Studies on Energy Efficient Design of Buildings for Warm and Humid Climate Zones in India

Santhosh M. Malkapur, Sudarshan D. Shetty, Kishor S. Kulkarni, and Arun Gaji

Abstract In recent years, significant efforts have been made to improve energy efficiency and decrease energy consumption. The idea of energy efficiency in structures is related to the energy supply needed to achieve desirable environmental conditions that minimize energy consumption. The residential sector is liable for a significant piece of the energy consumption in the world. Most of this energy is used in cooling, heating and natural ventilation systems. In this work, the energy analysis of a residential building is carried out by varying building envelope parameters such as aspect ratio, orientation and window to wall ratio of the building in order to lessen the energy demand for the cooling and heating. The building is modeled in a software tool and various parameters are assigned to study the thermal efficiency in a warm and humid climate zone in India. The results indicate that a square building with an aspect ratio of 1:1 is more thermally efficient structure and North–South orientation of the building is better than East–West orientation. Also increasing window to wall ratio decreases the thermal efficiency of the building. The findings of this work would be helpful in design phase of an energy-efficient residential building.

Keywords Energy efficiency · Warm and humid climate · Orientation · Aspect ratio · Window to wall ratio

1 Introduction

Designing an energy-efficient structure is one of the best methods to reduce energy costs in buildings. To design energy-efficient buildings, structural components and building envelope parameters must be optimized. It is critical to recognize the basic factors that are directly related to heat transfer processes. The theoretical design phase

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of a structure is the best ideal opportunity to incorporate feasible systems. Energy-efficient design methods provide additional value that benefits the end-user. An organized plan dependent on energy-saving standards diminishes economic expenses all through the lifecycle of the structure because of its lower energy consumption [1, 2]. Since there are additionally less CO_2 discharges into the environment all through the structure's yearly energy utilization, this is advantageous to society also. Energy saving is a high need in developed nations. Consequently, energy efficient measures are as a rule progressively executed in all possible areas.

2 Literature Review

The energy saving is a high need in the entire world. The residential sector is a major contributor to the total energy consumption. A large amount of energy is utilized in the cooling and heating systems. Energy efficient structures can be constructed by studying and applying the measures required for achieving it. The measures include shape of the building, building orientation, building envelope system, cooling, and heating, etc., of residential structures [3]. It is possible to improve the energy efficiency of buildings without any additional cost. Buildings should be oriented properly to get the maximum passive solar energy. Morrissey et al. [4] concluded that the concept of passive solar energy should be incorporated in design stage to improve the energy efficiency of buildings. The effect of passive parameters, for example, building shape and building orientation on heating demand has been theoretically examined by Aksoy and Inallib [5] by selecting a cold region (Elazig region) of Turkey. Building orientation was varied from 0° to 90°. It is concluded that structures with a square shape are more advantageous with respect to energy efficiency. Ourghi et al. [6] examined the effect of the shape for office building on its yearly cooling and total energy use. A streamlined examination technique is developed dependent on point-by-point investigations using a few blends of building geometry, glazing type, glazing area, and climate. An immediate connection has been made between relative minimization and complete structure energy use just as the cooling energy prerequisite.

Eskin and Turkmen [7] studied the electricity use in commercial buildings in Turkey. The interactions between various conditions, control systems, and heating/cooling loads in office buildings in the four significant climatic zones in Turkey were studied. This study is used to examine energy conservation opportunities on annual cooling, heating and total building load at four major climatic zones of Turkey. Jazayeri and Aliabadi [8] investigated energy efficiency in the cold and semi-arid climate of Shiraz, Iran. They evaluated energy efficiency in two stages. In the first stage, larger windows with NS facade were considered and in second stage all facades of equal window-to-wall ratio and different building aspect ratios were considered. When different facades are varied, the optimal aspect ratio of a building can be different for different Window to wall ratio (WWR). Friess et al. [9] studied the energy demand of residential villas in Dubai. Minimum insulation levels for external wall and roof wall (U-value = 0.57 w/m^2-k) and reinforcement concrete frame was considered non-insulated. This work studied the effect of thermal impact on the structure's energy consumption by using a software model. Simulation results showed that with suitable outside wall protection methodologies alone, energy savings of up to 30% are obtained. Studies were also carried out on energy simulation tools and the strengths and weaknesses of each tool were studied [10]. Most of the studies have focused on a particular envelope component in a generic building. There is a lack of comparative study of the relative efficiency and impact of passive design strategies.

3 Methodology

3.1 Model and Parameters

In this study, a residential single-family residence house is considered and the effects of different building envelope parameters are studied on the energy efficiency of the building. A single-family house with one floor and basement is modeled for study. Building overview details are provided in Table 1. The house is located at Gadag, Karnataka, which falls under climate Zone 1B: warm and humid as per ECBC [11]. Table 2 provides information on the geography and climate of Gadag. The floor plan is shown in Fig. 1 and the building envelope parameters which have been used as the input parameters in this study are presented in Table 3.

A residential building with three aspect ratios 1:1, 1:1.5 and 1:2 same building area 111.30 m^2 is considered for analysis. Hall, bedroom, kitchen, stairway, and

Table 1 Building overview details

Variable	Value
Total built-up area	111.3025 m^2
Building use	Single-family detached
Number of floors	Ground floor
Construction type wood-framed	Advance framing
Heating	Gas furnace + Electricity
Cooling	Air conditioner—ducted split system
Domestic hot water (DHW)	Electricity and Gas boiler with storage tank
Aspect ratio (building size)	1:1 (10.55 m × 10.55 m) 1:1.5 (8.62 m × 12.93 m) 1:2 (7.45 m × 14.96 m)
Orientation	North–South, East–West
Window to wall ratio (WWR)	30, 40, and 50%

Table 2 Details of geography and climate of Gadag

Variable	Value
City/state	Karnataka, Gadag
Climate zone	1B (warm and humid)
Latitude	N 15°53′
Longitude	E 76°02′
Elevation	650.0 m
Heating design	18 °C baseline
Cooling design	12 °C baseline
Building orientation	0° from the true north and 90° from east
Wind speed	8.2

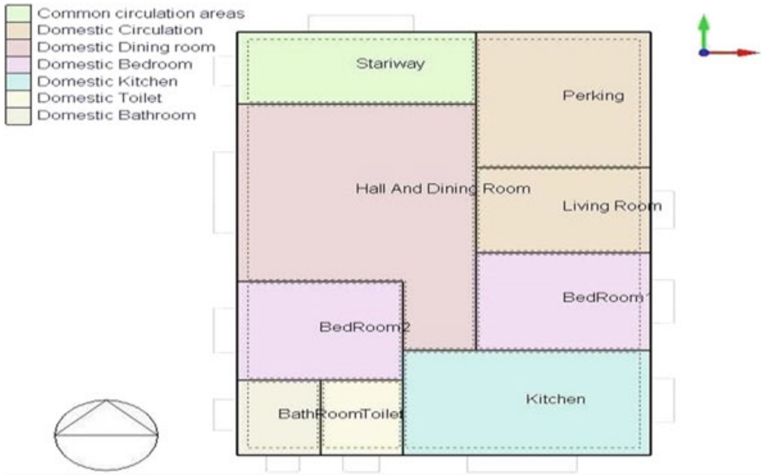


Fig. 1 Building floor plan

parking, etc., suitable dimensions of length and breadth are set out as given in Table 4.

