat gain in winter and avoid overheating in summer and bring the indoor air temperature near the comfort temperature zone (18-27 °C). In separate experimental studies, effect of static sunshade, brick cavity wall with brick projections, hollow roof and their combined effect on indoor air temperature was analysed [25, 26]. The present paper aimed to study the individual and combined effect of proposed static sunshade and brick cavity wall with brick projections experimentally and by using simulation software Autodesk Ecotect Analysis 2011 [27]. To study the effect of proposed static sunshade, brick cavity wall with brick projections and their combined effect on indoor air temperature, three rooms of habitable dimensions (3.0 m × 4.0 m × 3.0 m high) exposed to external atmospheric conditions were constructed and hourly temperatures on typical days for one month in summer and winter were analyzed.

Experimental methodology

India has tropical climate and is broadly classified into five climatic zones [28]. Tropical climate is characterized by significant hourly and large diurnal variations in temperature and sunshine that also vary considerably over the year [29]. The three rooms for experimentation are located in India at Birla Institute of Technology and Science, Pilani, Rajasthan, that lies in the composite climate zone [28]. To study the effect of static sunshade, brick cavity wall with brick projections and their combined effect on indoor air temperature, three test rooms (3.0 m × 4.0 m × 3.0 m high) having same orientation and exposed to similar conditions were constructed as shown in fig. 1. Room R1 has a horizontal static sunshade over window on south wall, solid brick walls 338 mm thick and solid RCC roof 100 mm thick. The

details of various building elements of rooms R1, R2, R3 are shown in tab. 1. Figure 2 shows the sections of rooms R1, R2, R3.

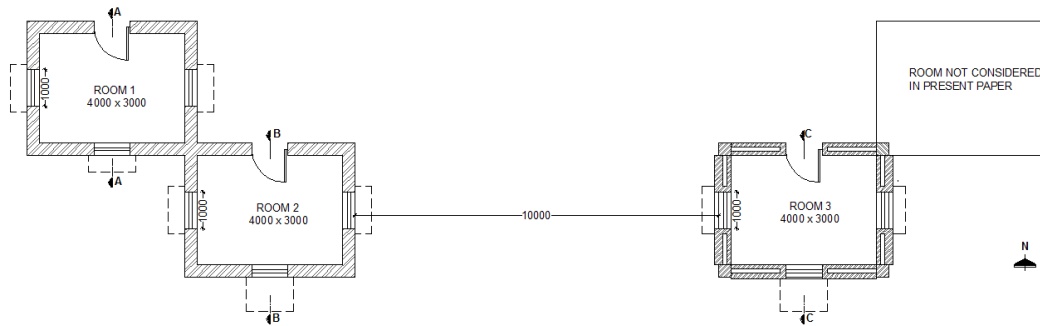


Figure 1. Plan of rooms R1, R2, and R3

Table 1. Details of building elements of rooms R1, R2, and R3

Building element	Room R1	Room R2	Room R3
Foundation	PCC 1:3:6, Random rubble stone masonry (sandstone), mortar 1:6	PCC 1:3:6, Random rubble stone masonry (sandstone), mortar 1:6	PCC 1:3:6, Random rubble stone masonry (sandstone), mortar 1:6
RCC plinth slab	RCC 1:2:4	RCC 1:2:4	RCC 1:2:4
Walls	338 mm thick load bearing brick walls, mortar 1:6	338 mm thick load bearing brick walls, mortar 1:6	Double leaf brick cavity walls, mortar 1:4, Inner leaf 112.5 mm thick, cavity 113 mm thick, outer leaf 112.5 mm thick
Roof	100 mm thick RCC (1:1.5:3)	100mm thick RCC (1:1.5:3)	100 mm thick RCC (1:1.5:3)
Plaster	Mortar 1:4	Mortar 1:4	Mortar 1:4
Openings	1,000 × 1,200 mm MS window frame and shutter	1,000 × 1,200 mm MS window frame and shutter	1,000 × 1,200 mm MS window frame and shutter
Static sunshade	RCC 1:1.5:3	Designed static sunshade, RCC 1:1.5:3	Designed static sunshade, RCC 1:1.5:3
Door	1,000 × 2,100 mm MS frame with wooden shutter	1,000 × 2,100 mm MS frame with wooden shutter	1,000 × 2,100 mm MS frame with wooden shutter

