Impact of thermal mass for future energy consumption: case study in adobe house

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Abstract: This paper examines thermal mass quality of building envelope as passive preventive phenomena for future energy consumption. It questions how much and what type of thermal mass is required for decreasing energy consumption according to future climate change. Summer energy performance of adobe house in Konya, Turkey is studied in terms of thermal mass characteristic by using dynamic simulation software. Measured and predicted microclimate data for 2017 and 2050s are used to compare passive impact of wall material choices, i.e. adobe, limestone, vertical hollow brick and volume of wall without night-time ventilation. In conclusion, the study reveals that thermal mass with lower density and thinner materials show higher energy performance for summers. Energy consumption is minimum with vertical hollow brick wall in 50 cm for 2017 and 30 cm for 2050s. It is deduced that thermal conductivity will still have higher impact than thermal mass on energy consumption.

Keywords: thermal mass; energy consumption; adobe brick; climate change; dynamic simulation.

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1 Introduction

Increase in global temperatures inevitably results in buildings that will accumulate more heat, and therefore more cooling energy load. The passive solutions supporting adaptability potential of building envelopes into climate change is subject to many researches, specifically focusing on type and amount of thermal mass by different wall materials (Hacker et al., 2008; Slee et al., 2014). Energy store and release cycles of thermal mass are affected by thermal capacity of materials, and diurnal and seasonal temperature changes of local climate. Higher differences between day and night temperatures in cold-arid climatic zones are deployed to discharge accumulated heat in thermal mass. Yet, the higher temperatures due to climate change will minimise discharge capability. Thus, the well-analysed choice on type/amount of thermal mass may serve as a passive solution for decreasing cooling loads.

What absorbs, store and set free thermal energy describes the feature of thermal mass, i.e. equivalent to thermal capacity (kJ/K). Thermal capacity described as the quantity of thermal energy that can be stored by the material is a constant for each material, and obtained with specific heat multiplied with mass that is a product of density and volume (Jankovic, 2012; Slee et al., 2014).

Various parameters (e.g., thermal capacity, dynamic modelling, energy analysis methods, earth wall material types) are examined for earth buildings to decrease energy consumption in early design phase of new constructions as well as retrofit projects of existing buildings (Parra-Saldivar and Batty, 2006; Tanaçan, 2008; Yan et al., 2005). Many researchers agree that earth as the building material with high thermal mass provides bioclimatic comfort and keeps indoor cool in the summer and warm in the winter. Moist air can easily pass through adobe wall because of low vapour permeability resistance, while reducing the risk of inner condensation of adobe walls during winter. The indoor air humidity is regulated by the adobe wall because of its porous property (Değirmenci, 2005; Goodhew and Griffiths, 2005; Hegyi et al., 2016; Minke, 2013; Pacheco-Torgal and Jalali, 2012).

Earth is used with high interest as a construction material because of its cultural heritage value and lower environmental impact (Delgado and Guerrero, 2006). New adobe buildings can be seen in Turkey. For instance, Saklıköy Country Club, a touristic complex containing hotel, restaurant and stable near Istanbul, was constructed with adobe in 1998. The research points out that adobe used as a load-bearing wall material has kept its durability, because construction details were attended thoroughly comparing to other local and conventional building materials (Tanaçan, 2008).

The adaptation potential of adobe to climate change has not been widely investigated in the literature. According to research in Burkina Faso, adobe presents a proper method for reducing cooling energy loads for climate change adaptation. The study focuses on the effect of climate change on energy consumption on an adobe house in Burkina Faso for present and the periods of 2020–2039, 2040–2059 and 2070–2089 (Ouedraogo, 2012). Yet, the literature survey indicates that there is no study relating the climate change effects to adobe buildings in Turkey.

This paper examines thermal mass quality of building envelope as passive preventive phenomena for future energy consumption. It questions how much and what type of thermal mass we need to use for decreasing energy consumption according to future climate change. With this context, totally twelve scenarios are defined with reference to different wall materials and thicknesses. Therefore, one storey detached house located in Konya is tested as the case building with vertical hollow brick (VHB), adobe and limestone in 30 and 50 cm walls for 2017 and 2050s weather data.

