Trombe Wall as a Passive Design Strategy in Tunisian Dwelling Using BIM Technology

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Abstract

In Tunisia, the energy consumption associated with the residential building sector has continuously increased over the last three decades. This sector was identified to be one of the most cost-effective sectors for reducing energy consumption by the progress and the use of efficient technologies. Passive and active systems using clean energies are developed to lessen the energy needs and provide a sustainable environment. The Trombe wall system is efficient if it is correctly designed. This study aims to assess the thermal efficiency of the Trombe wall system in the Tunisian climate. To achieve our goal, a promising new technology BIM (Building Information Modeling) is used to evaluate the thermal effect of passive solar heating in Tunisian dwellings. Therefore, Energy Use Intensity, Annual Energy Cost, and Life Cycle Energy Cost parameters are used to assess the performance energetic and environmental of Trombe wall system.

Keywords: BIM; Trombe wall; Revit, design; Passive strategy

1.Introduction

Principle of the passive solar heating depends on benefiting from the solar energy available in nature as the thermal flow amount is controlled without using any additional auxiliary electrical or mechanical means [1]. This kind of passive system use clean energies, and is developed to reduce the energy needs and to provide a sustainable environment [2]. Among, these systems a Trombe wall system was used. The name of this system was taken from the French scientist Michel Trombe who suggested it in 1880) consists of transparent cover (one, two or three layers of the transparent glass or plastic) and a 5-20 cm deep air vacuum in between the transparent cover and the storage mass (which must have a high thermal capacity) which is coated with a black or a selective paint. Thickness of the storage mass is between 6-18 cm and the black coated part of the storage mass is heated by the solar radiation penetrating through the glass layers [1] which it is facing south. Moreover, Trombe wall has some unique features, such as low cost, simple geometry and reliable operation [3]. Therefore, Trombe wall system appears as one of passive effective technical when it is well designed. The performance of daylighting has many aspects, including the comfort and health, visual function [4]. It provides heat gain leading to use this energy for heating. A research study

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in Izmir[I] shows efficiency of Trombe wall with different for improve the heat gain like PV panel, single glass and double glass modules. The experimental results of this studies in Izmir show that the heat stored in the wall during the day is transferred into the room during night time when there is no radiation, moreover that the simulation model of single glass with a shutter for the night time and the evening will provide more thermal gain for winter heating. As the PV module part has a lower solar radiation transmissivity, the air temperature in the air duct of the PV module part is less than the double and single glass parts which is necessary for providing higher electrical efficiency.

The literature review in this field in a cold weather shows that Trombe wall presents a good solution. It is beneficent in winter period the inner temperature reach 14.7°C, however in summer conditions, Trombe wall is an additional source of heat loads [5]. In mild-hot and subtropical climates the integration of PCMs (Phase Change Materials) in the inside surface of the intermediate partition of a Trombe wall helps to reduce the superficial temperature's variability. Also in this case a matching between the melting area and the average values of superficial temperatures is highly beneficial [6]. PV-TW (Photovoltaic- Trombe Wall) will be more feasible, especially in areas with good solar energy resources [7], such as Tunisian Coast. Consequently, many effective solutions have been applied. These solution consist especially in the use of renewable and sustainable energy like solar energy which is the most abundant Tunisian renewable resource, given that solar radiation varies from 1800kWh/m²/year (North) to 2800 kWh/m²/year (South). A study was performed using TRNSYS for the simulation of a simple typical Tunisian building [8]. The study shows that Trombe wall system saves 77% of energy demand for an insulated house with a bang with 8m ventilated wall surface. This study achieved a reduction of 97% of the annual heating load for a 6m² wall surface with external walls with double wall insulation 5cm of expanded polystyrene. This paper aims to assess thermal efficiency of Trombe wall system on intensity of use energy in Tunisian standard home using promising new technology BIM.

The literature review shows that BIM is rarely adopted in the developing country [8, 9, 10]. The advantages of this technology have been cited surveys have been carried out to determine the barriers and problems that prevent the adoption of BIM in the construction field [11, 12, 13, 14]. Thus, the parameters of cooperation, the development of trust and the lack of communication were investigated.

