Thermal Performance of Typical Residential Building in Karachi with Different Materials for Construction

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ABSTRACT

This research work deals with a study of a residential building located in climatic context of Karachi with the objective of being the study of thermal performance based upon passive design techniques. The study helps in reducing the electricity consumption by improving indoor temperatures. The existing residential buildings in Karachi were studied with reference to their planning and design, analyzed and evaluated. Different construction's compositions of buildings were identified, surveyed and analyzed in making of the effective building envelops. Autodesk® Ecotect, 2011 was used to determine indoor comfort conditions and HVAC (Heating, Ventilation, Air-Conditioning and Cooling) loads. The result of the research depicted significant energy savings of 38.5% in HVAC loads with proposed building envelop of locally available materials and glazing.

Key Words: Residential buildings, Karachi, Cooling loads, Thermal Performance.

1. INTRODUCTION

Energy consumption in the building sector is very high and expected to increase further due to increase in standards of living and change in building types. In Pakistan 50% of total energy is consumed only in building sector [1]. Population growth, demand for building services and more time spent inside buildings indicates upward trend in energy demand of buildings in the future.

Global warming and climate change are major environmental issues challenging the world today and forcing demands for sustainable housing with reduced impact on climate. Development of sustainable strategies is environmentally viable and socially inclusive. The main drivers behind promoting sustainable architecture are energy consideration as well health improvements. Sustainable construction is also efficient in its use of local and renewable materials. Pakistan is a developing country, facing severe energy crises, to cope up with this energy situation as a challenge. Need of hour is to save energy. The problem of energy efficiency for the buildings in hot humid climates has to be tackled by focusing on the design parameters, climate and its influence how indoor thermal comfort can be achieved.

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The climate of Karachi is featured as hot and humid and is located at 24Ú48'N and 66Ú59'E on coast as shown in Fig. 1. Karachi has mild winter and high relative humidity. Two main seasons are summer and winter with shorter spring and autumn. Summer season persists for longest period during the year. The level of precipitation is low for most of the year. Karachi receives the monsoon rains from July to September.

2. BUILDING ENVELOP

The main components of building envelop include are roof, walls, floors and windows. Building envelop is the key parameter as it is the barrier between internal and external environment. Building envelop can control indoor temperature irrespective of ambient temperature. Deviation of ambient temperature from indoor temperatures can be employed as a tool in architectural planning for indoor thermal comfort [2]. The research of conducted in hot and humid climate indicated that cooling energy saved up to 34.1% annually and 36.8% on peak cooling loads by improving building envelop using insulation, thermal mass, light color paint of external walls, glazing, window area and shading [3]. The research on orientation depicted that energy could be conserved by appropriate control of heating and air conditioning for cooling by proper planning [4]. The research already conducted at architectural department in Lahore resulted in a 29% decrease in cooling when an insulation of polystyrene was added by Arif, et. al. [5].

