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COMPREHENSIVE EVALUATION OF THERMAL PERFORMANCE AND TIME-LAG IN RESIDENTIAL APARTMENTS IN AMMAN

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Abstract

This exploration investigates the potential of enhancing energy efficiency in residential structures in Amman, Jordan, by introducing an innovative material termed "Phase Transition Substance with Fungal Integration (PTSF)." Through computational simulations using Autodesk-Revit, the analysis evaluates the thermal efficiency of a standard residential building, contrasting traditional construction materials with PTSF. The study centers on three crucial elements: outer walls (W.01), roof (R.01), and ground level slab (S.01), all initially not meeting prescribed thermal conductivity regulations.

Integration of PTSF notably improves the thermal efficacy of the building's shell, aligning with Jordanian standards for thermal insulation. Furthermore, a systematic examination explores the time delay of materials within the residential envelope, revealing an average lag of approximately 8 hours. This lag implies that, with the incorporation of the PTSF layer, the envelope requires 8 hours to transmit external temperatures (e.g., 30°C) to attain the interior's peak temperature, underscoring the material's potential in curbing energy consumption.

Keywords

Residential Apartments, Building Materials, Comparison, Phase Transition Substance, Fungal Integration, Thermal Performance

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1. Introduction

Jordan heavily depends on imported natural gas and crude oil, with 95% of its national energy requirements sourced from neighboring Arab nations, accounting for 18% of its GDP. The residential sector, responsible for 22% of energy usage and 42% of electricity consumption, encounters inefficiencies. Despite insulation standards in place since the 1980s, their enforcement is inconsistent, resulting in sporadic adoption of thermal insulation based on socioeconomic factors.

The construction industry significantly contributes to global energy consumption, influenced by population growth and escalating living standards. However, architectural practices have been inadequately adaptive. Effective thermal insulation is imperative for mitigating energy demand in residential spaces. Despite insulation standards in Jordan, enforcement is irregular. To address this, innovative approaches like Phase Transition Substances with Fungal Integration (PTSFs) for Thermal Energy Storage (TES) exhibit promise in harnessing solar thermal energy sustainably. Phase Transition Substance with Fungal Integration (PTSF) acts as a thermal reservoir and can be incorporated into the building's outer envelope. Operating as a heat sink, the PTSF undergoes a phase transition from solid to liquid during periods of high outdoor temperatures, utilizing a specific encapsulation vessel within the outer wall layers.

This thermal storage mechanism facilitates daytime cooling by minimizing heat transfer from the envelope to the interior of the residential structure. During cooler nights, PTSF undergoes a phase transition from liquid to solid, releasing stored heat and effectively warming the interior. This results in diminished heating and cooling requirements, reduced electricity consumption, and decreased energy demands during peak periods. Fungi mycelium plays a crucial role in this process, offering capabilities beyond visible attributes. This thesis focuses on comparing a current residential building in Jordan with a simulated one employing PTSF (Enhanced material) to evaluate its impact on thermal performance and energy consumption reduction.

The methodology employs a systematic analysis to estimate solar heat exposure duration for the residential building. An energy audit was conducted to gauge daily exposure in each section of the building in watt-hours. The study utilizes computational simulations through Autodesk-Revit software, contrasting a simulation of the building with its current material layering to another simulation with the PTSF layer. The thermal efficiency of the building's materials is assessed, starting with the existing envelope materials by computing the thermal conductivity (U-Value). Subsequently, the thermal efficiency of the building with the PTSF layer is evaluated using equations from Jordan's Thermal Insulation Code of 2009. (MEMR, 2009)

Jordan faces a critical energy security challenge, with a staggering 93% reliance on imported energy sources. This dependency severely impacts the country's sustainability and places significant burdens. The existing buildings in Jordan contribute significantly to energy consumption, lacking adherence to modern construction standards. Regrettably, many structures in Jordan neglect considerations for climate-responsive and energy-efficient design principles. Designers frequently opt for conventional methods, neglecting passive strategies crucial for effective building design. Consequently, a significant portion of these buildings falls short of achieving energy efficiency goals.

Hypothesis Assessment:

The enhanced material will contribute to reducing energy consumption in buildings, resulting in a notable decline in heating and cooling demands.

Using Phase Transition Substance with Fungal Integration (PTSF) will enhance the thermal efficiency of residential buildings.