3.2 Internal Loads and Schedules

The residential building of single-family with an occupancy of five people is considered for the present study. Details of activity, maximum occupancy, equipment load and lighting loads in each of the rooms are provided in Table 5.

Table 3 Building envelope parameters

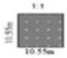
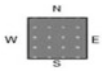
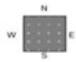
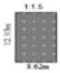
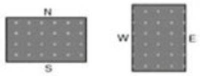
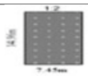
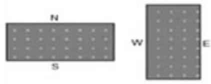
Building envelope parameters			
Model	Aspect ratio	Orientation North–South and East–West	Window to wall ratio %
Model 01	1:1 		30, 40, 50
 Model 02	1:1.5 		30, 40, 50
Model 03	1:2 		30, 40, 50

Table 4 Building geometry

Room	Activity						
Aspect ratio		1:1		1:1.5		1:2	
Building size		10.55 m × 10.55 m		8.62 m × 12.93 m		7.45 m × 14.96 m	
Length in m	Breadth in m	*L* (m)	*B* (m)	*L* (m)	*B* (m)	*L* (m)	*B* (m)
Hall/dining room	Eating and Drinking Seated quiet	5.7	2.56	4.67	4.45	3.84	5.92
Master bedroom	Sleeping	4.2	3	3.45	3.0	3.05	3.2
Bedrooms	Sleeping	4.24	2.7	3.35	3.0	3.0	3.6
Kitchen	Cooking	4.24	2.2	4.57	3.2	3.84	3.5
Stairway	Light manual work	5.7	2.0	4.67	2.2	3.84	2.22
Parking and open	Light manual work	4.24	2.24	3.35	3.15	3.0	4.07
Living room	Entry	4.24	2.2	3.35	2.6	3.0	2.8
Bathrooms and toilet	Standing/Walking	2.025	2.0	1.65	2.3	1.475	2.5

3.3 Building Envelope

The building envelope is the physical boundary between the outside and inside environments encasing a structure. It is comprised of a series of components and frameworks that shield the inside space from the impacts of the environment such as

Table 5 Activities and schedules (general energy code or ECBC, 2017)

Room	Activity	Maximum occupancy	Equipment load (W/m^2)	Lighting load (W/m^2)
Hall/dining room	Eating and drinking seated quiet	5	3.06	5
Master bedroom	Sleeping	2	3.58	3
Bedrooms	Sleeping	1 per room	3.58	3
Kitchen	Cooking	2	30.28	5
Stairway	Light manual work	5	2.16	5
Parking	Light manual work	5	1.57	5
Living Room	Entrée	1 per room	1.57	2
Bathrooms and toilet	Standing/Walking	1 per room	3.28	3

precipitation, wind, temperature, humidity and also ultraviolet radiation. The internal environment is comprised of the occupants, building materials, lighting, machinery and the HVAC system. Improving the structure envelope of houses is perhaps the most ideal approach to improve energy efficiency. This home is modeled using advanced framing techniques. Layer-by-layer details of the wall, roof, and floors are provided. Using these details, creating custom layers and, if necessary, materials using the Design-Builder software. Building envelope construction details are considered as per ECBC 2017 (Fig. 2).

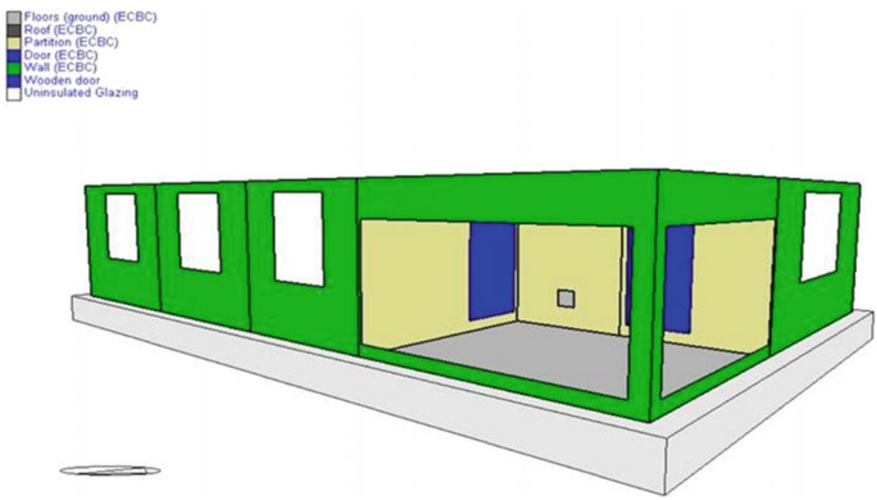


Fig. 2 Building envelope selected for the present study

3.4 Mechanical Systems

The building is considered to be centrally heated and cooled. The heating is provided through a gas furnace and the cooling system is a central split system. Efficiency details of the HVAC and SHW systems are provided as per ECBC 2017 (Table 6). The building is modeled in a software tool (Design builder) and various parameters are assigned to study the thermal efficiency in a warm and humid climate zone in India. Three envelope parameters namely aspect ratio (1:1, 1:1.5 and 1:2), orientation (North–South and East–West) and window-wall ratio (30, 40 and 50%) are varied by using three typical models and their energy efficiencies are evaluated.

Following are the details of the three models considered in this study:

Model 1—Single-family residential building with outer dimensions of 10.55 m × 10.55 m is considered for Model 1. Aspect ratio is kept as 1:1 and both orientations North–South and East–West are considered. Window to wall ratio is varied as 30, 40 and 50% (Fig. 3).

Model 2—Single-family residential building with outer dimensions of 12.93 m × 8.62 m is considered for Model 2. Aspect ratio of 1:1.5 and orientations in both

Table 6 Mechanical system details (general energy code or ECBC 2017)

Variables	Values
Heating load	
System type	Furnace
Fuel type	Electricity + Natural gas
Heating system efficiency (AFUE)	80%
Maximum supply air temperature (AT)	35 °C
Maximum supply air humidity ratio	0.0149
Heating capacity system	26 kW
Cooling load	
System type	Central air conditioning using a split system
Fuel type	Electricity
Cooling system EER	12.00
Cooling system SEER	17.50
Cooling system capacity	14 kW
Domestic hot water system (DHW)	
System type	A storage hot water system (standalone)
System fuel	Natural gas + Electricity
Energy factor	0.82
Hot-water delivery temperature	65 °C
Mains supply temperature	10 °C

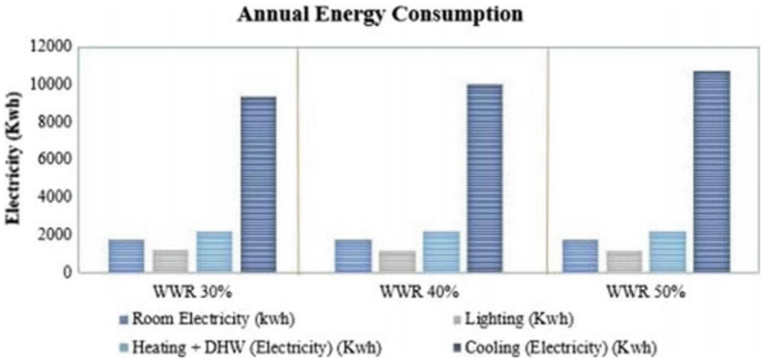


Fig. 3 Energy consumption for model-1

North–South and East–West direction are considered. Window to wall ratio is varied as 30, 40 and 50%.