The experimental work was carried out for one month in summer and winter each. The effectiveness of designed static sunshade and brick cavity wall with brick projections and analysis of thermal performance has been done by studying values of hourly indoor air temperatures in the three rooms and outdoor air temperature on typical days. Global Water air temperature sensors WE700 (least count 0.1 °C) [30] were used to take hourly room air temperature measurements. The sensors were installed in the centre of the room at the desk level [31] as shown in figs. 1 and 2. Global Water air temperature sensor WE700 shielded from solar radiation with a solar shield WE 770 [30] were used to take hourly outdoor air temperature measurements. All temperature sensors were connected to a Global Water GL500 data logger [32] and then temperature readings were stored on a computer. All readings were taken with windows and doors of the three rooms closed. The effectiveness of designed static sunshade has been studied by comparing outdoor air temperature and indoor air temperature in

rooms R1 and R2. Similarly, effectiveness of proposed brick cavity wall with brick projections has been studied by comparing outdoor air temperature and indoor air temperature in rooms R2 and R3. The combined effect of designed static sunshade and brick cavity wall with brick projections has been studied by comparing outdoor air temperature and indoor air temperature in rooms R1 and R3.

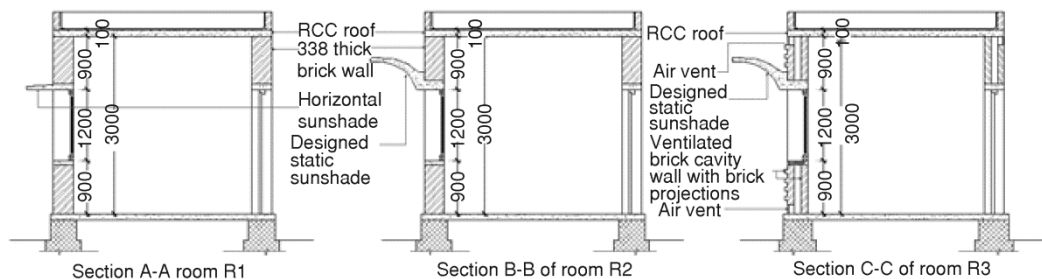


Figure 2. Section of rooms R1, R2, and R3

Experimental set-up

The three rooms for experimentation have a different combination of type of static sunshade and wall. Room R1 is a conventional room with a horizontal static sunshade over window on south wall and solid brick walls. Rooms R2 and R3 have the designed static sunshade (with RCC 1:1.5:3) over window on the south wall. The designed static sunshade has been designed by calculating solar angles for two design dates, which depends on seasonal characteristics as per methodology described by Ralegaonkar and Gupta [29]. Room R3 has the brick cavity walls with brick projections on east, west, south faces as per methodology described by Charde and Gupta [25]. The north wall will be in shade for most part of the year as duration of sunshine on it throughout the year for considered geographical location is less as compared to the other three walls. Hence the north wall is a brick cavity wall without brick projections. Air vents that open in the wall cavity have been provided on east, west, north and south brick cavity walls of room R3. Rectangular mild steel wall ties have been used to provide a connection between the outer and inner brick leaf of the brick cavity wall as per Technical Notes of Brick Industry Association [33]. There is a single window centrally located on each of the east, west and south walls and a centrally located door on the north wall of rooms R1, R2, and R3. All other design parameters for the three rooms are same. Hence the difference in indoor air temperature of the rooms will mainly be due to difference in heat transferred through the proposed static sunshade and brick cavity wall with brick projections.

Results and discussion

The indoor air temperature in the three rooms and outdoor air temperature was recorded at one hour intervals throughout the day for 24 hours in April and December 2011. Air vents in the brick cavity walls of room R3 were kept open in summer month of April while they were kept closed in winter month of December. The doors and windows of all three rooms were kept closed throughout the study period in summer and winter. Analysis of thermal performance has been done by comparing outdoor air temperature and indoor air temperature in the three rooms on typical days in different weeks in April and December 2011 as shown in figs. 3 and 4.