2 Material and methods

This study includes the following steps: firstly, measurement of 45 days climate data, i.e. monitoring process, for generating 2017 and 2050s microclimate data; secondly, modelling, simulating and then calibrating the case building according to monitoring results; thirdly, creation of different thermal mass scenarios, i.e. adobe, limestone, VHB for 30 cm and 50 cm for 2017 and 2050s; fourth, comparison of summer energy consumption values for 2017 and 2050s.

2.1 Case building

The case building, situated in Sonsuz Şükran Village, Konya-Turkey, at 37°97' latitude and 31°53' longitudes and 171° to the North, was built in a traditional way in 2010 in 2010 [Figure 1(a)]. All exterior and interior walls were built using adobe bricks. The thickness of adobe walls is 50 cm. For the foundation, the ground was filled with local stones up to 50 cm. For plinth, the stones were used up to 20 cm from ground level. All windows are single glazed with wooden frames. The roof was constructed with poplar tree beams with diameters of 25 cm, spaced at every 35 cm, and covered with 3.5 m long reeds and earth.

Figure 1 (a) The case building view (b) DesignBuilder model of adobe building (see online version for colours)

(a) (b)

2.2 Measurements

The case building was equipped both externally and internally with the diagnostic equipment, i.e., HOBO data loggers, to measure dry bulb temperature and relative humidity in every 10 minutes (28.07.2017–10.09.2017). The measurement range of data loggers is from –20°C to 70°C and from 5% to 95% RH, and the accuracy is ±0.35°C from 0° to 50°C and ±2.5% RH from 10% to 90% (Onset, 2018) (Table 1). The exterior and interior recordings were later used in local weather data generation and model calibration process.

Table 1 Technical specifications of data loggers

Data logger	*HOBO U12 T/RH/light/external data logger*
Measurement range	T: –20°C to 70°C RH: 5% to 95%
Accuracy	T: ±0.35°C from 0°C to 50°C RH: ±2.5% from 10% to 90%

Source: Onset (2018)

2.3 Weather data generation

Future climate data for 2050s (2041–2070) is derived for investigating effect of future climate change on energy consumption. Firstly, the climate change model is determined with the UK Handley Centre's third generation coupled atmosphere-ocean global climate model (Jentsch et al., 2008). Then, present-day weather information data, converted from 10-minute data to hourly, was morphed by using CCWorldWeatherGen tool (HadCM3, 2012). The generated file was used in dynamic simulation software.

2.4 Modelling and simulation

Dynamic simulation software, DesignBuilder v.4.6 (DesignBuilder, 2014), were utilised firstly to model the house, secondly to calibrate with the measurement data, and lastly to simulate for evaluating energy performance. The model covers 63 m^2 area with the height of 2.7 m [Figure 1(b)]. The outer walls comprise one layer of adobe brick and inner/outer 1.5 cm adobe plaster with overall heat transfer coefficient of 0.774 W/m^2K as seen in the first row of Table 2. The overall heat transfer coefficient for roof, ground and windows are 0.387, 1.183, and 3.835 W/m^2K, respectively. The model was run without night-time ventilation. The electricity sourced cooling system was applied in model for 45 days with a set point temperature of 26°C and setback temperature of 28°C.

2.5 Calibration

This paper considers three guidelines regarding calibration of model:

1 ASHRAE guideline 14-2002: measurement of energy and demand savings (ASHRAE55, 2002)

2 IPMVP: international performance measurement and verification protocol (IPMVP, 2002)

3 MVFEP: measurement and verification for federal energy projects (M&VGuidelines, 2008).

These documents describe two statistical indices, MBE and CV-RMSE, both expressed as a percentage. Values close to zero in both indicate better prediction for the models. This study accepts the calibration with hourly data approach: MBE values should not be over ±10% according to ASHRAE 14-2002, ±20% according to IPMVP, and ±10% according to MVFEP. CV-RMSE values should not be exceeded 30% according to ASHRAE 14-2002, 20% according to IPMVP, and 30% according to MVFEP.

2.6 Scenarios

Impact of high thermal mass for future energy consumption is analysed with selection of three locally available and commonly used materials representing low, medium and high thermal qualities (Table 3). Thus 12 different thermal mass scenarios, i.e., combination of wall materials, e.g., VHB, adobe and limestone, with variation of wall thicknesses, e.g., 30 and 50 cm, according to 2017 and 2050s weather data are created (Table 2). Scenario 1, indicated in grey line in Table 2, represents the current case of building. The wall sections are explained in Figure 2.