Model 3—Single-family residential building with outer dimensions of 14.96 m × 7.45 m is considered for Model 3. Aspect ratio is kept as 1:2 and both orientations North–South and East–West are considered. Window to wall ratio is varied as 30, 40, and 50%.

4 Results and Discussions

In this section, the results of the thermal analysis of the three models are presented and discussed. The thermal efficiencies are discussed in terms of electricity consumption for lighting, heating, DHW, cooling, annual energy consumption and temperature.

4.1 Thermal Energy Efficiency of Model-01

The results of the thermal energy efficiency for model-1 are presented in Table 7. It is seen that the room electricity requirement of 1722.28 kWh is constant for different window to wall ratios. When lighting electricity is considered, small variations are seen for different window to wall ratios. It is observed that for window to wall ratio of 30% lighting electricity is found to be 1197.14 kWh, 1179.70 kWh for 40% and 1169.16 kWh for 50%. Heating and DHW electricity remained constant for different window to wall ratios. The cooling electricity is found to vary for different window to wall ratios. It is seen that for window to wall ratio of 30% cooling requirement is found to be 9314.08 kWh and for 40% and 50%, the cooling requirements are found to be 10007.93 kWh and 10699.93 kWh respectively. There is a large variation in the annual energy consumption for different window to wall ratios. The annual energy consumption is found to be 14405.11 kWh, 15081.55 kWh and 15762.98 kWh for

Table 7 Energy consumption results model-1

Description		Values		
Aspect ratio		1:1		
Orientation		NS and EW		
Window to wall ratio		30%	40%	50%
Room Electricity (kWh)		1772.28	1772.28	1772.28
Lighting (kWh)		1197.14	1179.70	1169.16
Heating + DHW (Electricity, kWh)		2171.61	2171.61	2171.61
Cooling (Electricity, kWh)		9314.08	10,007.93	10,699.93
Annual energy consumption		14,405.11	15,081.55	15,762.98
Temperature in °C	Outside	36.60	36.60	36.60
	Inside	33.10	33.51	34.00

window to wall ratio of 30%, 40% and 50%, respectively. In general, it can be seen that irrespective of the orientation, the energy consumption is found to increase with increasing window to wall ratios. This is true due to the fact that there will be increased thermal energy transfer between inside and outside environments with increased window to wall ratios and vice versa.

The energy consumption model is presented in Fig.4. The difference in the cooling electricity requirement is found to be lesser by 693.85 kWh and 693.85 kWh for a window to wall ratio of 30% and 40% respectively in comparison with 50%. It is observed that the annual energy electricity requirement is found to be reduced by 676.44 kWh and 681.43 kWh for window wall ratio of 30% and 40% as compared to 50%.

From Fig.4, it is observed that the inside temperature increases by increasing the window to wall ratio for a constant outside temperature of 36.6 °C. The inside temperatures observed are 33.1, 33.5 and 34 °C for window to wall area ratios of 30%, 40% and 50%, respectively.

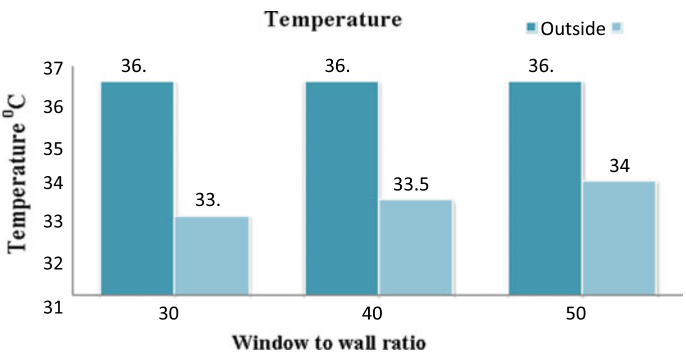


Fig. 4 Temperature variations between inside and outside environments (model-01)

Table 8 Annual energy consumption for WWR

Window to wall ratio (%)	Annual energy consumption (kWh)	Increase in %
30	14,405.11	–
40	15,081.55	4.7
50	15,762.98	4.5

Annual energy consumption for model-01 is found to increase for higher window wall ratios. The annual energy consumption is found to increase by 4.7 and 4.5% for window to wall ratios of 40% to 50% respectively as shown in Table 8. Also, daylight and sunlight dispersion map of model-01 is shown in Figs. 5, 6 and 7.

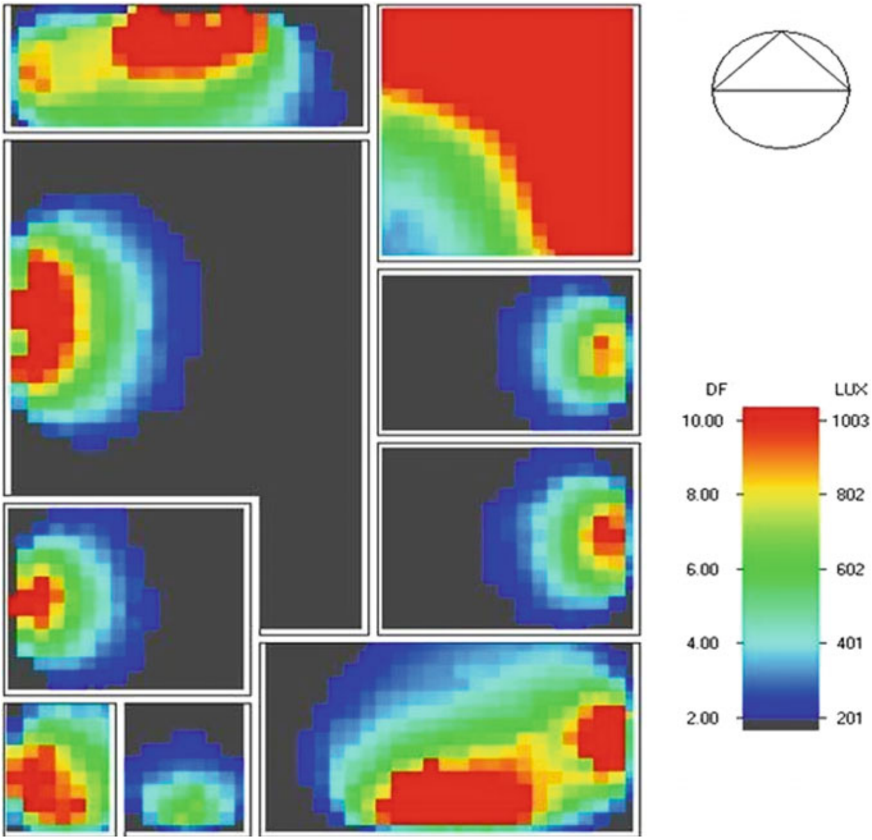


Fig. 5 Daylight inside the room (aspect ratio 1:1 and WWR30%)