Research Question:

Would utilizing Phase Transition Substance with Fungal Integration (PTSF) in residential building materials enhance the thermal efficiency of the envelope?

Research Objective:

To ascertain the feasibility of implementing TES (Thermal Energy Storage) technology in building envelopes to enhance thermal system efficiency and diminish operational energy costs in peak climatic conditions**.**

Prior Studies computed various materials' time delays at varying thicknesses, such as a study analyzing concrete time delays in the Mediterranean climate with diverse thicknesses. Another study investigated the thermal impact of time-delaying materials. Furthermore, a study scrutinized material time delays in Jordan's climate. A previous study explored sustainable heating and cooling systems with thermal energy storage, specifically examining its successful application in the built environment. The study examined phase transition materials, including material proportion characterization, computational modeling, and validation of thermal storage.

2. Literature Review

A. PCM (Phase Transition Material):

PCM undergoes transitions between solid and liquid states based on temperature fluctuations, storing heat as latent energy.

B. PTSF (Phase Transition Substance with Fungal Integration):

PTSF merges inorganic salt hydrate PCM with fungi mycelium, offering increased heat capacity and a melting temperature range spanning from 13°C to 121°C. Salt hydrates are economically feasible and extensively researched for thermal energy storage. The safety of this integration is affirmed by the Generally Recognized as Safe Notice (GRSN) issued by Sustainable Bio products.

C. PTSF in Jordan in Jordan:

PTSF employs salt hydrates like $CaCl_2.6H_2O$ from the Dead Sea, where declining water levels lead to salt accumulation. Salt evaporation ponds in the region extract salts for various applications, including PCM production for building envelopes. As the lake's water level diminishes, salinity intensifies, forming salt layers at the bottom.

Fungi mycelium, sourced from industrial areas due to its growth on waste, is readily available and cost-effective for experimentation. (Swiety, D.S., 2023)

D. Climate Region and Specific Melting Temperature PTSF:

Experiences a phase transition as it absorbs heat, transitioning into a liquid state and solidifying upon heat release, displaying specific melting and solidification thresholds. Two critical factors involve establishing a suitable melting point tailored to Amman's climate and ensuring PTSF remains in liquid form without leakage risks. Considering Amman's climatic diversity, with the Highlands enduring cold winters and hot summers, the ideal melting temperature corresponds to the peak average, approximately 28°C. For Mycelium integrated with $CaCl_2.6H_2O$, its documented melting point stands at 23°C. (Swiety. 2023)

E. Microencapsulation within PTSF:

PTSF serves as a phase transition material, transitioning into a liquid state when surpassing its melting point. To ensure containment and mitigate leakage risks, microencapsulation is employed. This entails utilizing a 1cm-thick sheet with hollow compartments as the container. These compartments are engineered to accommodate the PTSF mixture, adhering to specific characteristics detailed in the literature before the construction phase.

3. Methodology

Figure 1*: Simulation*

***(Source:** Illustrated by the Researcher)*

The methodology employed in this study centers on a comparative approach, involving simulations of a residential structure in Amman. Initially, the simulation reflects the building with its current materials, followed by a simulation after integrating a PTSF layer. The study area, situated in Khalda, Amman, falls within climatic zone two (highlands). Details of the building encompass a floor area of 150 square meters, a ceiling height of 2.75 meters, and the necessity for both cooling in summer and heating in winter. Utilizing Autodesk Revit, the thermal performance of the existing building envelope is scrutinized, considering Amman's climatic nuances. This simulation endeavors to elucidate the efficacy of the novel PTSF material in reducing energy demand, as depicted in figure 1 (Simulation).

The simulation utilizes adaptive algorithms with the DYNAMO plug-in within Autodesk Revit to maintain the U-Value of every layer and replicate the climatic conditions of Amman. The objective is to assess the impact of the PTSF material on energy demand within the context of Amman's climate.

The study also applied a parametric analysis to estimate the residential building's exposure to solar heat and conducted an energy audit to assess energy consumption. Lag time (τ) and Reduction Factor (δ) were crucial considerations in understanding thermal performance. Thicker materials and those with higher thermal mass, like PTSF, were found to enhance lag time and reduce the impact of external temperatures on the internal side of the building.