Table 2 Scenarios and thermal properties of walls

Sc. no.	*Wall material*	*Wall thickness [cm]*	*Year*	*Specific heat [J/kgK]*	*Density [kg/m^3]*	*U-value [W/m^{2}K]*
1	Adobe	50	2017	1,008	1,500	0.774
2	Adobe	30	2017	1,008	1,500	1.180
3	Adobe	50	2050s	1,008	1,500	0.774
4	Adobe	30	2050s	1,008	1,500	1.180
5	VHB	50	2017	800	600	0.610
6	VHB	30	2017	800	600	0.954
7	VHB	50	2050s	800	600	0.610
8	VHB	30	2050s	800	600	0.954
9	Limestone	50	2017	1,000	1,600	1.319
10	Limestone	30	2017	1,000	1,600	1.912
11	Limestone	50	2050s	1,000	1,600	1.319
12	Limestone	30	2050s	1,000	1,600	1.912

Figure 2 Wall sections of scenarios

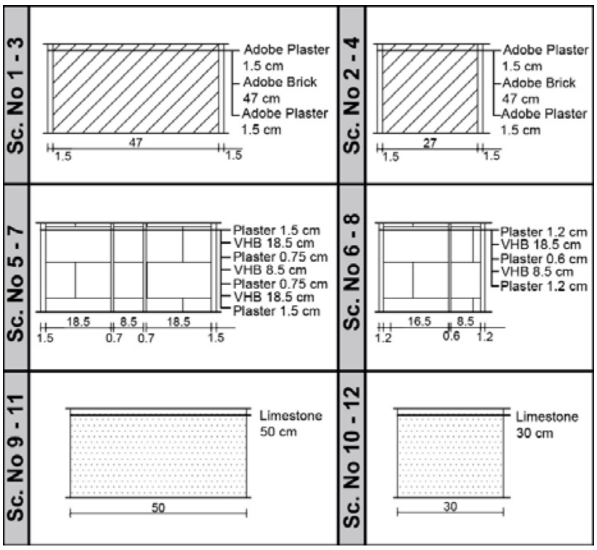


Table 3 Relationship between thermal mass characteristics and thermal capacity (kJ/K) of wall types

Sc. no.	*Thermal capacity [kJ/K]*	*Thermal mass*
Sc. 6-8: VHB_0.3	5,760	Low
Sc. 5-7: VHB_0.5	9,600	Low
Sc. 2-4: Adobe_0.3	18,144	Medium
Sc. 10-12: Limestone_0.3	19,200	Medium
Sc. 1-3: Adobe_0.5	30,240	High
Sc. 9-11: Limestone_0.5	32,000	High

3 Results and discussion

3.1 Evaluation of climate change

The current climate of Konya is continental, labelled with Csb in the Köppen climate classification (Kottek et al., 2006). The climatic comparison between 2017 and 2050s proves the increase of temperature and decrease of RH. Monthly mean maximum temperature is 25°C on August in 2017 and 30°C in 2050s. Monthly mean minimum temperature is 0°C on January in 2017 and 2°C in 2050s. Monthly mean maximum relative humidity is the highest on December with 75% and the lowest with 44% on August and September in 2017, while RH in 2050s will drop to 73% on December and 33% on August, respectively (ClimateConsultant, 2018).

3.2 Calibration results

The calibration results for 45 days convey that error ratios are within the acceptable range; thus, the model is accepted as calibrated (Table 4).

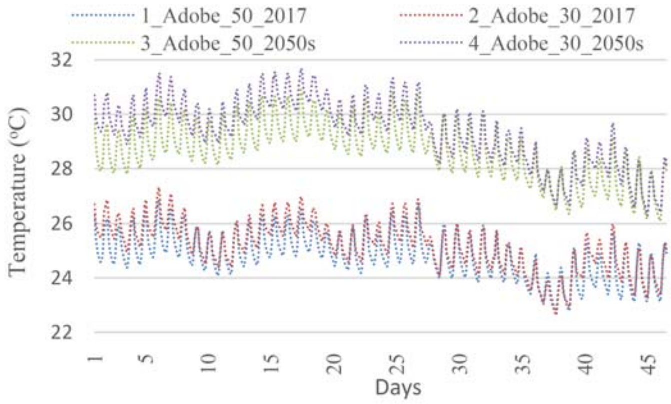
Table 4 Calibration results

Statistical indices (%)		*ASHRAE 14-2002*	*IPMVP*	*MVFEP*	*Calibrated model*
Hourly	MBE	±10	±20	±10	–0.15
	CV-RMSE	30	20	30	4.10