2. Study model

This technic bioclimatic is efficiency regarding climate parameters as solar radiation and the thermal properties of the envelop [15]. Trombe wall principle is based on thermosiphon phenomena. It is generally made of stone, brick, or concrete, with high inertia and black color installed at a small distance from a glazing “Fig 1”. The wall absorbs solar radiation and transmits part of thermal energy into the building by natural convection through the solar chimney formed by the glazing on one side and the wall on the other. The heat absorbed from the sun by the external surface of the wall is conducted slowly through the massive wall to the inner surface and then to the room by radiation and convection [16]. The advantage of the important heat capacity of the wall is storing heat from the sun during the day and releasing it into the building space during the night [17] - [18]. Our study is limited in Sousse city of Tunisia. In Sousse the period of heating and cooling concerning residential buildings are similar [19]. My selection is made for an apartment setting up in second floor (Fig 2).

2.1 Simulation tool

There are several softwares that are used for thermal simulation and each of them has its own interface and its own engine for modeling, calculation and analysis. Building actors use conceptual energy analysis tool in draft phase and then they use a dynamic thermal simulation in APD phase and finally the thermal regulatory calculation to classify the building according its thermal efficiency. For heating and cooling load calculation method, these soft wares are

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based to building type (residential or non-residential). They use for residential building calculation a detailed method RHB (residential heat balance) or the simplified method: RLF (residential load factor).

For non-residential buildings the detailed method HB (Heat balance) and simplified method RTS (radiance time series) are adopted [20] - [21]. Revit uses RTS method calculation, this software is able to assess Annual Energy Use Intensity (EUI) and Annual Energy Cost (EC). Furthermore, BIM model provides an effective platform to overcome the difficulties of acquiring the necessary building data in life cycle assessment (LCA) [22] such as Life Cycle Energy Cost (LCEC). In our study energy analysis, Revit is used to evaluate Trombe wall efficiency and based on EUI, EC and LCEC.

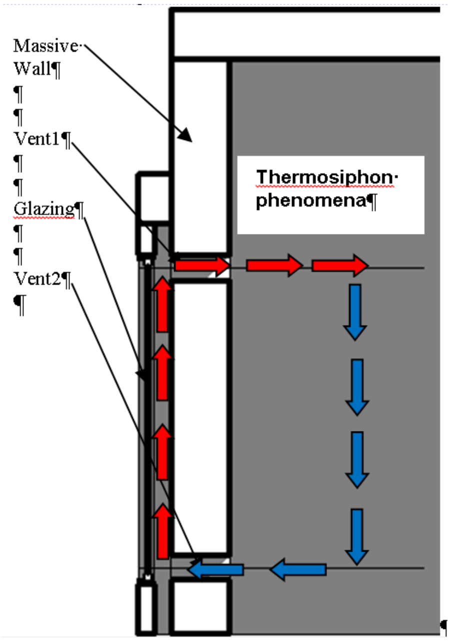

Figure 1- Trombe Wall Detail for House Model

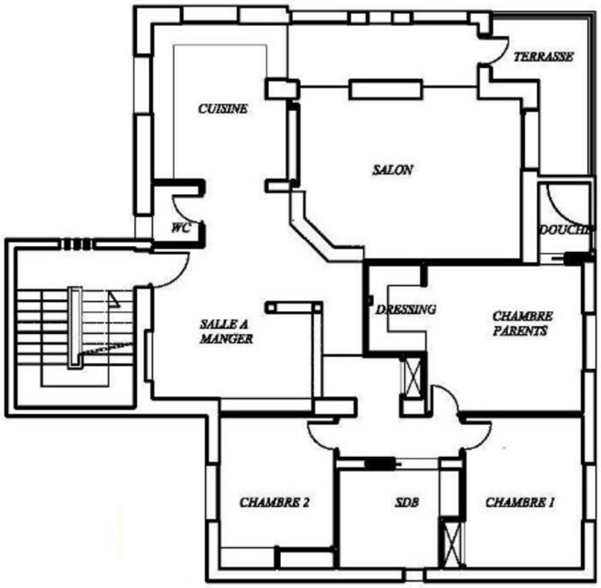

Figure.2.Standard Tunisian House Model Plan

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Revit presents two kind of energy analysis tool: Conceptual energy analysis (CEA) and Heating and cooling tools. In this paper, CEA is used to simulate a traditional model. CEA is a tool for overall conceptual analysis to compare several variants. He works in the cloud that enables her to analyze without disrupting the workflow. This thermal analysis is done from the draft phase. This tool consists of two modes: conceptual mass mode and building elements mode. Like shown previously a heat absorbed by a Trombe wall through a wall is conducted to inner after a time delay that corresponds to RTS (Radiant Time Series) method used by Revit to calculate the load of heating and cooling.