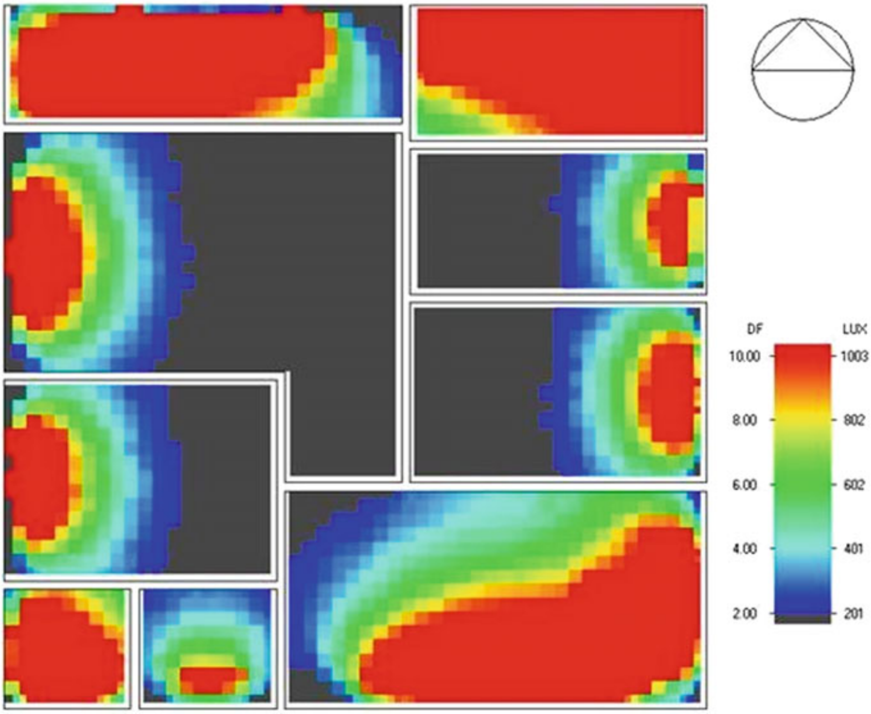


Fig. 6 Daylight inside the room (aspect ratio 1:1 and WWR40%)

4.2 Thermal Energy Efficiency of Model-02

The results of the thermal energy efficiency for model-2 are presented in Table 9 and Fig. 8. It is seen again that the room electricity requirement of 1530.4 kWh is constant for different window to wall ratios. Heating and DHW electricity did not vary for different window to wall ratios. When lighting electricity is considered, small variations are seen for different window to wall ratios. More variations are seen for cooling electricity for different window to wall ratios. It is seen that for window to wall ratio of 30%, cooling requirement is found to be 9314.08 kWh and for 40% and 50%, the cooling requirement are found to be 10007.93 kWh and 10699.93 kWh respectively. There is a large variation in the annual energy consumption for different window to wall ratios which can be seen in Table 9. The cooling electricity is found to increase significantly for increased window to wall ratios. Also with respect to orientation, North–South orientation is found to be better than the East–West orientation in improving the overall thermal efficiency of the building.

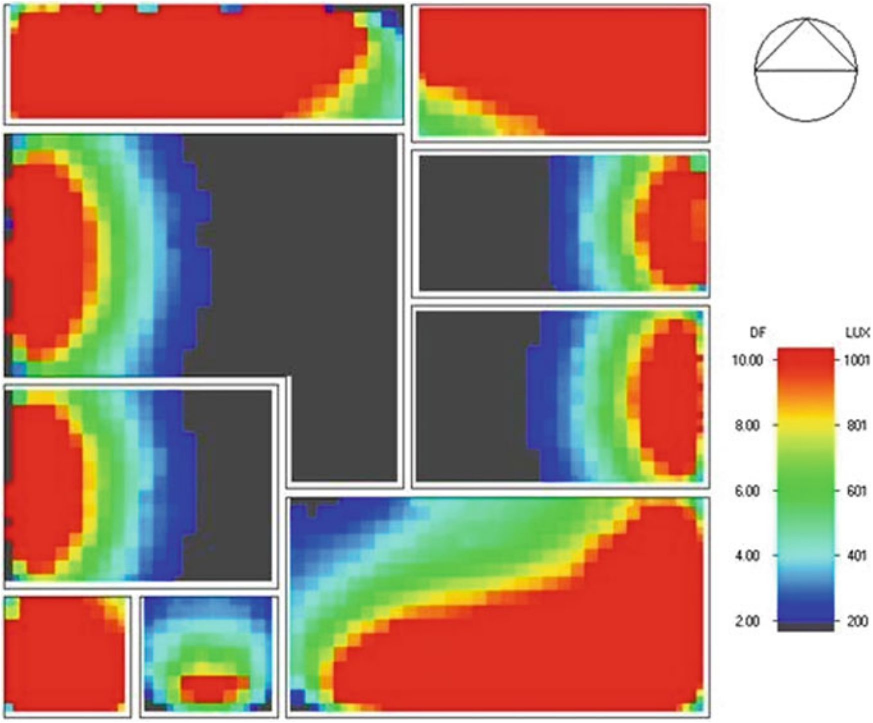


Fig. 7 Daylight inside the room (aspect ratio 1:1 and WWR50%)

Table 9 Energy consumption results of model-2

Description		Values					
Aspect ratio		1:1.5					
Orientation		North–South			East–West		
Window to wall ratio		30%	40%	50%	30%	40%	50%
Room electricity (kWh)		1530.4	1530.4	1530.4	1530.4	1530.4	1530.4
Lighting (kWh)		1158.5	1145.8	1139.5	1161.8	1146.7	1139.0
Heating + DHW (electricity, kWh)		2386.6	2386.6	2386.6	2386.6	2386.6	2386.6
Cooling (electricity, kWh)		10,937.0	11,429.1	11,893.9	11,352.5	11,764.6	12,180.4
Annual energy consumption (electricity, kWh)		16,012.5	16,491.9	16,950.3	16,431.3	16,828.3	17,236.4
Temperature (°C)	Outside	36.6	36.6	36.6	36.6	36.6	36.6
	Inside	34.25	34.50	34.75	33.77	34.0 1	34.24

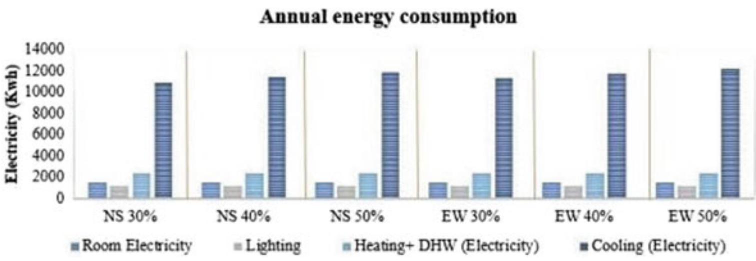


Fig. 8 Energy consumption model-2

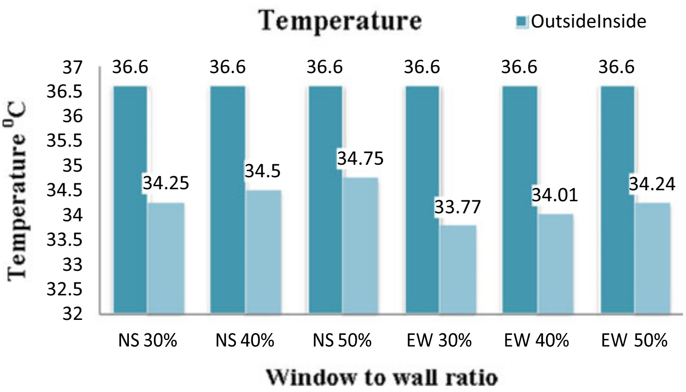


Fig. 9 Temperature variations between inside and outside environments for model-2

From Figure 9 it is observed that inside temperature increases with increasing window to wall ratio for constant outside temperature of 36.6 °C. Also, the North–South orientation is better than East–West orientation with respect to annual energy consumption (Fig. 10). On the other hand, East–West orientation is slightly better in reducing the inside temperatures of the building. Also, daylight and sunlight dispersion map of model-02 is shown in Figs. 11, 12 and 13 (Table 10).

