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The Benefits of Lower Thermal Mass Over Higher Thermal Mass Constructions in Sub-Mediterranean Climates

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Abstract.

Many researches examine the overall energy saving methods for buildings as well as other various researches focus on energy simulations using passive energy saving measures. However, there is a shortage of such studies regarding the Sub-Mediterraneanian climate and built environment. Furthermore, this research focus on the climatic conditions, fenestration and envelope design of buildings in Sub-Mediterranean in an attempt to enhance the comfort conditions. In addition, the research will help to better understand the interactive relationship between the building's construction material and the surrounding environment.

Climate is one of the most important factors that affect both urban planning and architectural design. Energy consumption of a building is strongly related to the climatic surrounding it which has a major effect on its thermal performance. This research contains a design for passive building design, taking into account building thermal performance. The simulation was carried out using the software Revit 2018.

Final results shows that the Trombe wall has the highest resistance (R-value) with minimal thickness, thus decreasing the heat loss between both the inside and outside surroundings, the energy costs were the least and the energy saving compared with brick walls around 6%. For the ceiling materials the lightweight concrete roof construction has showed a better insulation than the other types by decreasing the amount of energy cost and consumption by 4.2%. Overall the lower thermal mass walls and roofs proof to perform better due to the large amount of heat stored in summer months and substantial amount of energy needed to heat it in winter months.

Keywords: thermal mass, thermal comfort, built environment, building envelope.

1. Introduction

A building envelope is what separates the indoor and outdoor environments of a building. It is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions. Various components such as walls, fenestration, roof, foundation, thermal insulation, thermal mass, external shading devices etc. make up this important part of any building.

Thermal mass is the ability of a material to absorb and store heat. High thermal mass materials need a lot of heat energy to change their temperature, such materials are concrete, brick and tiles. Lightweight materials like timber require less temperature but are also considered low thermal mass materials.

The appropriate use of thermal mass helps reduce the costs of heating and cooling the building because they work as batteries, storing the heat or cool during the day and releasing it at night. If the thermal mass was correctly used, it could store heat up to 10-12 hours (Fgaier et al., 2016).

It is not advisable to locate thermal mass in rooms where they are poorly insulated as it could lead to more heat losses, as well as in rooms where auxiliary heating is used because it slows the response time of heating or cooling in the room.

Correct thermal mass designing could delay the heat flow in the building up to 10-12 hours, which lets it cool, or warm at night. In climates where the difference in temperature during day-night or between the seasons, it is better to have heavier thermal mass in order to achieve better time lag, as for climates with less temperature range, there is no need for heavy thermal mass.

1.1 The Mediterranean climate cover

A Mediterranean climate generally has mild wet winters and warm, dry summers. Some regions may see ice in winter months but usually just rain and slight rain in the summer. The Mediterranean countries are those that surround the Mediterranean Sea in Southern Europe, the Levant and North Africa regions border the Mediterranean as shown in Fig. 1.

Figure 1: Mediterranean climate

The thermal lag depends on the conductivity, insulation level, thickness of the materials and the temperature difference on both sides of the wall. The thermal mass could be essential for heating or cooling, and depending on the importance of it and its purpose, the location of it is critical. If the building requires heating, then the thermal mass should be located in the south and receives good solar radiation. If it is needed for cooling, then it should be located in a shaded place with good ventilation. Thus, the thermal mass needs to be located in the south with good solar radiation since heating is more required. Different materials have different thermal masses, depending on the amount of heat needed and the time lag it is needed in, different materials could be chosen.

An examination to the effect of the thickness and position of building façade insulation on the total energy demand was conducted, as well as other properties using eQUEST simulation. They were able to achieve a 25.92% reduction in the total heating and cooling demand by used an optimum strategy of combining the insulation, window/wall ratio, glazing and shading systems (Yu, et al., 2008). However, after reaching a specific amount of insulation thickness, the energy reduction continued but at a lower rate.

The insulations' layer position, whether it was on the external surface, internal surface, or within the wall had a little effect on the annual energy consumption, but the minimum consumption was when the insulation was installed on the internal surface. If the cooling energy was considered alone, it was concluded that the installation of the insulation inside the wall consumed more energy. If the purpose of the insulation was for cooling, then it was concluded that the optimum thickness of insulation was 25mm in order to consume the least energy. If it was for heating, then the optimum thickness was found to be 100mm.