2.2 Calculation Method

This method used to calculate the heating and cooling needs month by month according to space and area. It is suitable for the maximum design load. The different assumptions for RTS calculation method as following:

- Design conditions are periodic regular and steady for climate and occupation.
- The conditions of heat gain are identical cyclically for 24 hours.

Thus, the heat gain for a particular component at a particular hour is the same as the 24 prior, which is the same as 48h prior. This assumption is the basis for the RTS derivation from the HB method. For calculation of the cooling load, the RTS method takes into account the two delay time:

- Time delay by conduction
- Time delay by radiant [21].

Conduction Time Delay

The heat transfer by conduction through the walls makes from external surface envelope to interior area is caused by a difference between the inside temperature and the outside temperature. This heat gain will transfer to the inside after a time difference. This delay is due to the heat capacity of envelope and materials of construction. RTS method accounts for the conduction time delay effects by multiplying heat gain by 24h time series. The time series multiplication, in effect, distributes heat gain over time. Series coefficient is called conduction time factors. The conduction time factors reflect the percentage of earlier heat gain at the exterior of a wall or roof that becomes heat at the inside during the current hour.

Radiant Time Delay

Heat sources transfer energy to the indoor environment by a combination of convection and radiation. The convection heat gain portion converted instantly to a cooling load against the radiant part converts to a cooling load after a delay of one time period. This delay is due to the thermal capacity of the heat source internal or external gain. RTS method accounts for radiant time delay effects by multiplying heat gain by 24h time series. The time series multiplication, in effect, distributes heat gain over time. Series coefficient is called radiant time factors. The radiant time factors reflect the percentage of earlier heat gain that becomes cooling load at the current hour. Therefore, Revit for calculation is based on both time delay by conduction and time delay by radiant that depends on heat capacity (HC) using the following equation [21]:

$$\mathrm{HC} = \sum_{i=1}^{n}(\rho_i \times c_i \times t_i) \qquad (1)$$

Where:

n: is the total number of layers in the assembly.
C_i: is the density of the layer, kg/m³.
$\boldsymbol{\rho}_i$: is the specific heat of the layer, kj/kg.k
t_i: is the thickness of the layer all in constant units, m.

3. Modelization trombe wall system

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For assess thermal performance of Trombe wall system in Tunisian house, a geometric model is needed, and conceptual Massing design is adopted (fig 3). The Trombe wall system is oriented at south (fig 4). It has 6m² glazing. It is divided to two parts and each one has 3m² areas. It is setting up 0.15m height in south face. The storage wall has a low insulation. The heat absorbing wall surface is painted black matt. For convective heat transfer, two vents are located at the upper and the lower positions of the wall, each one measuring 0.25m/0.15m“Fig 5”. The lower vent is located 0.3m height but upper vent is setting 2.75m height. The air gap between the wall and the glazing is 0.10m like “Fig. 1”. Exterior wall has 0.25cm