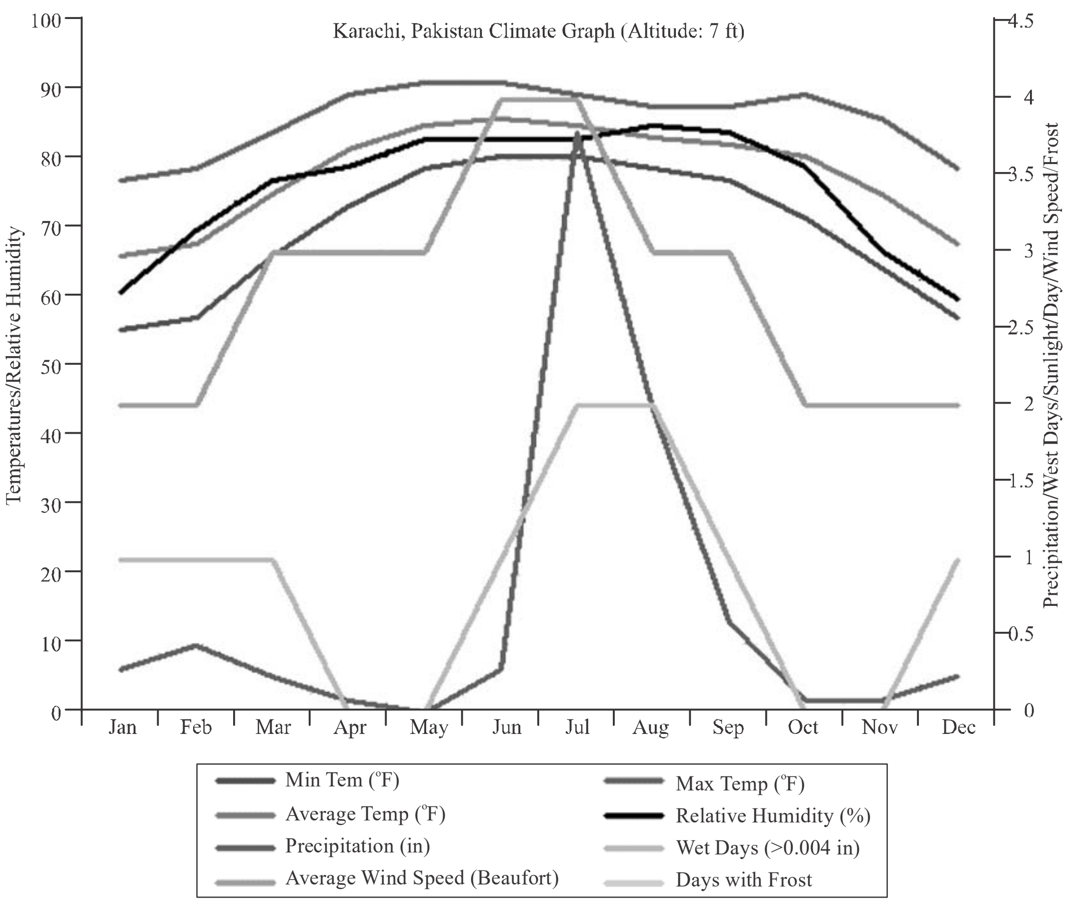


FIG. 1. KARACHI, PAKISTAN CLIMATE GRAPH (ALTITUDE 4M) (SOURCE: http://www.karachi.climatemps.com)

2.1 Roof

Roofs absorb maximum solar radiation in terms of area through which heating and cooling loss occurs [6]. Roof insulation is Important, heat entering through roof is major cause of discomfort for the air-conditioning system of buildings and the concrete roof without passive cooling techniques leads to increase cooling load; different insulations behaves accordingly [7-8]. In single and double story buildings 50-70% heat transfer through roof, in which hollow clay blocks were used as insulation and were 38-63% effective than conventional systems of insulation [9].

2.2 Floors

Thermal mass is very important referred to the high heat capacity, materials that can absorb heat, store it and release it later. In his research he concluded that floors of a building can store thermal energy and help in the regulation of indoor temperatures by absorbing and progressively releasing the heat gained through both external and internal means [10]. The research work of conducted in university of Florida recommended the increased airflow by designing raised floors. Raising the floor slab actually reduces the computed energy savings [11] and the insulation for the floor slab is beneficial, maximum 1m stripe of the perimeter below the floor slab should be insulated to facilitate heat transfer to the soil in summertime.

2.3 Walls

Research about the thermal performance of walls has emphasized upon importance of walls in building envelop, expected to provide thermal and acoustical comfort within the building [12]. Heat flow through wall can be reduced by wall insulation. Wall insulation will reduce both cooling and heating demands of the buildings [13]. Outer surface of the external wall must be reflective and light colored [14]. Massive construction on external walls of east and west can reduce solar heat gain. Their experiment results that by doubling wall thickness on east and west sides cooling loads reduced upto 7-10% [15].

2.3 Windows

Windows and shades can significantly affect air speed and distribution of indoor air flow. It was further concluded that the large windows are more effective in natural ventilation and can improve energy efficiency by glazing [16]. Double glazed low-energy windows with coating and gas filling of low U-value, energy can be saved by minimizing thermal bridges in the constructions and joints to make an airtight building envelop with low infiltration rate [17]. Ventilation is very important in hot and humid region. He recommended that increasing opening area more than 30% is not effective with context to ventilation [18]. The quantitative analysis of ancient buildings reveals that 30-35 % space of total covered area was left for circulation in the buildings in the form of verandah and corridor for natural ventilating and day lighting. [19].

3. METHODOLOGY

This research attempts to investigate potential savings in electricity use in residential buildings in Karachi. A single family residential building was selected as a case study for research purpose. Base case was simulated by number of times. Autodesk® Ecotect, 2011 was used for the analysis and the simulation purpose.