Figure 3 shows temperature records in summer month of April. Indoor air temperature in all the rooms varies between 21.8 °C to 33.3 °C, while there was a large variation in outdoor air temperature (12.9-39.2 °C). Thus the swing in indoor air temperature in all the rooms was less as compared to that in outdoor air temperature. Room R3 was cooler than rooms R1 and R2 in early morning hours and afternoon. This difference in indoor air temperature was maximum from 11:00 to 13:00. This may be attributed to the open air vents in the brick cavity wall with brick projections of room R3 which caused cooling of air in the wall cavity at night and shadow cast by brick projections on the wall. Indoor air temperature in room R3 was more than that in room R2 from 16:00 to 03:00 as these open air vents also caused heating of air in the wall cavity during day. After this, the indoor air temperature in room R3 was less than that in room R2. The minimum indoor air temperature in room R3 was less than that in room R2 due to the effect of brick cavity wall with brick projections.

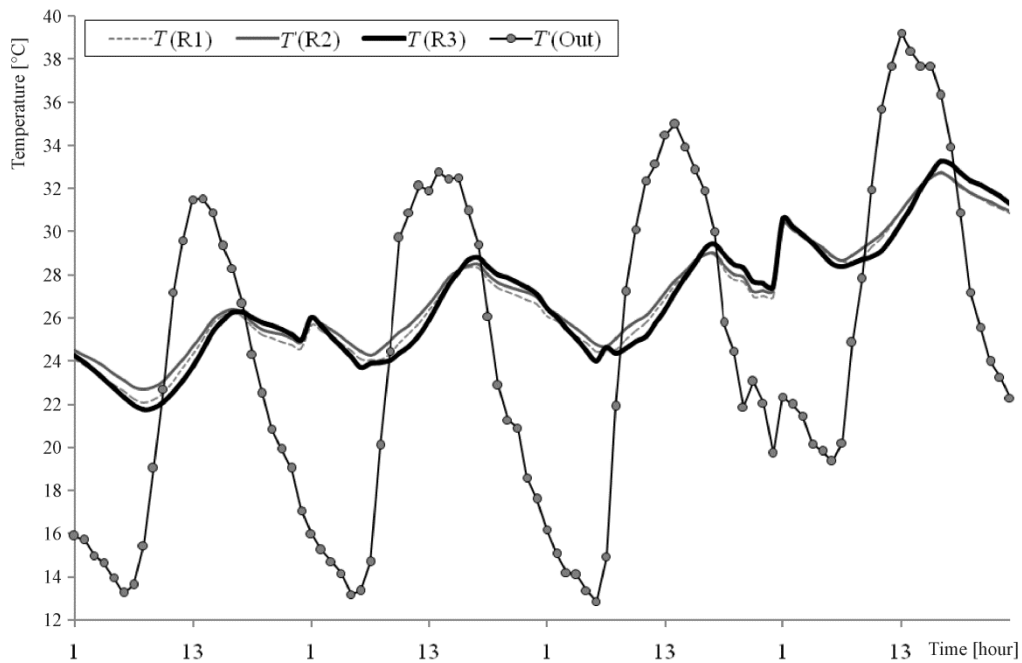


Figure 3. Indoor air temperature in rooms R1, R2, and R3 and outdoor air temperature in April

In winter month of December (fig. 4), indoor air temperature in rooms R2, R3 was more than that in room R1 throughout the day. The designed static sunshade was effective in raising the indoor air temperature in room R2 as compared to that in room R1 throughout the day. Room R3 was warmer than room R2 in the afternoon and late night due to the effect of the brick cavity wall with brick projections. Although room R3 had same or lower minimum indoor air temperature than that in room R2, room R3 had higher maximum indoor air temperature. Thus room R3 was able to gain more heat as compared to room R2. Room R3 was warmer than room R1 throughout the day. This difference in indoor air temperature of rooms R1 and R3 was maximum in the night duration from 20:00 to 23:00.