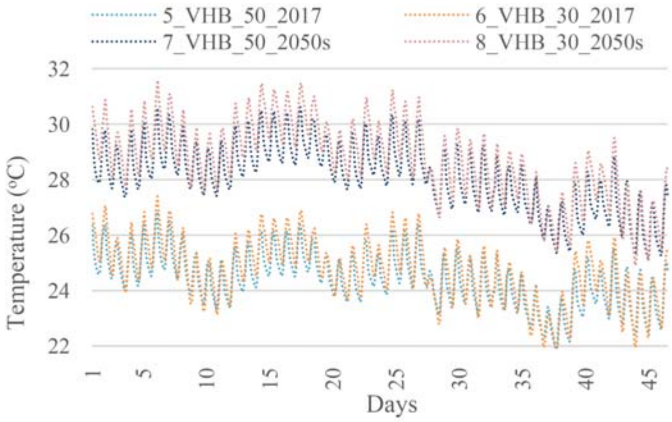
3.3 Results of indoor temperature and energy consumption

The indoor temperature shows remarkable difference between 2017 and 2050s. Figures 3(a), 3(b) and 3(c) introduce the impact of wall thickness according to 2017 and 2050s per each wall material. The highest temperature can be seen for the scenario 12 30 cm limestone wall in 2050s), ranging from 27°C to 32°C, while values vary between 22°C and 26°C for the scenario 1 (50 cm adobe wall in 2017) with the lowest values.

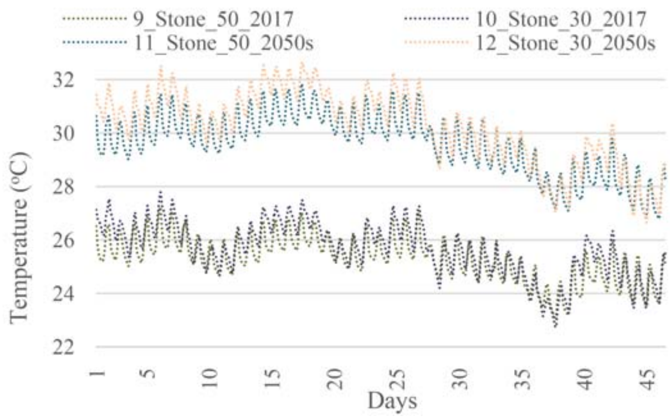
Figure 3 (a) Indoor temperature for scenarios 1, 2, 3 and 4 (based on adobe walls) (b) Indoor temperature for scenarios 5, 6, 7 and 8 (based on VHB walls) (c) Indoor temperature for scenarios 9, 10, 11 and 12 (based on limestone walls) (see online version for colours)



(a)

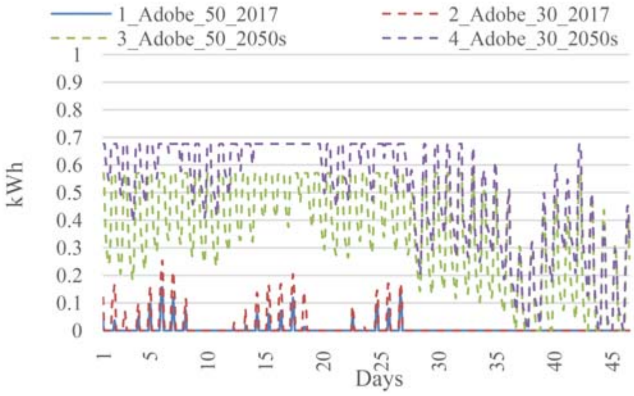


(b)

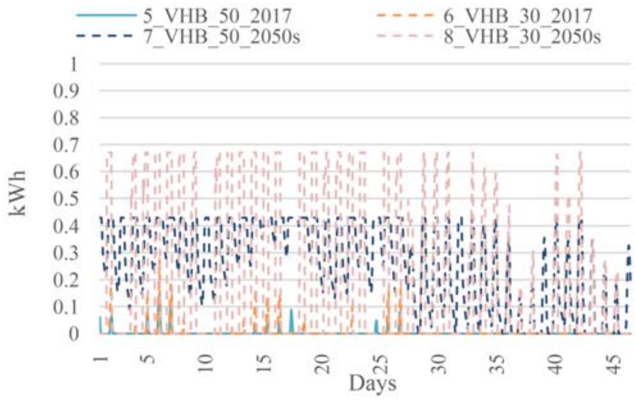


(c)