Autodesk® Ecotect, 2011 is energy simulation building tool. Real time hourly weather data for Karachi is compiled for this purpose. Weather tool was used for wind patterns and analysis shading devices and temperature variations. Autodesk® Ecotect, 2011 provides details on every stage of design and can modify design on any stage.

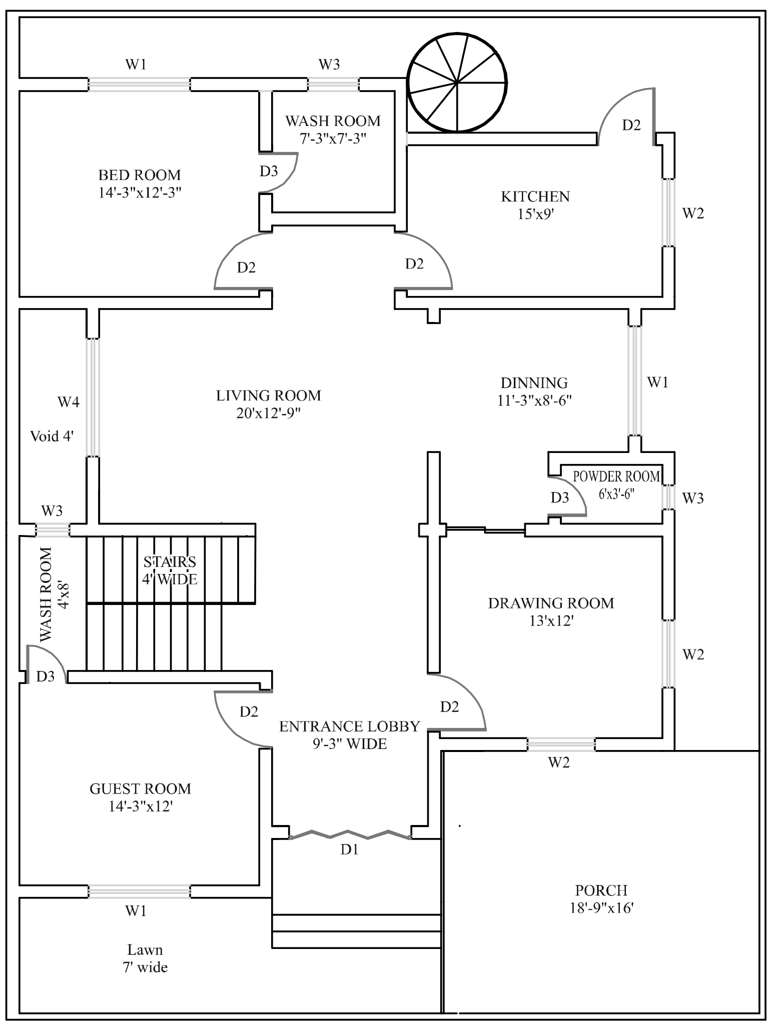
4. CASE STUDY BUILDING

The case study building is located in DHA Society Karachi Phase-VIII .The covered area is 205 sq yard (total area is 300 sq. yard), having 2 storeys. The architectural planning of the residential building is in accordance to the DHA bylaws. The residential building is oriented at -46ÚS Fig. 2(a-b). The design conditions are consider according to the standard indoor conditions as shown in Table 1, and is simulated with conventional construction materials which served as base case.

5. THERMAL PERFORMANCE OF CASE STUDY BUILDING WITH DIFFERENT MATERIALS OF CONSTRUCTION

The simulations were performed with the climatic data for the city of Karachi and after a number of runs; the following properties were evaluated and noted.

Base Case: In base case building traditional building materials were used. Concrete blocks were used in the walls. Mud Phuska was used as insulating material in the roof. Materials specifications and their u-values are given in Table 2.



