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Model Testing To Calculate Time-Lag Of Phase Change Material With Mycelium Integration In Residential Apartments, In The Case Of Amman

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Abstract

This study investigated the feasibility of reducing energy demand in residential buildings using a new material called "Phase Change Material with Mycelium Integration (PCMMI)", considering the climatic conditions in Jordan, Amman. A simple model was fabricated to test free form of PCMMI time-lag. The objective was to visually observe the phase change and measure the time-lag and compare the results with and without using PCMMI. The results from the model testing showed that the PCMMI reduced heat flow between the outdoor and indoor by 11^{o}C, while without PCMMI the heat flow reduction was 7^{o}C.

Keywords: *thermal performance; model testing; time lag; infra-red thermometer; charging phase; discharging phase*

1. Introduction

Jordan experiences a deficit of natural resources like natural gas and crude oil, resulting in the necessity to import 97% of its overall national energy needs from neighboring Arab nations. This reliance on external sources comes at a cost equivalent to 17% of Jordan's Gross Domestic Product (GDP). Within the country, residential usage constitutes 21% of energy consumption and 43% of total electricity utilization (1).

Efficient thermal insulation of structures emerges as a pivotal element in reducing the energy demand for heating and cooling within residential areas. Despite the implementation of insulation regulations in Jordan since the early 1980s, these rules have undergone limited enhancements and enforcement. Consequently, the application of thermal insulation in residential edifices has been inconsistent, influenced by factors such as income, property ownership, and educational attainment (2).

Advancing the energy efficiency of buildings stands as a critical field of study aimed at introducing innovative materials, systems, and technologies to decrease buildings' reliance on fossil fuels. At present,

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an encouraging avenue called Phase Change Materials with Mycelium Integration (PCMMIs) for Thermal Energy Storage (TES) purposes is emerging. This inventive approach effectively utilizes solar thermal energy in a passive and sustainable manner. Phase Change Material with Mycelium Integration (PCMMI) serves as a thermal mass and can be utilized in the building's exterior envelope. Acting as a heat reservoir, the PCMMI undergoes a phase change from solid to liquid during periods of high outdoor temperatures, utilizing a specific encapsulation container within the exterior wall layers. This heat storage process facilitates daytime cooling by reducing heat transfer from the envelope to the interior of the residential structure. (3)

During cooler nighttime conditions, when outdoor temperatures drop, the PCMMI solidifies by transitioning from liquid to solid state. This transition releases stored heat to the interior, providing effective interior heating. As a consequence, this approach leads to reduced heating and cooling loads, decreased electricity consumption, and lowered energy demands during peak periods.

Mycelium, a naturally occurring fungi root system, plays a pivotal role in this process. Much like an iceberg, there is more beneath the surface when it comes to mycelium's capabilities and contributions. In this thesis, the main study will focus on comparing a residential building in Jordan with its current materials with a simulated residential building that has PCMMI (Enhanced material) to see the affection of the new material on the thermal performance of the building and if it reduces energy consumption. (3)

The methodology used a model testing is a mock-up to test the PCMMI’s time-lag.

Energy security stands out as a paramount obstacle confronting Jordan. Addressing this challenge would alleviate the nation's burdens and strains, promoting its long-term sustainability. With a staggering 96% dependency on energy imports (1), Jordan's current building stock serves as a substantial energy consumer, displaying performance levels that fall short of contemporary construction standards. Regrettably, a majority of Jordanian structures receive scant attention to climate and energy-efficient design principles. A prevalent tendency among designers is to adhere to conventional designs, often overlooking or neglecting passive strategies, despite their potential to serve as pivotal objectives in the building's design (4, 5). Consequently, a significant portion of these buildings fail to deliver on these fronts

Hypothesis Assessment: The enhanced material will help reducing energy consumption in buildings, which will result in a significant drop in heating and cooling demands.

Research Question: Would using Phase Change Material with Mycelium integration (PCMMI) in the residential building material enhance the thermal performance of the envelope by increasing timelag?

Research Objective: To determine the feasibility of implementing TES (Thermal Energy Storage) technology in the buildings envelope to improve the thermal system efficiency and reduce operating energy costs in peak climatic conditions in relation with time lag.