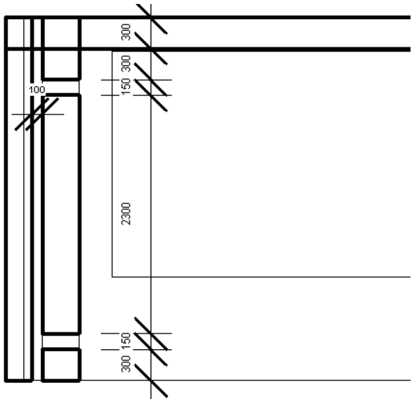

Figure 3- View of Upper and Lower Vents Positions in our study model

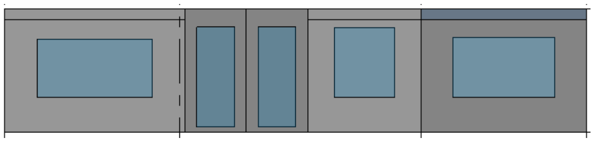

Figure 4- View of Trombe Wall Facing South Direction

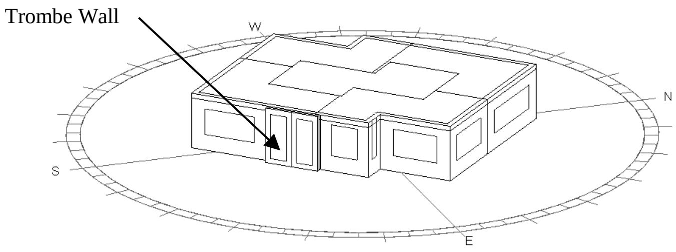

Figure 5- House Model Using Massing design for Trombe Wall System.

4 Input energy setting

After create geometric model, is needed to create an energetic model then to set “energy setting”. In energy setting workflow exhibits four parameters parts as: Common, Detailed Model, Energy Model, and Energy Model-Building Services.

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Common

In common part of dialog box, are needed to specify a location and building type “Fig. 6”.

Energy model Building Services

Energy model building services dialog box divides to different parts as: operation schedules, HVAC system, outdoor information.

Operations schedules

For a two models, a system that works half year (12/7) for period heating was chosen.

HVAC System

A system, 11 EER Packaged VAV, 84.5% heating boiler is adopted for heating.

Outdoor Air Information

According Roulet [23] air renewal rate is sum of ventilation and infiltration. This rate is considered steady in heating period that corresponds to 2.25 vol /h. According Ouartani [19] air renewal rate is varying in summer. During the daytime, she considered previous winter value but at night, she adds 10vol/h because, in cooling period occupant opens window at night to aerate his dwelling. Thus in summer air renewal rate is 12.25 vol /h. Therefore, the amount Outdoor air per area of a model is 2.18 l / s. m² in winter and spring meanwhile, in summer the outdoor air is 12 l /s.m². For simulation, 4 “Heated” zones were adopted in winter period. Then, 4 “Cooled” zones in summer period were affected. Finally, one zone “Natural Vented Only” and 3 “Unconditioned” zones were selected in condition type dialog box for a springer period.

Table 1 – Distribution of outdoor air flow in the zones

Simulation period	**Condition Type**	**Outdoor air flow (l/m².s)**
winter	4Heated zones	2,18
Summer	4Cooled zones	12
Spring	1Natural vented+3unconditioned zones	2,18

Detailed model

In dialog box, energy model proprieties are needed to adjust the percentage glazing of energetic model as 30% with 1m still height and 6m² total glazing area of Trombe wall system like seen prior is used. Then, to simulate Trombe wall system, Conceptual Mass mode for energy analysis and spaces are exported. “Fig. 7” displays Building constructions elements used for simulation test without Trombe wall and a test with Trombe wall.

Energy model

To simulate Trombe wall, the year is divided in 3 periods according table 2.

- Period of cooling (summer) from July to October
- Period of heating (winter) from November to February.
- Period without conditioned system (springer) from Mars to June.

Table 2 –Distribution of condition types in the zones

Simulation period	**Condition Type**
winter	4Heated zones

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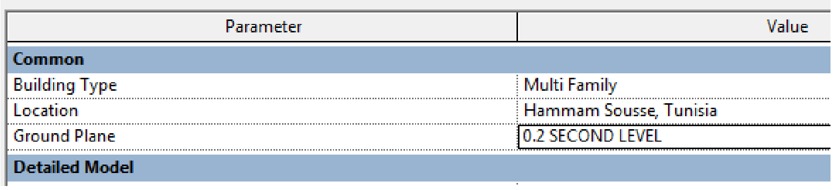
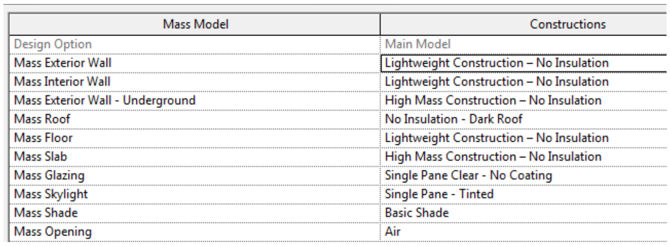
Summer	4Cooled zones
Spring	1Natural vented+3unconditioned zones