The methodology employed Autodesk-Revit software to simulate the apartments and visualize the envelope layers, both with and without PTSF. Thermal performance was assessed by computing the U-Value of the building materials. Initially, the U-Value of the existing materials was determined for each envelope component (such as exterior walls, roof, and ground floor slab) using equations derived from Jordan's Thermal Insulation Code of 2009.What sets this section apart is the consideration of the total thickness and conductivity of each component, factoring in the additional PTSF layer. The inclusion of PSTFwith its container adds approximately 1cm to the thickness of the layers. The specific values

Stage 1: A digital simulation conducted to assess the thermal performance of Phase Transition Substance with Mycelium Integration (PTSF) in residential apartments within the context of Amman.

The methodology utilized Autodesk-Revit software to simulate the apartment and illustrate the envelope layers with and without PTSF. Thermal performance was measured by calculating the thermal transmittance (U-Value) of the building's materials. Initially, the U-Value of the current materials was determined for each envelope component (Exterior walls, Roof, Ground Floor Slab) following equations from Jordan's Thermal Insulation Code of 2009.

How Thermal Performance was measured:

U-Value Calculation: U-Value, representing heat transferred per unit area, was calculated using the formula: $U = 1 / (R\_total)$, where R_total is the total thermal resistance. It considers factors like thermal conductivity (K-Value) and layer thickness (d).

Component Analysis: Each building component (e.g., External walls, Roof, Ground Floor Slab) was analyzed separately, with designated references (W.01, W.02, R.01, R.02, S.01, S.02).

Comparison with Codes: U-Values were compared with local codes to evaluate the thermal performance of current materials and assess the impact of using PCMMI.

A. Calculating U-Value (U):

$U = 1 / R\_total$, where $R\_total = \Sigma (d / K)$ for each layer in the material.

R: Thermal Resistance (m^2K/W)

U: Thermal Transmittance (W/m^2K)

K: Thermal Conductivity (W/mK)

d: Layer Thickness (m)

B. Component References:

(W.01) External walls of the current residential building

(W.02) External walls with enhanced material

(R.01) Roof of the current building

(R.02) Roof of the enhanced envelope

(S.01) Ground Floor Slab of the current building

(S.02) Enhanced Ground Floor Slab material

The thermal performance calculation involved analyzing each layer's thickness and conductivity, as detailed in Table 1 (The Current Residential Building Envelopes Materials).

Table 1: *The Current Residential Building Envelopes Materials*

W01 Layers	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.040
1	Jordanian Stone	60	2.27	0.026
2	Castin-Site Concrete	80	1.17	0.068
3	Extruded Polysterne	30	0.032	0.938
4	Hollow Concrete Block	100	1.00	0.100
5	Cement Plastering	20	0.72	0.028
Rsi	Internal Thermal Resistance	-	-	0.130
Total		290	-	1.330

R01 Layers	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.040
1	Ceramic Tile	8	1.05	0.008
2	Cement Mortar	20	0.54	0.037
3	Sand & Gravel	70	0.30	0.233
4	Water Proofing (bi-tumen roll)	4	0.17	0.024
5	Light Weight Concrete	100	0.16	0.625
6	Re-inforced Concrete Slab	300	1.85	0.162
7	Cement Plastering	20	0.72	0.028
Rsi	Internal Thermal Resistance	-	-	0.100
Total		522	-	1.257

S01 Layers	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.130
1	Ceramic Tile	8	1.05	0.076
2	Cement Mortar	20	0.54	0.037
3	Sand & Gravel	70	0.30	0.233
4	Re-inforced Concrete Slab	300	1.85	0.162

5	Water Proofing (bi-tumen roll)	4	0.17	0.024
6	Light Weight Concrete	100	0.16	0.625
Rsi	Internal Thermal Resistance	-	-	0.100
Total		502	-	1.387

(Source: *Illustrated by the Researcher)*

The approach to calculate thermal performance involves analyzing each component of the residential envelope (Exterior walls, Roof, Ground Floor Slab) and assessing their layers. U-Values are then calculated for each material, compared against local codes to evaluate current building materials' thermal performance, and contrasted with the use of PCMMI. The process for calculating thermal performance with the new material remains consistent, utilizing equations from Jordan's Thermal Insulation Code of 2009.

What sets this section apart is the consideration of the total thickness and conductivity of each component, factoring in the additional PTSF layer. The inclusion of PSTFwith its container adds approximately 10mm to the thickness of the layers. The specific values and calculations adhere to Jordan's Thermal Insulation Code of 2009, with detailed calculations provided in Chapter 5 for each component to assess thermal quality.