4.3 Thermal Energy Efficiency of Model-03

The results of the thermal energy efficiency for model-3 are presented in Table 11. It is seen again that the room electricity requirement and heating and DHW electricity do not vary for different window to wall ratios. When lighting electricity is considered, small variations are seen for different window to wall ratios. For cooling electricity, considerable variations are seen for different window to wall ratios. It is seen that with increasing window to wall ratios, the cooling requirement increases irrespective of the orientation. There is a large variation in the annual energy consumption for

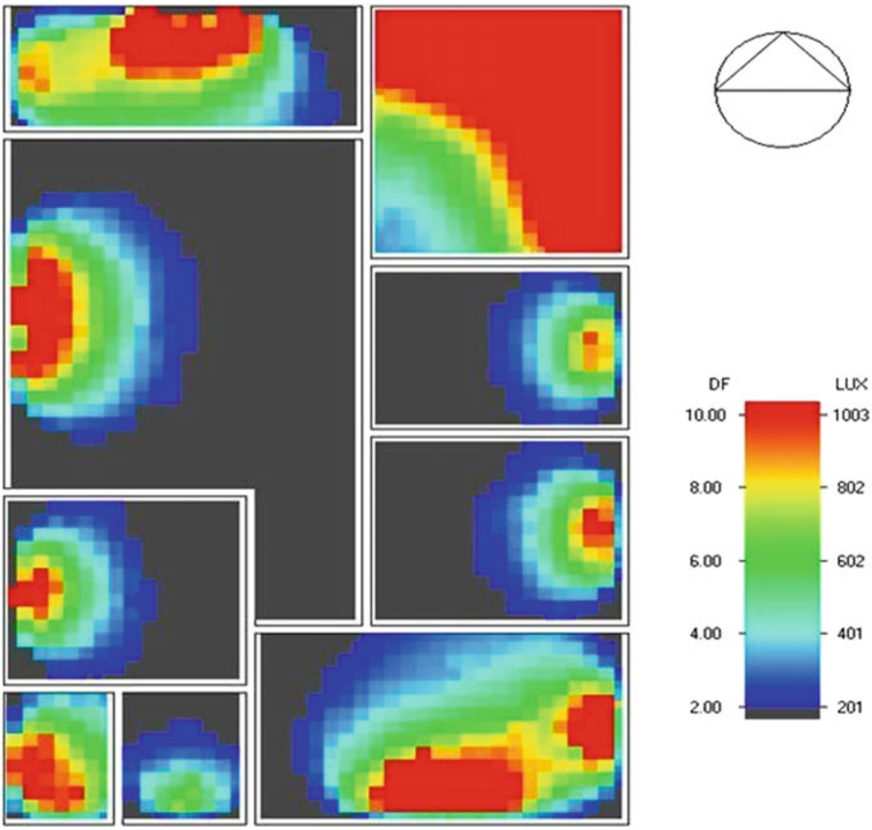


Fig. 10 Daylight inside the room (aspect ratio 1:1.5 and WWR30%)

different window to wall ratios, which can be seen in Table 11 and Fig 13. Also with respect to orientation, North–South orientation is found to be better than the East–West orientation in improving the overall thermal efficiency of the building.

The cooling electricity values of building with North–South orientation are found to be 12576.8 kWh, 13367.2 kWh and 14411.0 kWh for the window to wall ratio of 30, 40 and 50%, respectively. Similarly, for East–West orientation the cooling electricity values are found to be 12883.7 kWh, 13483.0 kWh and 14416.1 kWh for the window to wall ratio of 30, 40 and 50%, respectively (Fig. 14).

From Fig. 15, it is observed that inside temperature increases with increasing window to wall ratio for both North–South and East–West orientations for a given outside temperature. For the outside temperature of 36.6 °C, the inside temperatures are found to be 34.5, 34.61, and 34.65 °C for North–South orientation and for window to wall ratio of 30, 40, and 50% respectively. Similarly, for East–West orientation the inside temperatures are found to be 33.75, 33.9, and 34.1 °C for window to wall ratio

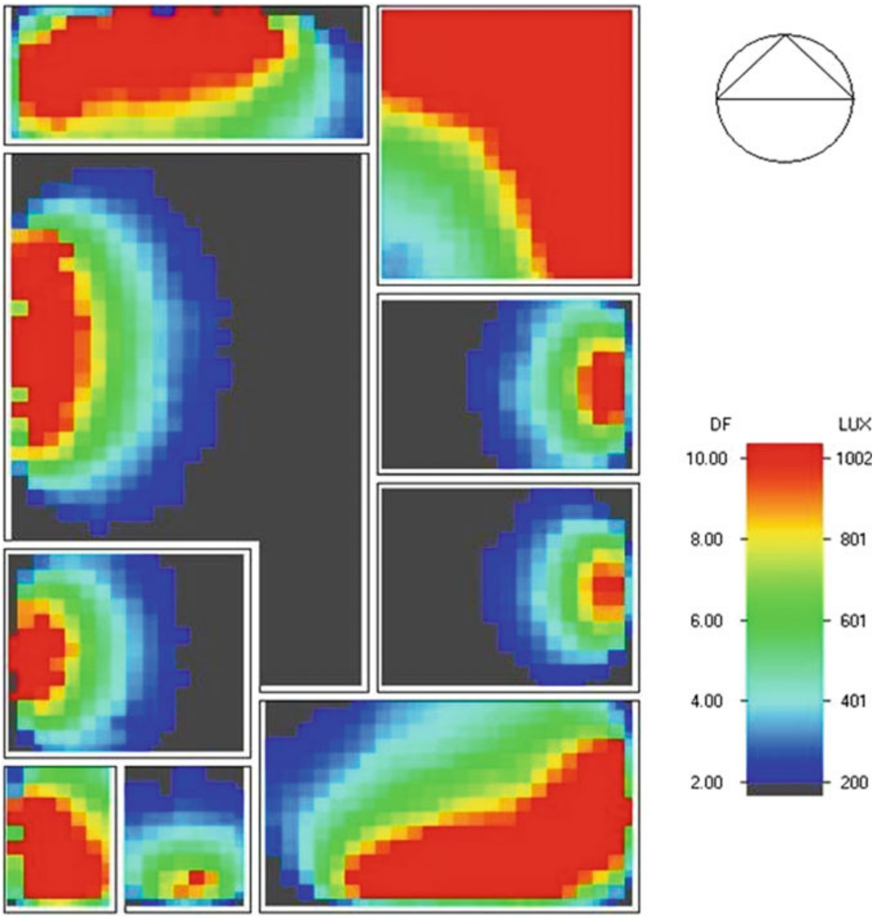


Fig. 11 Daylight inside the room (aspect ratio 1:1.5 and WWR40%)

of 30, 40, and 50%, respectively. Daylight and sunlight dispersion map of model-03 is shown in Figs. 15, 16 and 17.