Due to the different thickness of each purpose, this means that an economic analysis needs to be done in order to find the most cost and energy effective thickness of insulation. This means that the insulation would not correspond optimally to each component alone, or the provided insulation would not provide the lowest heat transfer value U for the building (Fasano & Zinzi, 2006). For that, two methods were used to perform the most economic evaluation of the building façade insulation.

It was conducted that the optimal insulation thickness was inversely proportional to the cost of insulation material and its thermal conductivity. The overly thick insulation layer consumed unnecessary high initial cost with low reduction in fuel consumption. As for the very thin insulation layer, consumed less initial cost but generated higher fuel consumption.

The features and specifications of the most-cost effective overall insulation level is not as accurate as insulating each component separately (Fasano & Zinzi, 2006). The increase of the building's insulation would increase the PWF until reaching the optimal level. After that, a light increase would happen. The authors reached to a conclusion that the optimal insulation was reached when the PWF is produced at highest, and that is compatible with the lowest pay back rate (PBR).

Other studies focused on the environmental analysis instead of the cost analysis. A study on the thermal, energy, and emergetic analysis to check on the environmental cost and benefits of the building façade (Pulselli, et al., 2009). A procedure that evaluated the energy, which defines the amount of solar energy used in order to obtain a final product. The comparison was done on three models (Odum, 1996) :

- A conventional air cavity wall with insulation
- A cavity wall with an external cork covering added
- A ventilated wall with external brick panels fixed on an extruded frame

This study was examined for cold, warm, and hot climates. The authors reached to a result that the walls that are insulated and ventilated had better thermal energy and energy performances. When it comes to natural resources, in hot and warm climates, the energetic analysis had a more important role than in colder climates, due to the fact that reducing cooling demands had greater environmental benefit than reducing heating demand.

The environmental impact of a mud house was examined to evaluate the thermal performance, embodied energy, energy payback time, CO_2 emission mitigation potential and resulting carbon credits. The results showed that there is a potential for energy saving (Odum, 1996). They saved for heating and cooling loads up to 1481 kWh/year and 1813 kWh/year, respectively. On the other hand, it showed that the building mitigated 5.2 metric ton/year of CO2 emissions into the atmosphere. So, they concluded that the materials that are chosen need to not only be chosen based on the lower embodied energy, but also based on the lower environmental impact.

Several researchers around the world carried out studies on improvements in the building envelope and their impact on building energy usage. Energy savings of 31.4% and peak load savings of 36.8% from the base case were recorded for high-rise apartments in the hot and humid climate of Hong Kong by implementing passive energy efficient strategies. The strategies include adding extruded polystyrene (EPS) thermal insulation in walls, white washing external walls, reflective coated glass window glazings, 1.5m overhangs and wing wall to all windows (Chel & Tiwari, 2009).

2. Methodology

Walls are a predominant fraction of a building envelope and are expected to provide thermal and acoustic comfort within a building, without compromising the aesthetic of the building. The most important factor is thermal resistance (R-value) of the walls, since it has major effect on the energy consumption of the building itself, especially for a large area of buildings' walls. The market available center-of-cavity R-values and clear wall R-values consider the effect of thermal insulation. However, the influence of framing factor and interface connections is not taken into consideration.

Thermal insulation of walls have a greater chance of surface condensation, for regions with an ambient air humidity of 80% or higher. This is considered to be a huge problem during winter seasons and colder region with such humidity levels (Cheung, et al,2005) .The condensation of the moisture air can enhance the growth of bacteria on exterior walls, thus reducing the life cycle of the wall material and leading into undesirable conditions. However, in Sub-Mediterranean the humidity levels can range from 36% in June up to 69% in January . Additionally, walls can be classified based on their construction material; wood-based wall, metal-based wall, masonry-based wall and advanced building walls. Advanced building walls improve the energy efficiency which is to be discussed in this section.

A Trans wall is a transparent modular wall that provides both heating and illumination of the dwelling space. These walls are comprised of water enclosed between two parallel glass panes supported in a metal frame. A semi-transparent glass absorbing plate is at the centre of the parallel glass panes. The incident solar radiation is partially absorbed by the water and semi-transparent glass plate, the rest of the transmitted radiation causes both heating and illumination that are required by the indoors.