Table 2 (The Envelopes Materials with PSTF) showcases the position of the new material, PTSF, in relation to other layers of the envelope.

Table 2: *Thermal Transmittance of the residential materials with PTSF*

Layer	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.040
1	Jordanian Stone	60	2.27	0.026
2	Castin-Site Concrete	80	1.17	0.068
3	Extruded Polysterne	30	0.032	0.938
4	Phase Change Material with Mycellium Integration	10	0.2	0.500
5	Hollow Concrete Block	100	1.00	0.100
6	Cement Plastering	20	0.72	0.028
Rsi	Internal Thermal Resistance	-	-	0.130
Total		300	-	1.830

Layer	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)

Rso	External Surface Resistance	-	-	0.040
1	Ceramic Tile	8	1.05	0.008
2	Cement Mortar	20	0.54	0.037
3	Sand & Gravel	70	0.30	0.233
4	Water Proofing (bi-tumen roll)	4	0.17	0.024
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7	Phase Change Material with Mycellium Integration	10	0.2	0.500
8	Cement Plastering	20	0.72	0.028
Rsi	Internal Thermal Resistance	-	-	0.100
Total		532	-	1.757

Layer	**Name**	**Thickness (mm)**	**K Value (W/mK)**	**R Value (m^2K/W)**
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1	Ceramic Tile	8	1.05	0.076
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6	Water Proofing (bi-tumen roll)	4	0.17	0.024
7	Light Weight Concrete	100	0.16	0.625
Rsi	Internal Thermal Resistance	-	-	0.100
Total		512	-	1.887

(Source: *Illustrated by the Researcher)*

Stage 2: A parametric investigation undertaken to ascertain the time delay of Phase Transition Substance integrated with Mycelium in residential apartments situated in Amman.

Utilizing Autodesk software, the parametric analysis simulated a residential structure in Amman, considering the local climate and geographical setting. It evaluated the duration of surface heat exposure and scrutinized energy consumption patterns. The study emphasized the significance of delay duration in envelope materials, which retards the transfer of heat between the exterior and interior of the building.

Delay Duration Computation:

The parametric analysis integrated maximum solar irradiance and surface sensors to ensure precise simulation. It also integrated ground reflection, GPS coordinates, and weather data to accurately depict sky distribution. After simulating the model with current materials, the analysis unveiled the duration of heat exposure and energy consumption, as depicted in Figure 2 (The results of the parametric analysis).

Figure 2: *Parametric Analysis Results*

***(Source:** Illustrated by the Researcher)*

Regarding PTSF Delay Duration, the material undergoes a shift from solid to liquid, acting as a thermal mass that amplifies delay duration and material performance. PTSF absorbs heat when the outside temperature surpasses 23°C, releasing it to the interior until the temperature drops below 23°C.

In summary, integrating PTSF into the building's envelope reinforces thermal mass, prolongs delay duration, and enhances thermal performance.

4. Results and Discussion

Stage 1 Results: A digital simulation conducted to assess the thermal performance of Phase Transition Substance with Mycelium Integration (PTSF) in residential apartments within the context of Amman.

The thermal performance assessment findings, as delineated in Table 3 (Results of the U-Value for the residential building materials integrated with PTSF), were derived from scrutinizing each element of the residential envelope and juxtaposing U-Values against local regulations. Specific designations were allocated to each building component for clarity: (W.01) for the existing residential structure's outer walls, (W.02) for the outer walls upgraded with new material, (R.01) for the current roof, (R.02) for the roof of the enhanced envelope, (S.01) for the existing building slab, and (S.02) for the improved slab material. (Swiety, D. S. 2023)

Table 3: *Results of the U-Value for the Residential Building Materials Integrated With PTSF*

W01 Layers	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.040
1	Jordanian Stone	60	2.27	0.026
2	Castin-Site Concrete	80	1.17	0.068
3	Extruded Polysterne	30	0.032	0.938
4	Hollow Concrete Block	100	1.00	0.100
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3	Sand & Gravel	70	0.30	0.233
4	Water Proofing (bi-tumen roll)	4	0.17	0.024
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7	Cement Plastering	20	0.72	0.028
Rsi	Internal Thermal Resistance	-	-	0.100
Total		522	-	1.257