Also, an overall comparison of electricity usage, annual energy consumption and temperature for different Aspect Ratios are presented in Figs. 18, 19 and 20 (Table 12).

5 Conclusion

(1) In warm and humid climate conditions, the aspect ratio of 1:1, for a square building, energy consumption is 8–12% lesser in comparison with aspect ratio of 1:1.5.

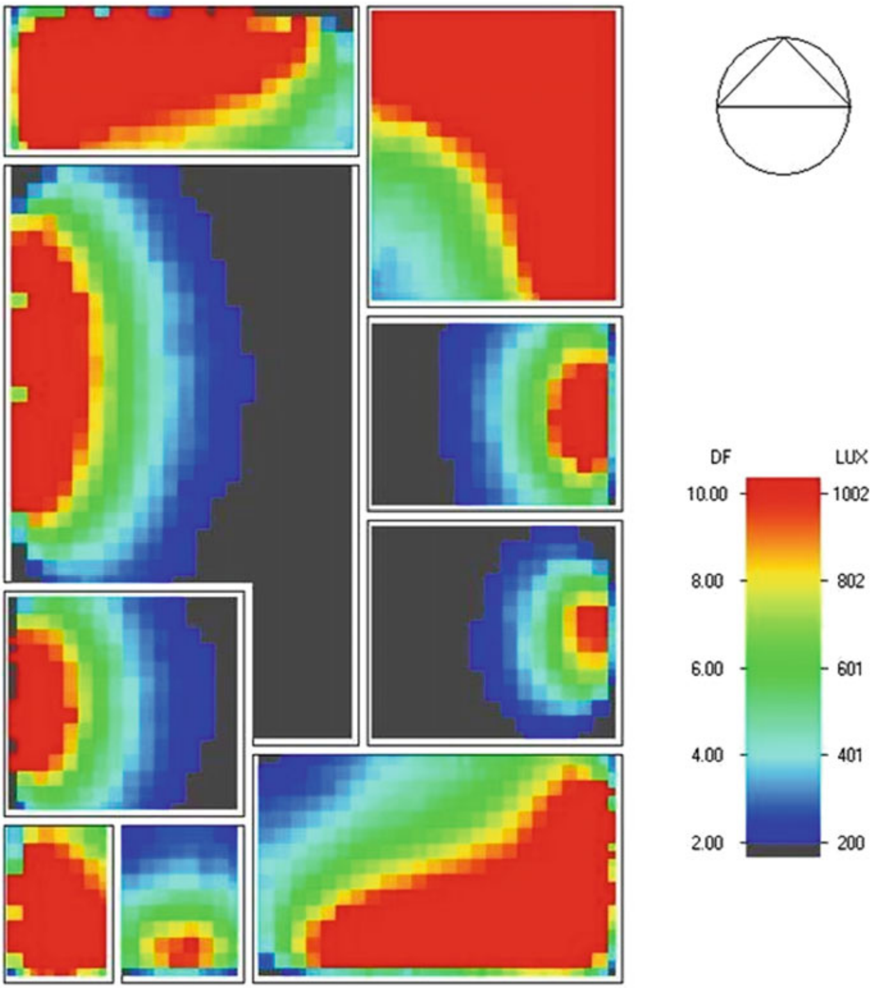


Fig. 12 Daylight inside the room (aspect ratio 1:1.5 and WWR50%)

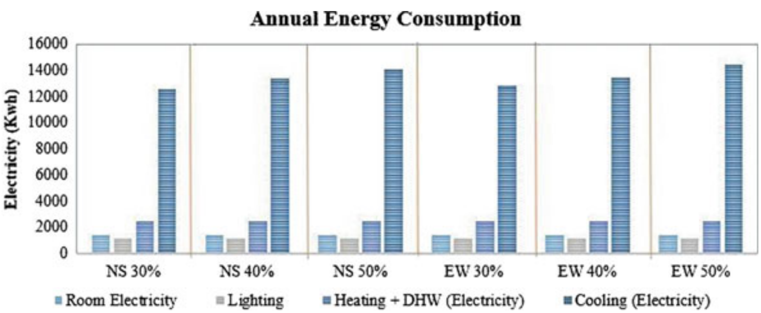


Fig. 13 Energy consumption chart model-3

Table 10 Annual energy consumption for NS and EW model-02

Window to wall ratio (%)	Annual energy consumption (kWh)		Difference in %
	NS	EW	
30	16,012.5	16,431.3	2.61
40	16,491.9	16,828.3	2.03
50	16,950.3	17,236.4	1.68

Table 11 Energy consumption results model-3

Description		Values					
Aspect ratio		1:2					
Orientation		North–South			East–West		
Window to wall ratio		30%	40%	50%	30%	40%	50%
Room electricity (kWh)		1448.9	1448.9	1448.9	1448.9	1448.9	1448.9
Lighting (kWh)		1131.9	1172.0	1167.83	1179.6	1170.9	1166.5
Heating + DHW (electricity, kWh)		2516.8	2516.8	2516.8	2516.8	2516.8	2516.8
Cooling (electricity, kWh)		12,576.8	13,367.2	14,111.0	12,883.7	13,483.0	14,416.1
Annual energy consumption (electricity, kWh)		17,674.4	18,504.9	19,244.5	18,029.0	18,619.6	19,548.3
Temperature (°C)	Outside	36.6	36.6	36.6	36.6	36.6	36.6
	Inside	34.5	34.61	34.65	33.75	33.9	34.1

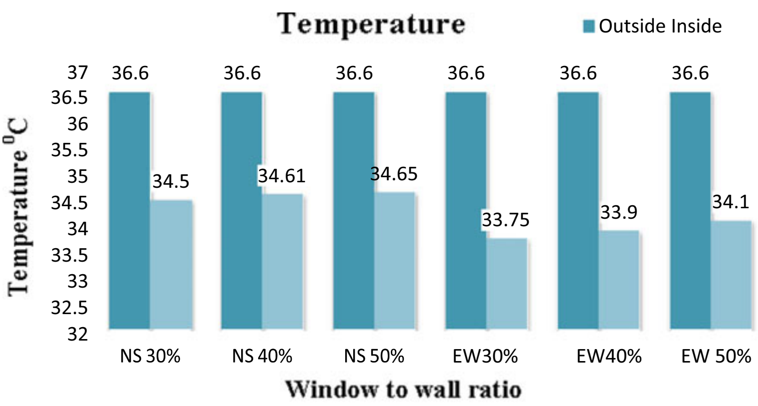


Fig. 14 Temperature variations between inside and outside environments for model-3