Light weight concrete (LWC) represents any type of concrete with a density that ranges between 1600-2000 kg/m3. It can be mixed with light weight aggregates in order to increase its thermal mass (such as foamed slag). One common type of LWC is the autoclaved aerated concrete (AAC) which is produced by the mixing of aluminium powder with concrete to generate miniscule air bubbles. AAC density ranges between 600-800 kg/m3. These LWC are most useful on countries that mostly use concrete.

Ventilated or cavity walls are the type of walls that have double layer of masonry wall with air gap in between them. Ventilated walls can be categorized into two types, (i) walls with forced ventilation in the gap (ii) walls with natural ventilation. These types of walls are mainly used to improve the passive cooling of a building.

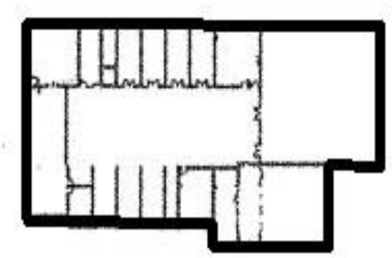
A further modification of walls to save energy and increase its thermal storage is by cooperating phase change material (PCM) with light weight wall. The amount of PCM used defines the thermal storage capacity of the wall. Using PCM-based gypsum board for internal walls has reduced both the indoor maximum temperature by 4.2˚C and also the heating demand during night time. This shows us the benefits of using PCM-based over non-PCMbased gypsum board for internal walls lining (Aelenei & Henriques, 2008) (Athienitis, 1997)

The adaptive thermal comfort approach could be used to minimize energy consumptions by more than half by reducing the time where energy required for cooling and heating. This substantial saving can be achieved by involving the occupants in the building thermal process by doing extra small actions to restore their thermal comfort instead of totally relaying on mechanical heating or cooling. (Albatayneh et al, 2019,A) (Albatayneh et al, 2018,A) (Albatayneh et al, 2018,B) (Albatayneh et al, 2017,A) (Albatayneh et al, 2016,A) (Albatayneh et al, 2017,B) (Albatayneh et al, 2018,C) (Albatayneh et al, 2015) (Albatayneh et al, 2016,B) (Albatayneh et al, 2017,C) (Albatayneh et al, 2017,D) (Albatayneh et al, 2018,D) (Albatayneh et al, 2018,E) (Albatayneh et al, 2018,F) (Albatayneh et al, 2019,B)

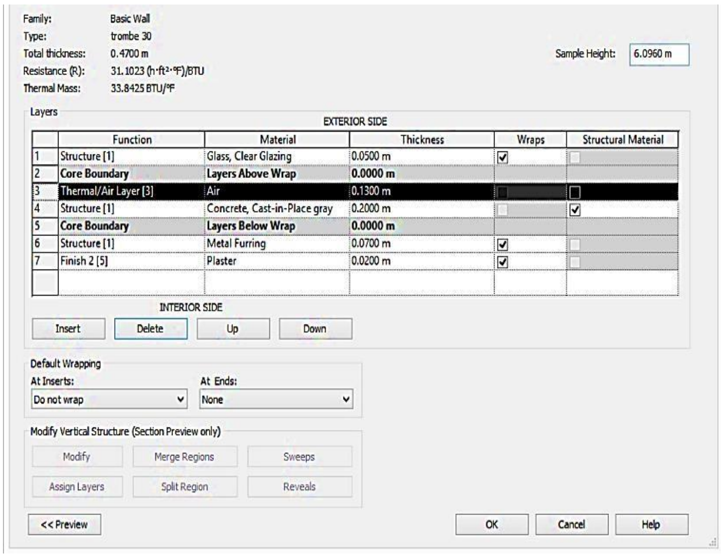
The building area is 1099m2 with 2.8m height using different walling materials as shown in Fig. 2.

Figure 2: a) building to view layout, b) Components and specifications of a trombe wall

a)



b)



3. Results and Discussions

The annual energy consumption per square meter of a trombe wall was found to be 49kWh/m2/year. As for the total energy consumption of the building, it was found to be 295636kWh/year. The energy consumption was found to be 3.3 USD/m2/year, as for the total energy consumption, it was 49435 $USD/year. In comparison to a poorly insulated wall, the energy being saved from a trombe wall was 6.1%.