Previous studies a study in 2022 called, Mycelium: The Building Blocks of Nature and the Nature of Architecture, by Carly Regalado, used the comparison methodology, between building blocks of PCMMI in America (7) Made a fabricated model to test the phase changing. And this master thesis results comply with it.

2. Literature Review

- **Phase Change Material (PCM)**

Phase Change Materials (PCMs) are substances capable of transitioning between solid and liquid states based on temperature changes. They possess the unique ability to absorb and store heat as latent energy, resulting in a phase shift from solid to liquid when heat is absorbed, and from liquid to solid when heat is released upon cooling (8).

- **Phase Change Material with Mycelium Integration (PCMMI)**

Phase Change Material with Mycelium Integration (PCMMI) denotes the combination of PCM and mycelium. Research on PCMMI centers on utilizing inorganic salt hydrate PCM integrated with mycelium, known for its elevated heat capacity compared to other PCMMI variations. Inorganic salt hydrate PCM comprises salt, water forming a crystal matrix, and mycelium. These elements exhibit substantial latent heat and a melting temperature range spanning from 15°C to 117°C. The versatility and relatively low cost of salt hydrates make them a widely studied option for thermal energy storage systems (3).
The safety of integrating mycelium with building materials has been acknowledged, supported by the Generally Recognized as Safe Notice (GRASN) presented by Sustainable Bioproducts (9).

• PCMMI in Jordan

In the context of Jordan, PCMMI utilizes salt hydrates such as $CaCl_2.6H_2O$ (Calcium Chloride Hexahydrate), which can be readily sourced from the Dead Sea. The decreasing water levels of the Dead Sea result in the accumulation of salt on its bed (10). The area's salt evaporation ponds are utilized to extract sodium chloride and potassium salts for various purposes, including the production of PCM for building materials (11). As the water level declines, the lake's salinity increases, causing salt layers to form at the bottom (12). In contrast, mycelium can be obtained from industrial zones since it grows on industrial waste, ensuring convenient availability and affordability as a raw material for experimentation (13).

• Microencapsulation within PCMMI

PCMMI functions as a phase change material, transitioning into a liquid state when exposed to temperatures beyond its melting point. To prevent any potential leaks, a protective covering becomes essential. Microencapsulation serves as a containment method for PCMMI, employing a 100mm-thick sheet as the container, equipped with empty pockets. The pockets within the sheet are designed to accommodate the PCMMI mixture before the construction phase. The sheets are then filled with the PCMMI mixture possessing the specific traits studied and outlined in the literature (14).

3. Methodology

Time-Lag (Φ): Refers to the duration required for a heat wave to traverse the layers of the envelope materials (16). In the climatic zone of Amman, a more extended time lag is advantageous (16). This time lag is enhanced by utilizing thicker materials, which heighten the resistance of heat wave movement from the exterior to the interior. It also improves when an envelope material is capable of absorbing heat, as seen with PCMMI. PCMMI is a substance that absorbs heat at a specific temperature and subsequently releases it during the night, thereby extending the time lag. Figure 1 (Time-lag in materials) visually demonstrates the functioning of time lag and presents a representation of heat wave progression over time.

The Decrement Factor (μ): The thermal mass effect influences the time lag by diminishing the ease with which heat waves penetrate envelope materials. This effect lessens the impact of external temperatures on a building's interior temperature. The decrement factor quantifies this reduction and is determined by dividing the temperature on the interior side of the wall by the temperature on the exterior side of the wall. To put it scientifically, the decrement factor is expressed as Tsi (the maximum swing or heat wave in temperature on the inside) divided by Tso (the swing or heat wave in external temperature).

The required time for the heat to transfer from the external side of the envelope to the internal side depends on the materials characteristics, conductivity (K), U-Value and thickness.

The methodology calculated the time lag depending on a test model. The objective was to visually observe the phase change and measure the time-lag and compare the results with and without using PCMMI. The model testing was done based on two references (17; 18).