Parameter	Value
Common	
Building Type	Multi Family
Location	Hammam Sousse, Tunisia
Ground Plane	0.2 SECOND LEVEL
Detailed Model	

Figure 6- Energy setting, common parameters workflow



Mass Model	Constructions
Design Option	Main Model
Mass Exterior Wall	Lightweight Construction – No Insulation
Mass Interior Wall	Lightweight Construction – No Insulation
Mass Exterior Wall - Underground	High Mass Construction – No Insulation
Mass Roof	No Insulation - Dark Roof
Mass Floor	Lightweight Construction – No Insulation
Mass Slab	High Mass Construction – No Insulation
Mass Glazing	Single Pane Clear - No Coating
Mass Skylight	Single Pane - Tinted
Mass Shade	Basic Shade
Mass Opening	Air

Figure 7- Conceptual Constructions Workflow For Trombe Wall System

5. Result for simulation

Energy analysis results of six tests using Conceptual Mass Mode show that annual energy use in standard house shown in as following:

Test 1

Table 3 –Annual intensity of energy use using conceptual mass mode without trombe wall in winter, summer and spring period of Tunisian house

Period of simulation	**Condition Type**	**Outdoor air flow (l/m^2.s)**	**Annual**	**(EC)**
winter	4H	2,18	977	3459
Summer	4C	12	887	4340
Spring	1NV+3UN	2,18	395	1445

Test 2

A thermal feature of Trombe wall system is added to envelope model.

Table 4 –Annual EUI, EC and LCE using Trombe wall oriented South-East, in Tunisian house

Period of simulation	**EUI (MJ/m^2/yr)**	**(EC)($)**	**LCEC($)**
winter	1016	3650	49720
Summer	933	4622	62955
Spring	326	1262	17191

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Test 3

In this part of paper, the last test model is rotated to 45°.

Table 5 –Annual EUI, EC and LCE using Trombe wall oriented South, in Tunisian house

Period of simulation	EUI (MJ/m²/yr)	(EC)($)	LCEC ($)
winter	1001	3594	48949
Summer	926	4585	62446
Spring	323	1252	17058

Test 4

Concerning test 4, the same thermal features is used as test 3 and the glazing thermal parameter are changed.

Table 6 –Improvement of mass exterior wall of trombe wall model, based on EUI, AEC and LCEC in heating period

Conceptual Construction	EUI (MJ/m²/yr)	(EC) ($)	LCEC ($)
High mass construction-No Insulation	914	3246	44217
High mass construction-High Insulation	910	3339	45475

Table 7 –Improvement of mass exterior wall of trombe wall model, based on EUI, AEC and LCEC in heating period

Conceptual Construction	EUI (MJ/m²/yr)	(EC) ($)	LCEC ($)
High mass construction-No Insulation	864	4246	57828
High mass construction-High Insulation	892	4396	59873

Test 5

Table 8 –Improvement of mass glazing of trombe wall model, based on EUI, AEC and LCEC in heating period

Conceptual Construction	U W/(m².°K)	SHGC	Tvis	EUI (MJ/m²/yr)	(EC) ($)	LCEC ($)
Double Pane Clear – LowE (Emissivity), Hot Climate, Low SHGC	1.68	0.44	0.70	838	3018	41111
Double Pane Clear - High Performance, LowE, High Tvis, Low SHGC	1.63	0.27	0.64	828	2919	39753
Double Pane - Reflective	2.40	0.19	0.10	849	2966	40402

Table 9 –Improvement of mass glazing of trombe wall model, based on EUI, AEC and LCEC in heating period

Conceptual Construction	U W/(m²K)	SHGC	Tvis	EUI (MJ/ m²/yr)	EC ($)	LCEC ($)
Double Pane Clear – LowE (Emissivity), Hot Climate, Low SHGC	1.68	0.44	0.70	875	4305	58633
Double Pane Clear - High Performance, LowE, High Tvis, Low SHGC	1.63	0.27	0.64	799	3895	53045