It is noticed that the resistance of a trombe wall is high compared to other wall constructions. This kind of wall is constructed from clear glazing, air, concrete (cast-in-place gray), metal furring, and plaster; respectively from the outer surface to the inner surface.

The annual energy consumption of a CMU insulated wall per square meter is 48 kWh/m2/year, while the total energy consumption is 304422 kWh/year. The energy cost of a CMU insulated wall is 3.3USD/m2/year, while the total annual energy consumption in SubMediterraneanian Dinars is 48765 $USD/year. In comparison to a poorly insulated wall, the energy being saved from a CMU insulated wall was 0.18%.

The resistance of the CMU insulated wall was moderate in comparison to other wall constructions. The thermal mass of this construction is high. The components in the CMU insulated wall are: concrete masonry units, air, rigid insulation, damp-proofing, concrete masonry units, metal furring, and gypsum wall board; respectively from outer surface to inner surface.

The energy consumption of a poorly insulated wall was found to be 48 kWh/m2/year. As for the total energy consumption, it was 293476 kWh/year. The energy cost in dollars was found to be 3.3 USD/m2/year. As for the total energy cost in Sub-Mediterraneanian Dinars, it was 53454 $USD/year.

The resistance of such a construction was low in comparison to other structures. As for the thermal mass, it was relatively high. The components of this structure are: concrete masonry units, air, concrete masonry units, and gypsum wall board; respectively from the outer surface to the inner surface.

The annual energy consumption per square meter for an ACT system roofing was found to be 48 kWh/m2/year. As for the total energy consumption, it was 337656 kWh/year. The annual energy cost for such a system was 6.1 USD/m2/year. It was calculated and converted to Sub-Mediterraneanian Dinars, and the result was 51323 $USD/year.

The resistance and thermal mass of this type of construction are the lowest. The components that were used in this construction are: the very basic components, concrete and ceiling tiles.

The annual energy consumption for a square meter for masonry wall was found to be 49kWh/m2/year. As for the total energy consumption, it was 324532 kWh/year. The annual energy consumption per square meter for this construction was 3.5 USD/m2/year. The total annual energy consumption in Sub-Mediterraneanian Dinars was 58565 $USD/year. Comparing this type of construction to the reference construction, the energy savings reached to 1.3%.

The resistance and thermal mass were relatively higher than the ACT roofing system. The components of the masonry wall construction are: concrete and acoustic ceiling tile.

The annual energy consumption for a square meter for masonry wall was found to be 51kWh/m2/year. As for the total energy consumption, it was 326456 kWh/year. The annual energy consumption per square meter for this construction was 3.3 USD/m2/year. The total annual energy consumption in Sub-Mediterraneanian Dinars was 58454 $USD/year. Comparing this type of construction to the reference construction, the energy savings reached to 4.2%. This type of construction has the highest resistance and thermal mass. The components of this construction are: concrete (lightweight) and acoustic ceiling tile. The summary of the results in Tab.1 and Tab.2.

Table 1. Saving percentage for different walling systems.

	Energy consumption kWh/Year	Cost ($USD)/Year	Saving Percentage/year compared to the base scenario
Trombe	295636	49435	6.1%
CMU Insulated	304422	48765	0.18%
poorly insulated	293476	53454	0.00%

Table 2. Saving percentage for different types of roofs.

	Energy consumption kWh/Year	Cost ($USD)/Year	Saving Percentage/year compared to the base scenario
ACT system	337656	51323	0.00%
Masonry	324532	58565	1.3%
Lightweight	326456	58454	4.2%

4. Conclusions

This research examine the thermal mass of walls and how they affect the thermal performance of commercial building in Amman which considered to be a Mediterranean climatic zone thus requiring high thermal mass walls to store more heat and dissipate it over a longer period of time.

Various types of walls are discussed through the chapter with the inner material and the insulation used in each. Passive Solar walls are the most known and feasible types of walls, that can be used in buildings with climatic zone as Amman as they offer a higher thermal mass than other traditional walls.

According to the wall material results, the Trombe wall has the highest resistance with minimal thickness, thus decreasing the heat loss between both the inside and outside surroundings, the energy costs were the least and the energy saving in such a construction were the highest, corresponding to 6%. For the ceiling materials the lightweight concrete roof construction has showed a better insulation than the other types by decreasing the amount of energy cost and consumption by 4.2%.

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