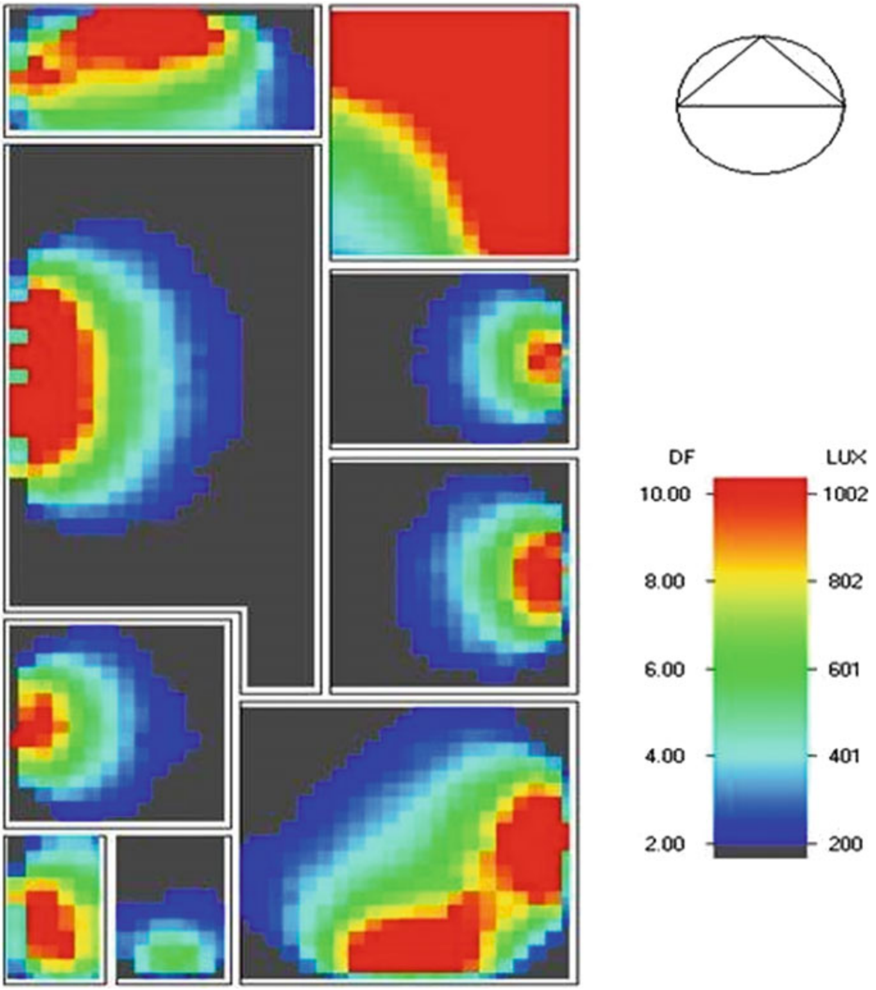


Fig. 15 Daylight inside the room (aspect ratio 1:2 and WWR30%)

(2) Annual energy consumption for North–South orientation is found to be lesser as compared to the East–West orientation for window to wall ratio 30%, 40%, and 50% respectively. The trend remains same for increased aspect ratios of 1:1.5 and 1:2.
(3) A window to wall ratio increases overall energy consumption of the building. However, the energy required for lighting decreases.
(4) Every 10% increase in the window to wall ratio, the inside temperature increases by 0.25–0.5 °C.

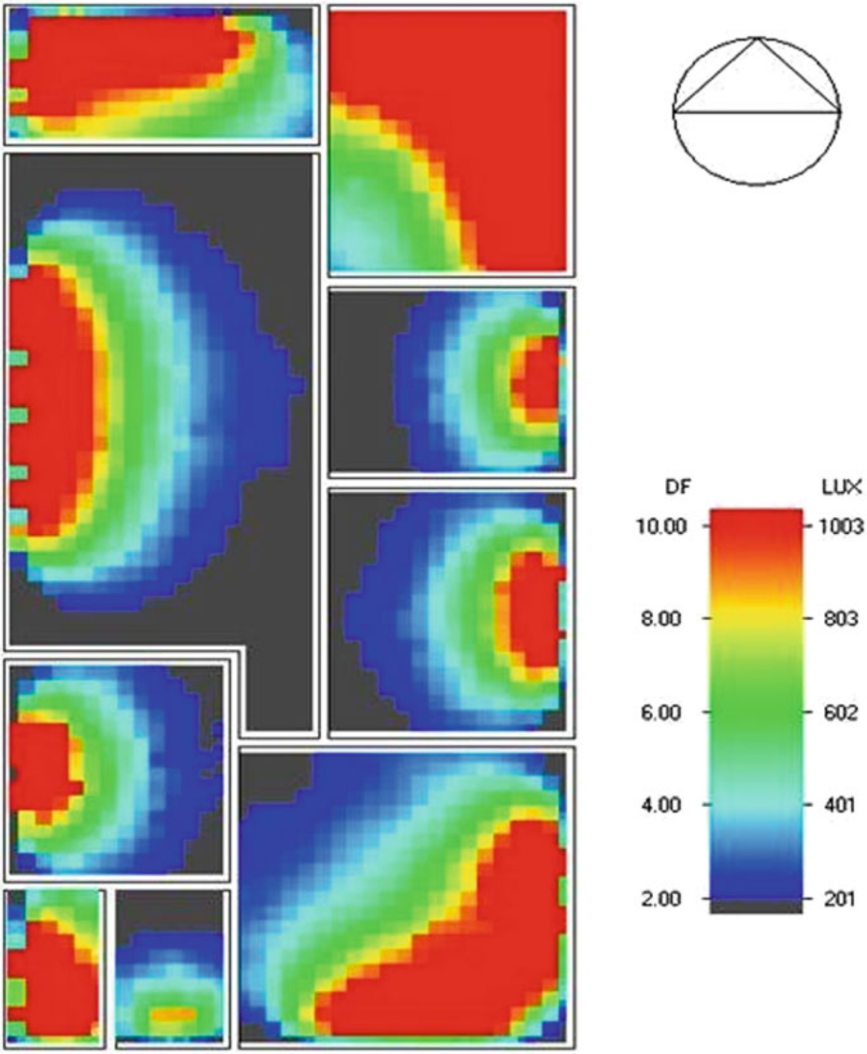


Fig. 16 Daylight inside the room (aspect ratio 1:2 and WWR40%)

The study is conducted based on the analytical approach using a software tool. Hence, further study involving actual experimentation can be conducted to validate the obtained results.