GROUND FLOOR PLAN

FIG. 2(a). SELECTED CASE STUDY GROUND FLOOR PLAN

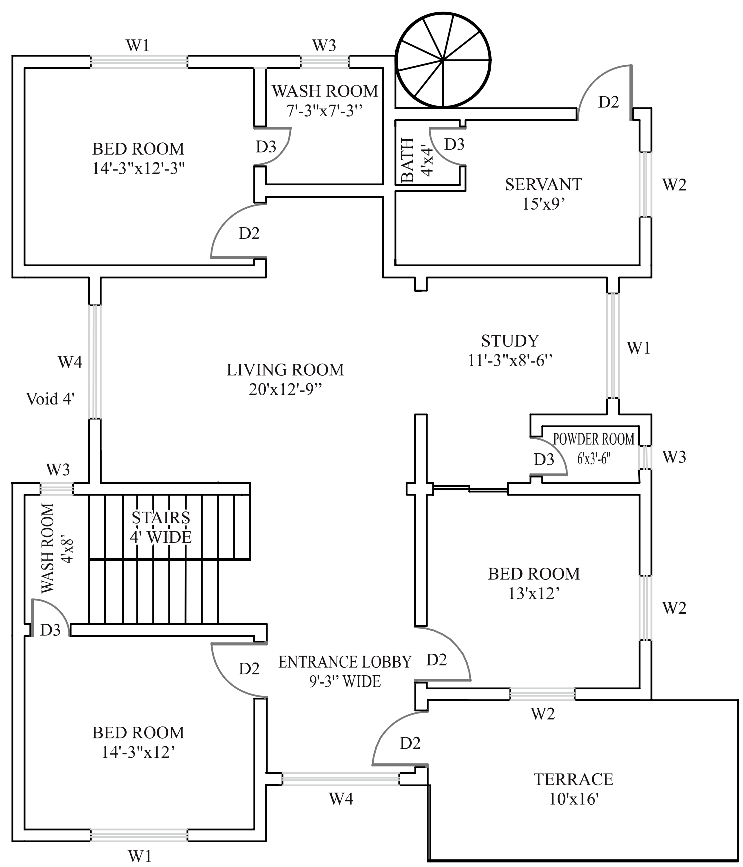
Case-I**:** In base case Mud Phuska was used as roof insulation material. 3 inches Mud Phuska has 0.520 (W/mK) conductance value. In Case-I 1(one) inch polyurethane having conductance value 0.023 (W/mK) was used instead of Mud Phuska. Modified Material properties are given in Table 3.

Case-II: Walls are also critical and main component of building envelop. They transfer heat from inner to outer. In Case-II aerated concrete block was used instead of simple concrete blocks. Aerated blocks have pores or small cavities. Ordinary concrete blocks have Conductance value 1.3 W/mK. Aerated blocks conductance value is 0.240W/mK. Aerated blocks are better insulator due to air cavities and porosity. Modified material properties of wall and roof are given in Table 4.

Case-III: Windows are used for day lighting and control air flow. Ventilation is important in selected case study. But windows intakes extra heat into buildings. For avoiding extra heat double glazed windows was use instead of single glaze window. In walls instead of aerated block-1 (one) inch insulation was used with ordinary concrete blocks. In roof 2 inch Polyurethane insulation was used. Walls, windows and roofs modified materials are given in Table 5.

TABLE 1. INDOOR DESIGN CONDITIONS AS PER WEATHER FILE OF KARACHI, AUTODESK ECOTECT, 2011.

Relative Humidity	75%
Wind Speed	3m/s
Thermostat Range	24
HVAC System	Full Air-Conditioning
Air Change Rate	0.50/hr
Wind Sensitivity	0.50/hr



FIRST FLOOR PLAN

FIG. 2(b). SELECTED CASE STUDY FIRST LOOR PLAN

TABLE 2. THERMAL PROPERTIES FOR BUILDING COMPONENTS AND MATERIAL (BASE CASE)

No.	Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
1.	Roof U Value 1.020 (W/m²k)	Roof Tiles	1 1/2 "	1900	800	0.84
		PCC	2"	950	656	0.209
		Mud Phuska	3"	1620	880	0.520
		Bitumen	0 3/8 "	1700	1000	0.50
		Concrete	6"	2300	656	1.046
		Air Gap	6"	1.3	1004	5.56
		Plaster Ceiling Tiles	3/8 "	1120	840	0.38
2.	Intermediate Floor U Value 0.500	Ceramic Tiles	3/8 "	2000	850	1.2
		PCC	2"	950	656	0.209
		Concrete	6"	2300	656	1.046
		Air Gap	6"	1.3	1004	5.560
		Insulation Fiber Glass	1 15/16 "	12	840	0.04
		Plaster Board	3/8 "	1250	1088	0.42
3.	Ground Floor U Value 1.330	Ceramic Tiles	3/8 "	1900	656	0.309
		PCC	2"	2000	656	0.755
		Brick Masonry	4"	2000	836	0.711
		Sand	4"	2240	840	1.711
		Soil	9"	1300	1046	0.837
4.	Walls U Value 1.800	Plaster	3/8 "	1250	1088	0.431
		Concrete Block Medium Weight	8"	1800	840	1.3
		Plaster	3/8 "	1250	1088	0.431
5.	Windows U Value 5.430	Standard Glass	1/4 "	2300	836	1.046
6.	Doors U Value 2.980	Plywood	1/8 "	530	1400	0.140
		Air Gap	1 5/6 "	1.3	1004	5.560
		Plywood	1/8 "	530	1400	0.140