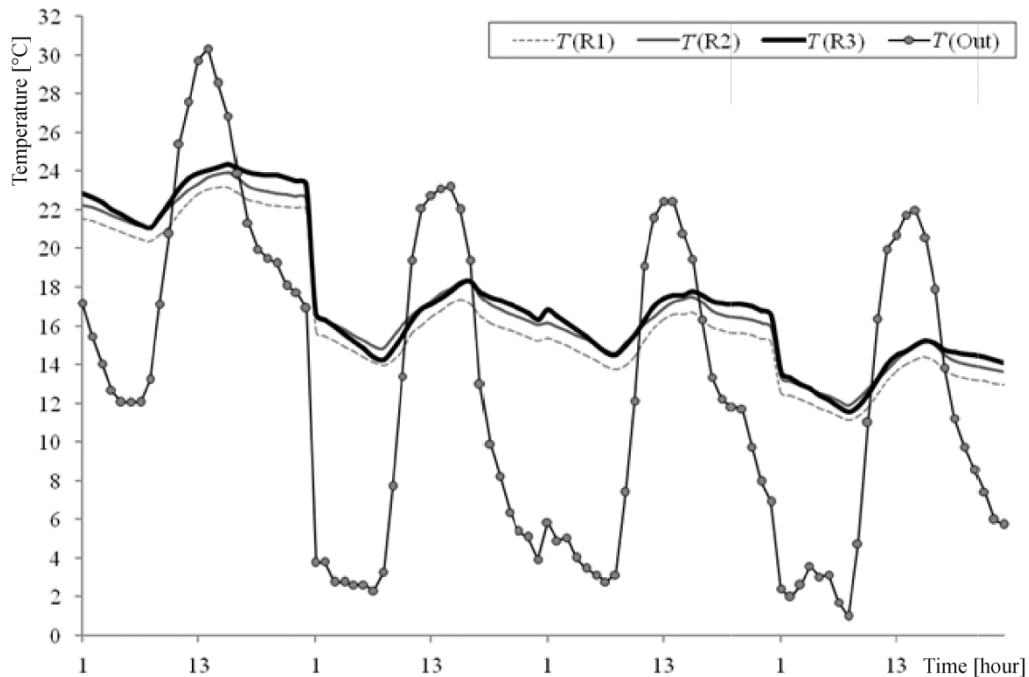


Figure 4. Indoor air temperature in rooms R1, R2, and R3 and outdoor air temperature in December

Simulation analysis

Software Autodesk Ecotect Analysis 2011 was used to simulate and compare the rooms. The simulation results were compared with the experimental results to try efficacy of the software in predicting indoor air temperature. Autodesk Ecotect Analysis 2011 uses the Chartered Institute of Building Services Engineers (CIBSE) Admittance Method to determine internal temperatures and heat loads. Thermal models in Autodesk Ecotect Analysis 2011 are based on the spatial arrangement of discrete zones. The climatic variables used in the simulation weather file were obtained from the U.S. Department of Energy website [34] for the weather station nearest to the experimental setup for the day (14th December) for which the analysis was performed.

The limitations and assumptions associated with modelling of the rooms are listed below:

- thermal properties of sunshades were neglected as they were assigned non-thermal zones;
- metal frame in windows and vents were not modelled due to limitations of the modelling tools;
- thermal mass of the brick projections on the walls of room R3 was assumed to be distributed uniformly over the whole wall;
- the vents opening in the wall cavities of the walls of room R3 were modelled as windows with custom material having air as outer layer and brick as inner layer;
- the required weather information, not collected due to limitations of the experiment, was acquired from an external source (US Department of Energy) [34].

The model of the three rooms is shown in fig. 5. Thermal zone for room R1 was a simple rectangular zone created with zone tool. Windows and door were inserted on appropri-

ate locations. Separate non-thermal zones were created for the sunshades and plinth. 100 mm thick concrete slab was used as floor material, while 100mm thick RCC covered with 25 mm thick concrete stone, 5 mm thick plaster and 20 mm thick ceramic tiles was used for roof.