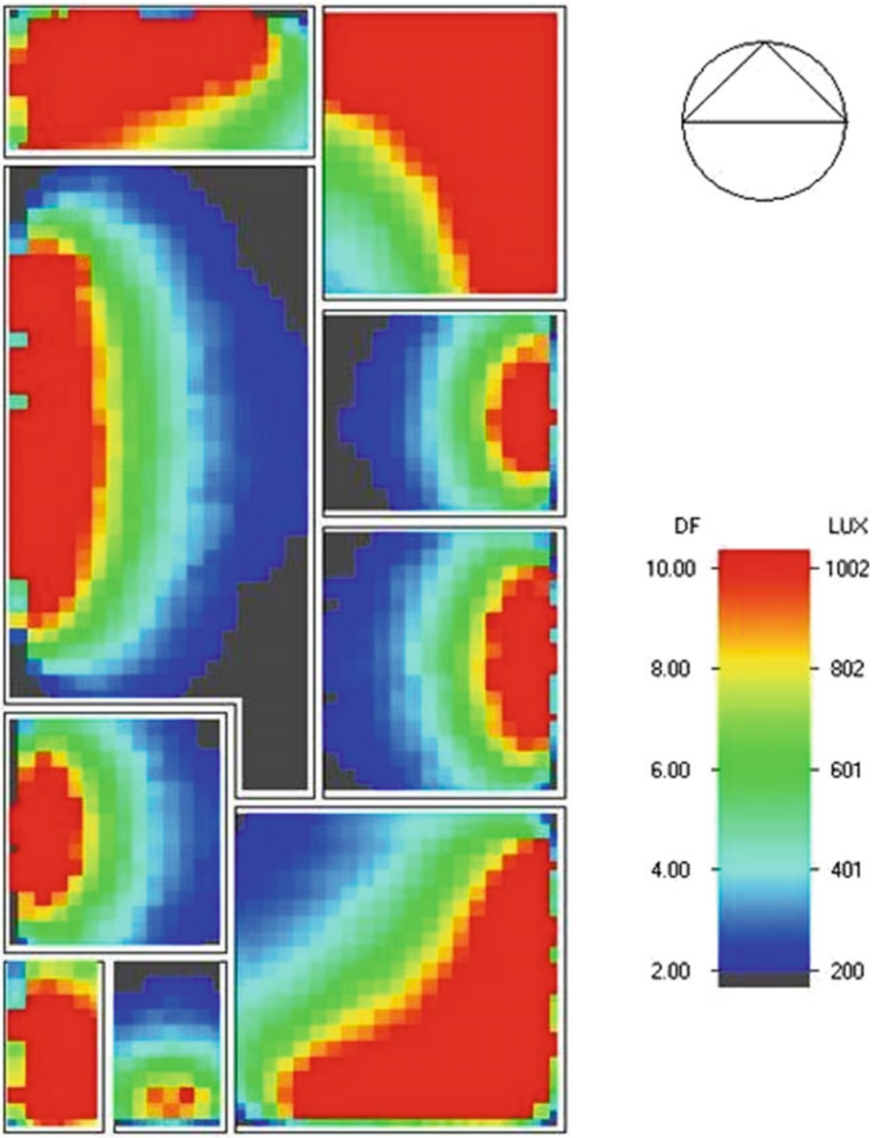


Fig. 17 Daylight inside the room (aspect ratio 1:2 and WWR50%)

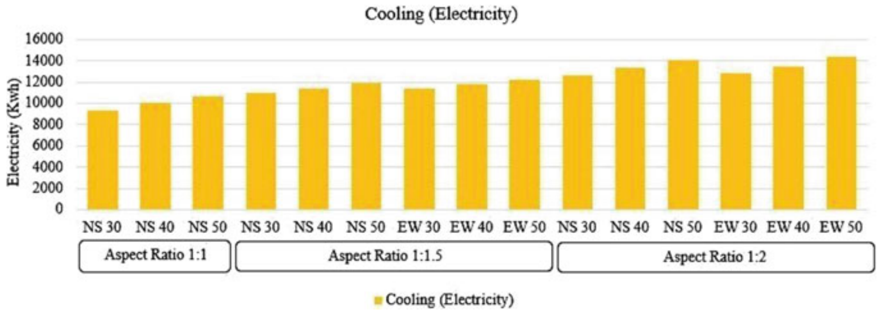


Fig. 18 Cooling load for all the models

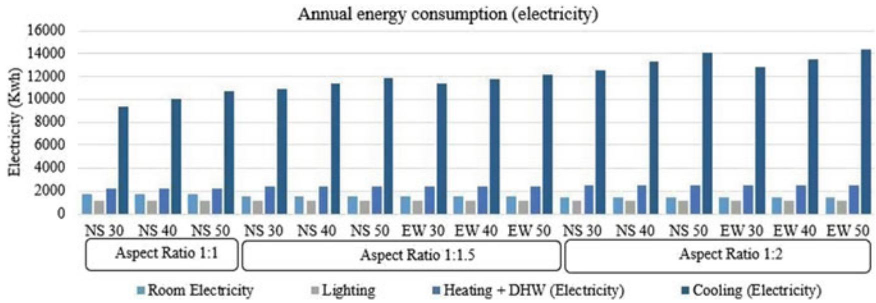


Fig. 19 Annual energy consumptions for all the models

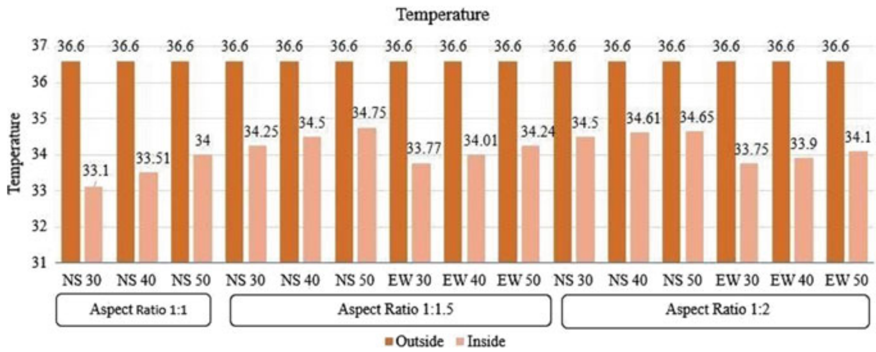


Fig. 20 Summary of temperature variations between inside and outside environments

Table 12 Annual energy consumption for NE and EW model-03

Window to wall ratio (%)	Annual energy consumption (kWh)		Difference in %
	NS	EW	
30	17,674.4	18,029	2.01
40	18,304.9	18,619.6	1.72
50	19,244.5	19,548.3	1.58

References

1. Aneesh NR, Shivaprasad KN, Das BB (2018) Life cycle energy analysis of a metro station building envelope through computer based simulation. Sustain Cities Soc 39:135–143
2. Snehal K, Das BB (2021) Experimental setup for thermal performance study of phase change material admixed cement composites—a review. In: Smart technologies for sustainable development, pp 137–149
3. Pacheco R, Ordonez J, Martinez G (2013) Energy-efficient design of the building. Renew Sustain Energy Rev 16:3559–3573
4. Morrissey J, Moore T, Horne RE (2011) Affordable passive solar design in a temperate climate: an experiment in residential building orientation. Renew Energy 36:568–577
5. Aksoya UT, Inallib M (2006) Impacts of some building passive design parameters on heating demand for a cold region. Build Environ 41:1742–1754
6. Ourghi R, Al-Anzi A, KrartI M (2007) A simplified analysis method to predict the impact of shape on annual energy use for office buildings. Energy Convers Manage 48:300–305
7. Eskin N, Turkmen H (2008) Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey. Energy Build 40:763–773
8. Jazayeri A, Aliabadi M (2018) The effect of building aspect ratio on the energy performance of dormitory buildings in cold and semi-arid climates of Iran. In: International conference on sustainability, green buildings, environmental engineering & renewable energy, pp 1–6
9. Friess WA, Rakhshan K, Hendawi TA, Tajerzadeh S (2012) Wall insulation measures for residential villas in Dubai: a case study in energy efficiency. Energy Build 44:26–32
10. Maile T, Fischer M, Bazjanac V (2007) Building energy performance simulation tools a life-cycle and interoperable perspective. Center Integr Facility Eng Working Paper 1–49
11. Energy Conservation Building Code (2017) ECBC, Bureau of Energy Efficiency