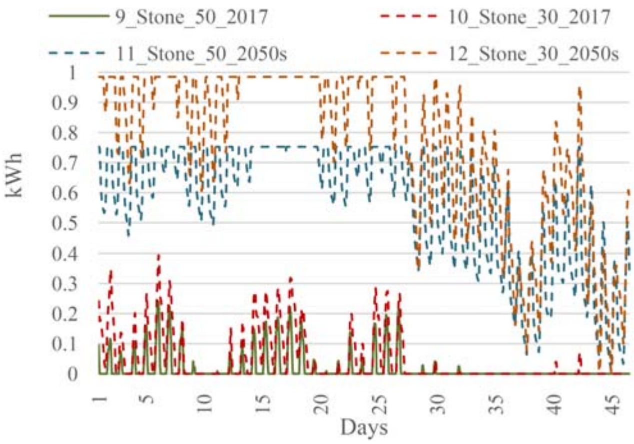
Figure 4 (a) Energy consumption for scenarios 1, 2, 3 and 4 (based on adobe walls) (b) Energy consumption for scenarios 5, 6, 7 and 8 (based on VHB walls) (c) Energy consumption for scenarios 9, 10, 11 and 12 (based on limestone walls) (see online version for colours)



(a)



(b)



(c)

Figures 4(a), 4(b) and 4(c) indicate the daily ranges of energy consumption per hour for adobe, VHB and limestone walls, respectively.

Table 5 Energy consumption for all scenarios for 45 days (see online version for colours)

	ADOBE				*VHB*				*LIMESTONE*			
	2017		*2050s*		*2017*		*2050s*		*2017*		*2050s*	
Energy consumption (kWh)	*50 cm*	*30 cm*	*50 cm*	*30 cm*	*50 cm*	*30 cm*	*50 cm*	*30 cm*	*50 cm*	*30 cm*	*50 cm*	*30 cm*
	1	2	3	4	5	6	7	8	9	10	11	12
	4.8	15.3	388.5	542	2.7	6.2	279.1	197	18.4	51.05	611.3	824

Total energy consumption values for 45 days are indicated in Table 5. Considering the lowest and highest levels of energy consumption:

1 for 2017, the lowest and highest energy consumption is seen in scenario 5 with the value of 2.7 kWh (50 cm, VHB) and scenario 10 with the value of 51.05 kWh (30 cm, limestone), respectively

2 for 2050s, the lowest and highest energy consumption is seen in scenario 8 with the value of 197 kWh (30 cm, VHB) and scenario 12 with the value of 824 kWh (30 cm, limestone), respectively.

Considering the effect of wall thickness on energy consumption in 2017:

- for adobe walls, the scenario 2 (30 cm) consumed 3.2 times more energy comparing the scenario 1 (50 cm)
- for VHB walls, the scenario 6 (30 cm) consumed 2.3 times more energy comparing the scenario 5 (50 cm)
- for limestone walls, the scenario 10 (30 cm) consumed 2.8 times more energy comparing the scenario 9 (50 cm).

Considering the effect of wall thickness on energy consumption in 2050s:

- for adobe walls, the scenario 4 (30 cm) consumed energy 1.4 times more comparing the scenario 3 (50 cm)
- for VHB walls, the scenario 8 (30 cm) consumed 1.4 times less energy comparing the scenario 7 (50 cm)
- for limestone walls, the scenario 12 (30 cm) consumed 1.3 times more energy comparing the scenario 11 (50 cm).

According to the results, it is possible to achieve some relevant conclusions as follows:

- the study reveals that thicker walls always allow less consumption in summer for 2017 (Figure 5)
- thicker walls except VHB enable less energy consumption for 2050s (Figure 5)

- the lowest energy consumption values for 2050s is achieved by scenarios with low thermal mass, i.e., VHB with 30 and 50 cm (Figure 5).
- vertical hollow brick allows least energy consumption with the lowest thermal mass capacity and the best U-value for 2050s (Figures 5 and 6 and Table 6)
- lower wall U-value is essential factor to consume less energy for both 2017 and 2050s (Figure 6 and Table 6).