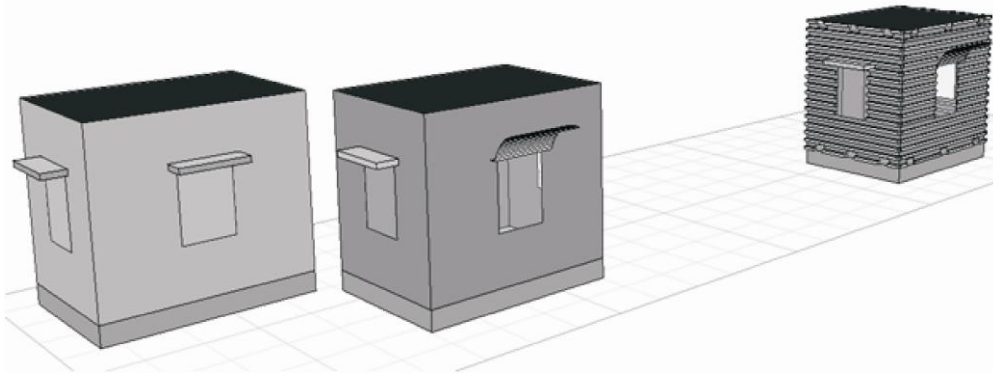


Figure 5. Model of rooms R1, R2, and R3 in Autodesk Ecotect Analysis 2011

Room R2 was modelled in same way as room R1 except for the sunshade on south wall. Only lower surface of the sunshade was modelled. For room R3, a new material made up of 113 mm thick air gap sandwiched between 112.5 brick masonry was created for the cavity walls. To account for the additional shading and thermal mass due to brick projections on the west, east and south wall, the projections were modelled as non-thermal zones and their thermal mass was distributed uniformly over the main walls. So the thickness of the outer layer was increased for all three walls depending on the dimensions of the brick projections. The vents opening in the wall cavity were simulated as windows made up of a material consisting of air gap as outer layer and 112.5 mm thick brick masonry as inner layer. This is a simplification and it might have caused some deviation from the actual results.

Table 2 shows the values of thermal transmittance for different simulated building elements. Figure 6 shows the comparison of the experimental and simulated results on 14th December. There is a difference between the experimental and simulation results. This may be attributed to the available weather file, in which the climatic variables (not available from the experiment) were input from a weather station closest to the experimental setup. Limitations in modelling the brick cavity wall with brick projections exactly like the experimental case may have led to the difference in experimental and simulation results.

Table 2. Thermal transmittance values of building elements of rooms R1, R2, and R3

Building elements	Thermal transmittance [Wm ⁻² K ⁻¹]
Walls of rooms R1, R2	1.43
North wall of room R3	1.39
East and west walls of room R3	1.30
South wall of room R3	1.35
Roof of rooms R1, R2, R3	3.51
Floor slab of rooms R1, R2, R3	3.22
Door of rooms R1, R2, R3	1.87
Windows of rooms R1, R2, R3	5.44
Open vent of room R3	1.94
Closed vent of room R3	1.94

Conclusions

In the composite climate zone in India, the need is to design a room that would keep the indoor air temperature more in winter and less in summer as compared to outdoor air temperature. In present paper three rooms with a different combination of building elements were compared experimentally and using software Autodesk Ecotect Analysis 2011. From the experimental study in actual rooms of habitable dimensions it can be inferred that the variation of indoor air temperature is less as compared to outdoor air temperature. The designed static sunshade helped to raise indoor air temperature throughout the day in winter. The brick cavity wall with brick projections lowered the indoor air temperature in summer and raised it in winter afternoon and nights. The combined effect of the designed static sunshade and brick cavity wall with brick projections helped to lower indoor air temperature in summer mornings, afternoons and raise it in winter throughout the day. The combined effect of the building elements is thus useful for energy conservation in buildings in composite climate as per seasonal needs. The simulation of the rooms with software Autodesk Ecotect Analysis 2011 showed that there were certain differences in the experimental and simulation results. These may be attributed to the limitations in the availability of climatic variables and limitations in modelling the rooms.