• Model testing to calculate time-lag

The model testing is a mock-up to test the PCMMI's time-lag. The model testing was setup at the University of Jordan in the School of Engineering, held in the building operation laboratory "مختبر مشغل المباني". The objective was to visually observe the phase change and measure the time-lag and compare the results with and without using PCMMI. The model testing was done based on two references (17; 18).

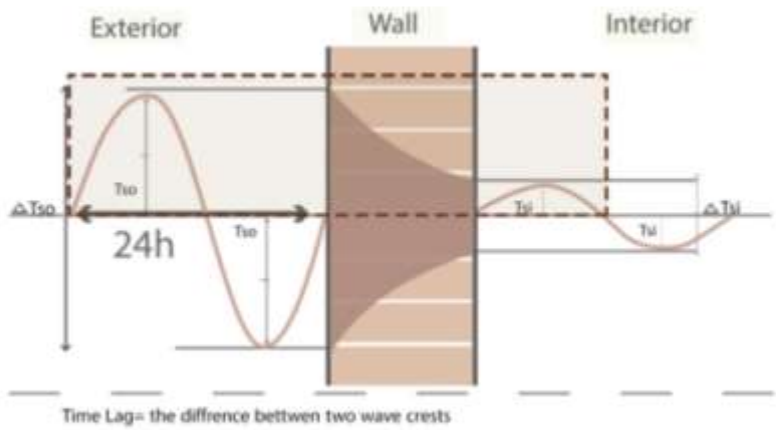

Figure 1 Time-Lag in Materials

General Information about the Mock-Up seen in Figure 2 (Model testing set-up):

1) The materials used in the mockup were recycled materials from the faculty (wooden container and glazed openings). As seen in a previous study mock-up (Sung Ho Choi, 2019).
2) The temperature was measured using a laboratory thermometer.
3) The model testing set-up:

i) It is composed of three main models; (A): the cooling model, (B): the heating model and (C): the test sample (**which has free form PCMMI**).

ii) The three models are cuboid containers, model A and B had the same dimensions: Height (32 cm) Length (20 cm) and a width of (5 cm). Model C only differs in width, having a width of (3cm) (17; 19).
iii) Model A and model B have a window shaped opening to allow the heating and the cooling points to transfer their temperature (energy) (17).
iv) Model A and B (heating and cooling elements) have adjustable positioning to see the PCMMI material changing phase.

4) The aim of the model testing is to observe the PCMMI changing phase with the outside temperature greater than 25^{0}C and how it solidifies when the temperature drops. The Time-Lag was calculated manually to see if it achieved a good lagging in heat transfer.
5) The **PCMMI** used in the model testing was around 350 grams.

Figure 2 Fabrication Set-Up

The process of the model testing was as the following:

Charging Phase Process (when PCMMI is exposed to temperatures higher than its melting point 25 ^{0}C)

1. Heating Model A by pouring boiled water and using a thermometer to make sure that the water reached the desired temperatures of testing which were (31, 32, 33, 34)^{0}C
2. PCMMI was added into Model C to investigate its effect in heat transfer.
3. Then measuring the temperature between Models C and B every 1.5 minutes for 6 minutes for each testing temperature from model A. Measurements were obtained by using an infrared thermometer shown in figure 63 (Khetib, Y., 2021).

Figure 3 Infra-red Thermometer

4. Results were documented and will be shared in Chapter 6.
5. Then the same four mentioned temperatures were tested when there was no PCMMI in Model C.
6. Then measuring the temperature between Models C and B every 1.5 minutes for 6 minutes for each testing temperature from model A. Measurements were obtained by using an infrared thermometer shown in Figure 63 (Khetib, Y., 2021).
7. Results were documented and will be shared in Chapter 5.

Discharging Phase Process (when PCMMI is exposed to temperatures lower than its melting point 25 ^{0}C)

1. Cooling down Model A by leaving the water in and using a thermometer to make sure that the water reached the desired temperatures of testing which were (18, 19, 20, 21)^{0}C.
2. PCMMI was added into Model C to investigate its effect in heat transfer
3. Then measuring the temperature between Models C and B every 1.5 minutes for 6 minutes for each testing temperature from model A.
4. Results were documented and will be shared in Chapter 5.
5. Then the same four mentioned temperatures were tested when there was no PCMMI in model C.
6. Then measuring the temperature between Models C and B every 1.5 minutes for 6 minutes for each testing temperature from model A.
7. Results were documented and compared. Results are shared in Chapter 5.