6. RESULTS AND DISCUSSIONS

The selected case study in the climatic conditions of Karachi was assumed to be the base case. A number of simulations were performed using Autodesk® Ecotect, 2011 and interactive behavior of methodology used, demonstrated reduction in the energy loads for heating as well as cooling the spaces in the residential building. Analysis results in total energy load of Base Case as 21625.25 KWh including 20179.15 KWh as cooling loads and 1446.1 KWh as heating loads. In Case-I by changing Insulating material in the roof, reductions was observed in the loads. Total load of Case-I was 18863.47 KWh including cooling loads of 17184.14 KWh and of heating loads 1279.332 KWh. A 12.7% reduction was observed in energy consumptions including 14.8% savings in cooling and 11% in heating demands.

In Case-II by changing wall material from ordinary to porous blocks, more reduction was observed as compared to Case-I. The building loads were 15680.63 KWh including 15002.6 KWh cooling and 678.251 KWh of heating. This results in 27.5% reduction in total energy loads including 25% in cooling and 53% in heating demands.

In Case-III by changing window's glazing and insulated walls instead of Aerated concrete block, the energy loads were reduce to 13307.3 KWh, comprising of 13048.32 KWh in cooling and 258.984 KWh in heating. In this Case maximum energy savings were observed. Total energy savings were 38.5% including Cooling load reductions up to 35% and reduction in heating was 82%. The comparison of thermal performance of all Cases with percentage reductions is evaluated which is shown in Fig. 3. Building envelop of Case-III is more effective

TABLE 3. THERMAL PROPERTIES FOR BUILDING COMPONENTS AND MATERIAL (CASE-I)

Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
Roof U Value 0.48	Roof Tiles	1 1/2 "	1900	800	0.84
	PCC	2"	950	656	0.209
	Polyurethane Expanded	1"	1620	880	0.023
	Bitumen	0 3/8 "	1700	1000	0.50
	Concrete	6"	2300	656	1.046
	Air Gap	6"	1.3	1004	5.56
	Plaster Ceiling Tiles	3/8 "	1120	840	0.38

TABLE 4. THERMAL PROPERTIES FOR BUILDING COMPONENTS AND MATERIAL (CASE-II)

Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
Walls U Value 0.983	Plaster	3/8 "	1250	1088	0.431
	Concrete Block Aerated	8"	750	1000	0.240
	Plaster	3/8 "	1250	1088	0.431

than the previous construction materials. Indoor temperatures were also improved by making effective building envelop deigns as shown in Fig. 4.

7. CONCLUSION

The purpose of study is to investigate the effective building envelop composition for energy conservation in residential buildings in Karachi. From the base case to the Case-III, total reduction in energy consumption was 38.5%, including 35% reduction in cooling and 82% in heating demands. The indoor temperatures were controlled for minimizing the energy use by using construction materials only. Therefore, the thermal Comfort and healthier environment in residential buildings can be achieved by providing proper insulation materials.

8. FUTURE RECOMMENDATION

The future research studies may involve composite materials of construction. Major barriers of technical, economic and financial behavior and awareness of end users may be overcome.

9. LIMITATIONS OF STUDY

This study focused on construction materials and their thermal properties, other associated properties for buildings should also be investigated in detail.