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Double Pane - Reflective	2.40	0.19	0.10	797	3881	52856

Test 6

Table 10 –Best improvement using mass glazing and trombe wall model, based on EUI, AEC and LCEC in cooling period

Description of conceptual construction parameters	Period of simulation	EUI (MJ/m²/yr)	(EC) ($)	LCEC ($)
High Mass Construction with no insulation + Double Pane Clear - High Performance, LowE, High Tvis, Low SHGC + Roof mass with high insulation	winter	748	2703	36820
	Summer	727	3500	47676

BIM provides great potential for conducting whole building LCA (life cycle assessment), LCEC value that corresponds to Fuel amount of our analyzed model may use during 30 years period and amount of EUI in design stage [24]. Table III and Table IV show that a model without Trombe wall system need lower annual energy use than model with Trombe wall system. Moreover, test 1 exhibits maximal load energy in winter period. However, to compare test 1 and 2 was found that model with Trombe wall system has high energy use intensity in summer heating period. However, in spring Trombe wall system decrease EUI, EC and LCEC. In order to reduce amount and cost of energy needed using Trombe wall system, some improvements parameters were considered. Then in test3, last model is rotated to South direction. Table 4 and 5 show the difference of EU between Trombe wall system located in South-east and a model setting in South A gap of EUI increases especially in winter period because heat gain rises in South orientation and it is efficient in heating period. Meanwhile, EUI of Trombe model remains higher than a model without Trombe wall in winter and summer. Due to leakage of heat load through glazing and envelope in these periods. Therefore, is need to improve a thermal quality of Trombe wall model. Table VI shows that high mass with high insulation able to save energy needed in heating period. However, table VII displays that high mass construction of exterior wall without insulation is better in cooling period. Moreover, last conceptual construction is validated for two periods, such as it is able to reduce energy use intensity of Trombe wall model in cooling and heating periods. Then for further improvement is retain high mass construction no insulation as conceptual construction. Test5 displays improvements results of thermal quality of glazing. It reveals that Double Pane Clear High Performance Low E High Tvis, low SHGC glazing that provides the best results in heating period. This conceptual construction has 0.27 SHGC and 0.64 as Tvis. Such as it allows 15% as save EUI in heating period. However, Pane Reflective glazing has the best results in cooling period. It provides 0.19 as SHGC and 0.10 as Tvis. It provides 10% as EUI saving in cooling period. Despite prior improvements saving energy intensity percentage remains low during annual period. Fiorito [6] found that heat capacity and variation of PCM position in the external envelope are beneficent to reduce energy use in all climates. In addition, Abbassi [15] shows that roof insulation is beneficial in Trombe wall model in Tunisian climate. Therefore, is needed to mix different strategies in order to rise percentage of energy saving EUI, EC, and LCEC. Then firstly, is opted the Double Pane Clear, High Performance Low E, High Tvis and low SHGC that provides a compromise between Tvis and SHGC value then high mass exterior wall and finally high mass roof insulation. The findings results in test 6 shows that combined improvement able to reduce EUI, EC and LCEC of Trombe wall model in cooling and heating period. Moreover, all prior tests show that annual EC and LCEC for 30 years are higher in cooling period than heating period.

6. Conclusions

Several tests are generated in order to assess efficiency of Trombe wall system in standard Tunisian house using BIM technology based Energy on Use Intensity, Annual Energy Cost and Life Cycle Energy Cost. Findings results in test2 and 3 show that Trombe wall system setting up in South façade is better than South-east. Test 4 determines out that high mass construction no insulation for exterior walls provides more efficient in heating and cooling period

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than high mass with high insulation. In addition, test 5 exhibits that compromise value of SHGC and Tvis of glazing; it is able to save 15% on EUI in heating period and 10% as EUI in cooling period. Meanwhile, combined vary strategies like inertia, SHGC, Tvis glazing and high mass roof insulation enable to reduce EUI. As a result, mixed strategies improvement allows to 17% EUI in cooled period and 23% in heated period. Therefore, Trombe wall system is effective in Tunisian climate only with accurate improvement.

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