Throughout the next chapter, the results of each methodology stage will be illustrated.

4. Results and Discussion

The room temperature where the model testing was conducted was 21^{0}C.

The methodology for the model testing was by changing the heat source temperature into 31^{0}C, 32^{0}C, 33^{0}C and 34^{0}C respectively and measure model C temperature (which has the PCMMI). The discharging phase starts when the outside temperature drops below 25^{0}C, so four other temperatures will be studied for the solidifying phase by cooling model A to temperatures 18^{0}C, 19^{0}C, 20 ^{0}C and 21^{0}C respectively. **Charging Phase Results** (when the PCMMI melts) in comparison with the temperature of model C (without PCMMI) is illustrated in Table 1 (Charging Temperatures).

Temperature of model A (°c)	18	19	20	21
Temp. difference with no PCMMI	18-19= -1	19-20= -1	20-21= -1	21-22= -1
Temp difference with PCMMI	18-22= -4	19-23= -4	20-24= -4	21-25= -4

Table 1 Charging Temperatures

Table 1 illustrates effectiveness of PCMMI in construction. The results of the model testing conducted within 10 minutes with temperatures above 30 degrees showed efficient time lag. Table 2 (charging temperature differences) shows PCMMI average 11 degrees temperature difference between the exterior and interior (saving the thermal comfort which leads to energy reduction).

Table 2charging temperature differences

Temperature of model A (°c)	18	19	20	21
Temp. of Model C with no PCMMI	19	20	21	22
Temp. of Model C with PCMMI	22	23	24	25

Discharging Phase Results (when the PCMMI solidifies) in comparison with the temperature of model C (with no PCMMI) is illustrated in Table 3 (Discharging Temperatures). The results show that the "interior" maintained thermal comfort when the outdoor temperature (Model A) dropped below 21°C. This is due to the fact that PCMMI released its gained "latent heat" to the interior.

Table 3 Discharging Temperatures

Temperature of model A (°c)	31	32	33	34
Temp. difference with no PCMMI	31-24= 7	32-25= 7	33-26= 7	34-27= 7
Temp difference with PCMMI	31-19= 12	32-21= 11	33-22= 11	34-23= 11

Table 4 (Discharging Temperatures Differences) illustrates the temperature differences between the exterior and interior, with and without using PCMMI. The higher the difference in temperatures; the better thermal comfort.

Table 4 Discharging Temperatures Differences

Temperature of model A (°c)	**31**	**32**	**33**	**34**
Temp. of Model C with no PCMMI	24	25	26	27
Temp. of Model C with PCMMI	19	21	22	23

The advantages of the model testing using **Free Form PCMMI**:

1) Saving the interior thermal comfort with minimal energy demand.
2) Keeping the interior thermal comfort in hot and cold outdoor temperatures.
3) Recommending its usage in actual residential construction.

5. Conclusion

Time-Lag of the envelope's materials without PCMMI: the time lag of the The model testing showed that adding PCMMI as a free form material reduced the heat transfer by $11^{o}C$ when the outdoor temperature is above $25^{o}C$. When the outdoor temperature dropped below $22^{0}C$ the PCMMI kept the interior in its comfort temperature which was more than the outside temperature by $4^{0}C$.

The contribution of the study; PCMMI was studied by multiple researchers and its effectiveness in reducing energy demand. This thesis is the first study to investigate the feasibility of applying Phase Changing Materials into residential buildings in Jordan-Amman, contributing to its climatic conditions and locations. The study resulted in proving that PCMMI performs effectively in "high-land" climatic zone.

Limitations and Challenges of the study; There were no studies found online that studied PCMMI in Jordan as an envelope material. But through the adapted methodologies and the related references, this limitation was converted into an advantage as the first study in Jordan. Obtaining important information from different associations (such as the Jordanian thermal codes from [JGBC], and construction materials with its dimensions from Ministry of Energy and Minerals [MEMR]), as input data for the studies calculations and for comparison purposes.

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