TABLE 5. THERMAL PROPERTIES FOR BUILDING COMPONENTS AND MATERIAL (CASE-III)

No.	Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
1.	Walls U Value 0.520	Plaster	3/8 "	1250	1088	0.431
		Polyurethane Foam	1"	40	1674	0.032
		Concrete Medium Weight	8"	1800	840	1.3
		Plaster	3/8 "	1250	1088	0.431
2.	Roof U Value 0.330	Roof Tiles	1 1/2 "	1900	800	0.84
		PCC	2"	950	656	0.209
		Polyurethane Expanded	2"	1620	880	0.023
		Bitumen	0 3/8 "	1700	1000	0.50
		Concrete	6"	2300	656	1.046
		Air Gap	6"	1.3	1004	5.56
		Plaster Ceiling Tiles	3/8 "	1120	840	0.38
3.	Windows U Value 2.7	Standard Glass	1/4 "	2300	836	1.046
		Air Gap	1 3/16 "	1.3	1004	5.560
		Standard Glass	1/4 "	2300	836	1.046

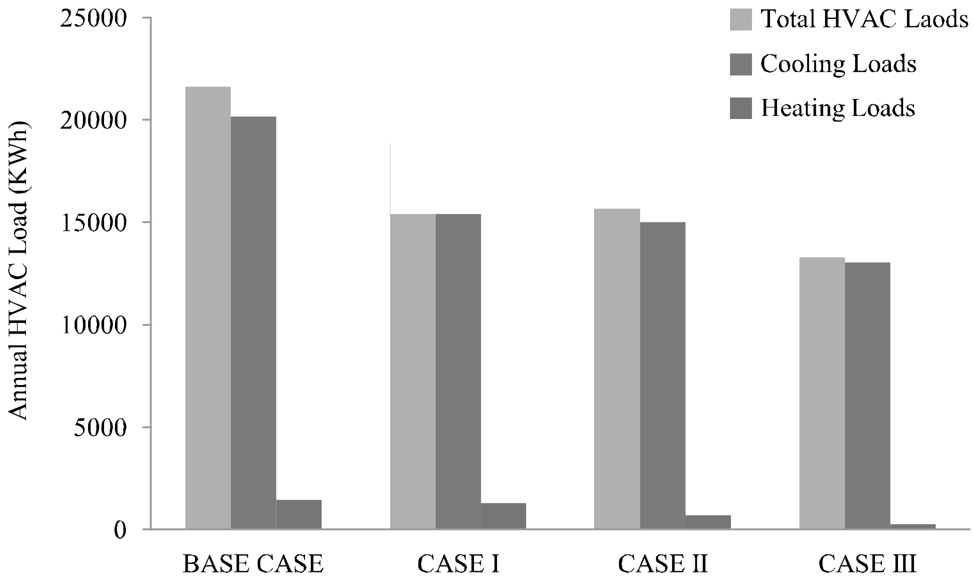


FIG. 3. COMPARISON OF THERMAL PERFORMANCE IN (KWH) OF ALL FOUR CASES ANNUALLY

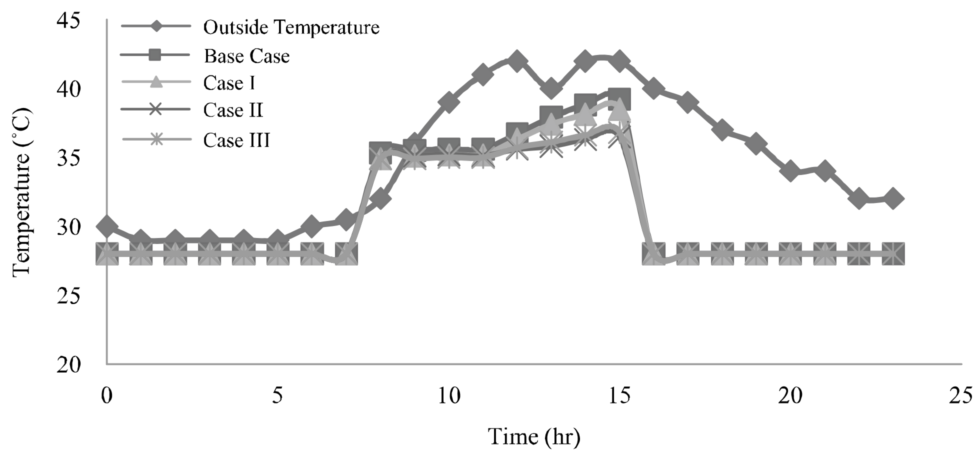


FIG. 4. REDUCTION IN INDOOR TEMPERATURES ON 3RD JUNE (ONE OF HOTTEST DAY)

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