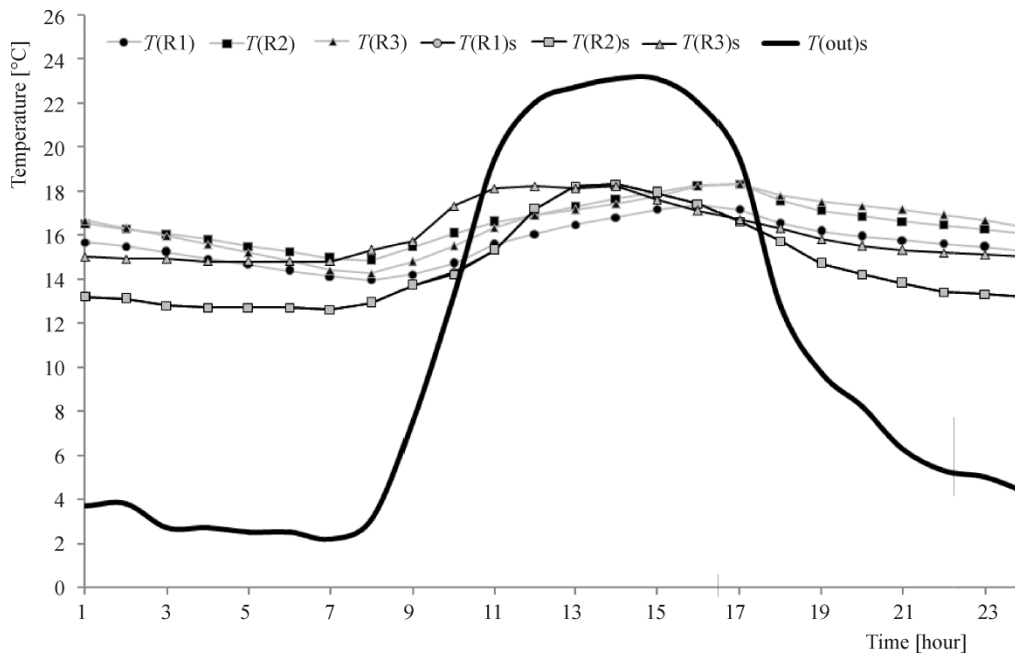


Figure 6. Comparison of experimental and simulation results on December 14

Acknowledgements

The authors would like to acknowledge University Grant Commission (UGC) New Delhi for funding the construction of the rooms and purchase of instruments for experimental work. They also acknowledge help provided by Engineering Services Division (Maintenance), BITS, Pilani for the construction of rooms.

Nomenclature

MS	– mild steel	$T(\text{Out})$	– outdoor air temperature (experimental)
PCC	– plain cement concrete	$T(\text{R1})\text{s}$	– indoor air temperature in room R1 (simulation)
RCC	– reinforced cement concrete	$T(\text{R2})\text{s}$	– indoor air temperature in room R2 (simulation)
$T(\text{R1})$	– indoor air temperature in room R1 (experimental)	$T(\text{R3})\text{s}$	– indoor air temperature in room R3 (simulation)
$T(\text{R2})$	– indoor air temperature in room R2 (experimental)	$T(\text{Out})\text{s}$	– outdoor air temperature (simulation)
$T(\text{R3})$	– indoor air temperature in room R3 (experimental)		

References

- [1] Dakwale, V. A., et al., Improving Environmental Performance of Building through Increased Energy Efficiency: A Review, *Sustainable Cities and Society*, 1 (2011), 4, pp. 211-218
- [2] ***, SP41, *Handbook on Functional Requirements of Buildings (Other than Industrial Buildings)*, Part 1-4, Bureau of Indian Standards, New Delhi, 1987, pp. 3-74
- [3] Kapur, N. K., A Comparative Analysis of the Radiant Effect of External Sunshades on Glass Surface Temperatures, *Solar Energy*, 77 (2004), 4, pp. 407-419
- [4] Garg, S. N., Bansal, N. K., Calculation of Appropriate Size Fixed Sunshade Overhangs over Windows of Different Orientations, *Energy Conversion and Management*, 26 (1986), 3-4, pp. 283-288
- [5] El-Refaie, M. F., Performance Analysis of External Shading Devices, *Building and Environment*, 22 (1987), 4, pp. 269-284
- [6] Etzion, Y., An Improved Solar Shading Design Tool, *Building and Environment*, 27 (1992), 3, pp. 297-303
- [7] Jorge, J., et al., A Practical Tool for Sizing Optimal Shading Devices, *Building and Environment*, 28 (1993), 1, pp. 69-72
- [8] Chandra, M., Design Principles of External Shading Devices for Solar Control in Buildings, *Institution of Engineers (India)*, 77 (1997), 1, pp. 44-52
- [9] Hellstrom, B., et al., Description of ParaSol v3.0 and Comparison with Measurements, *Energy and Buildings*, 39 (2007), 3, pp. 279-283
- [10] Kabre, C., WINSHADE: A Computer Design Tool for Solar Control, *Building and Environment*, 34 (1999), 3, pp. 263-274
- [11] Hiller, M. D. E., et al., TRNSHD – A Program for Shading and Insolation Calculations, *Building and Environment*, 35 (2000), 7, pp. 633-644
- [12] Zalewski, L., et al., Study of Solar Walls – Validating a Simulation Model, *Building and Environment*, 37 (2002), 1, pp. 109-121
- [13] Pulselli, R. M., et al., Energy and Energy Based Cost-Benefit Evaluation of Building Envelopes Relative to Geographical Location and Climate, *Building and Environment*, 44 (2009), 5, pp. 920-928
- [14] Ciampi, M., et al., Ventilated Façades Energy Performance in Summer Cooling of Buildings, *Solar Energy*, 75 (2003), 6, pp. 491-502
- [15] Aviram, D. P., et al., Thermal Properties of a Variable Cavity Wall, *Building and Environment*, 36 (2001), 9, pp. 1057-1072
- [16] Del Coz Diaz, J. J., et al., Analysis and Optimization of the Heat-Insulating Light Concrete Hollow Brick Walls Design by the Finite Element Method, *Applied Thermal Engineering*, 27 (2007), 8-9, pp. 1445-1456
- [17] Zhang, Z. L., Wachenfeldt, B. J., Numerical Study on the Heat Storing Capacity of Concrete Walls with Air Cavities, *Energy and Buildings*, 41 (2009), 7, pp. 769-773
- [18] Friess, W. A., et al., Wall Insulation Measures for Residential Villas in Dubai: A Case Study in Energy Efficiency, *Energy and Buildings*, 44 (2012), 1, pp. 26-32
- [19] Derome, D., Desmarais, G., Exposure to Condensation Moisture of Sheathing in Retrofitted Leaky Wall Assemblies, *Journal of Architectural Engineering*, 12 (2006), 2, pp. 72-82
- [20] Bolatturk, A., Optimum Insulation Thicknesses for Building Walls with Respect to Cooling and Heating Degree-Hours in the Warmest Zone of Turkey, *Building and Environment*, 43 (2008), 6, pp. 1055-1064
- [21] Tiwari, G. N., et al., A Comparison of Passive Cooling Techniques, *Building and Environment*, 29 (1994), 1, pp. 21-31