Figure 5 Relationship between thermal capacity and energy consumption (ADB: adobe, LS: limestone) (see online version for colours)

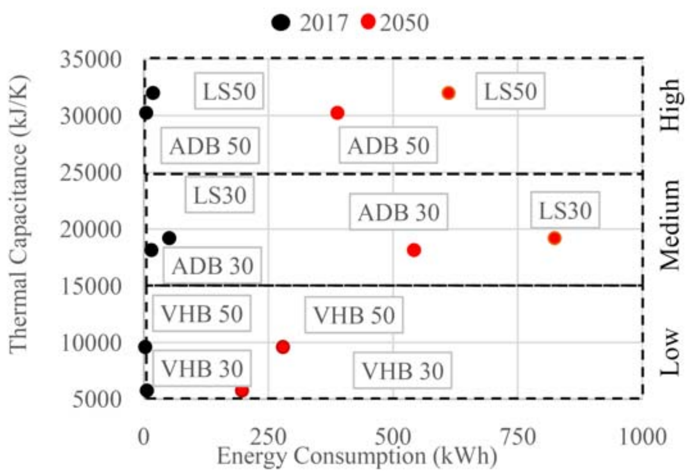


Figure 6 Relationship between U-value of walls and energy consumption (ADB: adobe, LS: limestone) (see online version for colours)

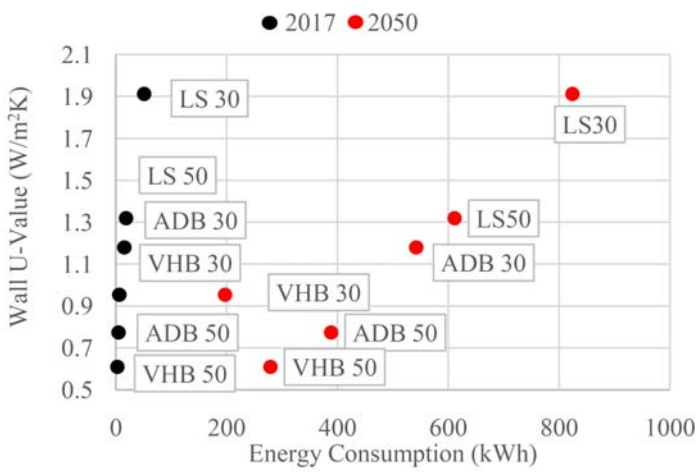


Table 6 Lowest and highest energy consumption and thermal mass

Lowest energy consumption		
Year	2017	2050s
Thermal mass	Low	Low
Wall U-value	0.61	0.954
Scenario no.	5 (VHB, 50)	8 (VHB, 30)
Consumption	2.7 kWh	197 kWh
Highest energy consumption		
Year	2017	2050s
Thermal mass	Medium	Medium
Wall U-value	1.912	1.912
Scenario no.	10 (Limestone, 30)	12 (Limestone, 30)
Consumption	51.05 kWh	824 kWh

4 Conclusions

This study investigated impact of high thermal mass for future energy consumption. Type and amount of thermal mass by different wall materials is examined as the passive solution supporting adaptability potential of building envelope into climate change. One storey detached house in Konya, Turkey was analysed for summer period without night-time ventilation in terms of different thermal mass quality of building envelope by using dynamic simulation software.

The current case of building envelope with high thermal mass (50 cm adobe) shows higher energy performance, yet it fails to achieve its performance in 2050s. It conveys that the adaptation potential of adobe to climate change decreases in the future.

The impact analysis of different wall scenarios on energy consumption according to climate change indicates that:

- thermal mass with lower density and thinner materials show higher energy performance for summers without night-time ventilation
- U-value of building envelope becomes more influential performance parameter than high thermal mass capacity on energy consumption of 2050s
- energy consumption is minimum with vertical hollow brick wall in 50 cm for 2017 and 30 cm for 2050s, following with adobe and limestone, respectively.

This study deals with overheating factor of climate change in the continental climate in which the diurnal temperature changes are remarkable impact on lowering indoor temperatures. For the future of this study, the examination of night-time ventilation would be beneficial to observe its potential effect as passive preventive phenomena for future energy consumption.

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