- [22] Kumar, S., et al., Amalgamation of Traditional and Modern Cooling Techniques in a Passive Solar House: A Design Analysis, *Energy Conversion and Management*, 35 (1994), 8, pp. 671-682
- [23] Hong, S. H., et al., The Warm Front Study Group, The Impact of Energy Efficient Refurbishment on the Space Heating Fuel Consumption in English Dwellings, *Energy and Buildings*, 38 (2006), 10, pp. 1171-1181
- [24] Krishnan, A., et al., Indigenous Architecture of Two Indian Deserts and Modern Climatic Responsive Solutions, *Renewable Energy*, 8 (1996), 1-4, pp. 272-277
- [25] Charde, M., Gupta, R., Design Development and Thermal Performance Evaluation of Static Sunshade and Brick Cavity Wall: An Experimental Study, *Energy and Buildings*, 60 (2013), May, pp. 210-216
- [26] Charde, M., Gupta, R., Annual Thermal Performance of a Hollow Roof in Combination with a Cavity Wall and Static Sunshade: Experimental Study of Energy-Efficient Rooms, *Journal of Energy Engineering*, 139 (2013), 4, pp. 281-289
- [27] ***, Autodesk Inc., Autodesk Ecotect Analysis 2011
- [28] ***, National Building Code of India, Part 8 Building Services- Section 1 Lighting and Ventilation, Bureau of Indian Standards, New Delhi, 2005
- [29] Ralegaonkar, R. V., Gupta, R., Design Development of a Static Sunshade Using Small Scale Modeling Technique, *Renewable Energy*, 30 (2005), 6, pp. 867-880
- [30] ***, Weather Sensor Manual (revised), Global Water Instrumentation Inc., Gold River, Cal., USA, 2009
- [31] ***, Indoor Space Temperature Guidelines, Columbia University,
<http://policylibrary.columbia.edu/indoor-space-temperature-guidelines>
- [32] ***, *GL500 Datalogger Manual*, Global Water Instrumentation Inc., Gold River, Cal., USA, 2006
- [33] ***, The Brick Industry Association, Technical Notes 44B – Wall Ties for Brick Masonry,
<http://www.gobrick.com/TechnicalNotes/tabid/7658/Default.aspx>
- [34] ***, Energy Efficiency and Renewable Energy, Weather Data, US Department of Energy,
http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=IND/cname=India