S01 Layers	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.130
1	Ceramic Tile	8	1.05	0.076
2	Cement Mortar	20	0.54	0.037
3	Sand & Gravel	70	0.30	0.233
4	Re-inforced Concrete Slab	300	1.85	0.162
5	Water Proofing (bi-tumen roll)	4	0.17	0.024
6	Light Weight Concrete	100	0.16	0.625
Rsi	Internal Thermal Resistance	-	-	0.100
Total		502	-	1.387

***(Source:** Illustrated by the Researcher)*

Moreover, Table 4 (Results of the U-Value for residential building materials integrated with PTSF) illustrates the outcomes of computing the thermal transmittance (U-Value) for every element of the residential structure with the inclusion of a PTSF layer. This comparison offers insights into the influence of integrating PTSF on the thermal efficiency of external walls (W.02), the roof within the enhanced envelope (R.02), and the upgraded slab material (S.02). It facilitates a thorough assessment of PTSF's effectiveness in improving thermal insulation and diminishing heat transfer in each building component. (Swiety, D. S. 2023)

Table 4: *Results of the U-Value for Residential Building Materials Integrated With PTSF*

Layer	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.040
1	Jordanian Stone	60	2.27	0.026
2	Castin-Site Concrete	80	1.17	0.068
3	Extruded Polysterne	30	0.032	0.938
4	Phase Change Material with Mycellium Integration	10	0.2	0.500
5	Hollow Concrete Block	100	1.00	0.100
6	Cement Plastering	20	0.72	0.028
Rsi	Internal Thermal Resistance	-	-	0.130
Total		300	-	1.830

Layer	Name	Thickness (mm)	K Value (W/mK)	R Value (m^2K/W)
Rso	External Surface Resistance	-	-	0.040
1	Ceramic Tile	8	1.05	0.008
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3	Sand & Gravel	70	0.30	0.233
4	Water Proofing (bi-tumen roll)	4	0.17	0.024
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Rsi	Internal Thermal Resistance	-	-	0.100
Total		532	-	1.757

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Rso	External Surface Resistance	-	-	0.130
1	Ceramic Tile	8	1.05	0.076
2	Cement Mortar	20	0.54	0.037
3	Phase Change Material with Mycellium Integration	10	0.2	0.500
4	Sand & Gravel	70	0.30	0.233
5	Re-inforced Concrete Slab	300	1.85	0.162
6	Water Proofing (bi-tumen roll)	4	0.17	0.024
7	Light Weight Concrete	100	0.16	0.625
Rsi	Internal Thermal Resistance	-	-	0.100
Total		512	-	1.887

***(Source:** Illustrated by the Researcher)*

Stage 1 Discussion: A digital simulation conducted to assess the thermal performance of Phase Transition Substance with Mycelium Integration (PTSF) in residential apartments within the context of Amman.

- **Wall Thermal Efficiency:**

i. Thermal transmittance of walls without PTSF: 0.75 W/m²K (standard threshold: 0.57 W/m²K).

ii. Thermal transmittance of walls with PTSF: decreased to 0.54 W/m²K (below code threshold). The suggested enhancement displayed a 28% advancement in thermal effectiveness compared to the current condition. (Swiety, D. S. 2023)

- **Roof Thermal Efficiency:**

i. Thermal transmittance of the Roof minus PTSF: 0.8 W/m²K (code threshold: 0.550 W/m²K).

ii. Thermal transmittance of the Roof inclusive of PTSF: decreased to 0.53 W/m²K, a 33% decline. PTSF notably augmented the roof's thermal efficiency. (Swiety, D. S. 2023)

- **Ground Floor Slab Thermal Efficiency:**

i. Thermal transmittance of the Ground Floor Slab sans PTSF: 1.6 W/m²K (code threshold: 1.2 W/m²K).

ii. Thermal transmittance of the Ground Floor Slab incorporating PTSF: dropped to 1.18 W/m²K, marking a 26% enhancement. PTSF boosted the thermal effectiveness.

In synopsis, the absence of PTSF rendered the three primary constituents (external walls W.01, roof R.01, and ground floor slab S.01) non-compliant with code standards. PTSF, by reducing thermal transmittance, ameliorated thermal efficiency, aligning with code mandates. The decreased thermal transmittance signifies improved insulation, critical for curtailing heat exchange between the interior and exterior. The suggested PTSF layer significantly contributed to adhering to Jordanian thermal insulation regulations. (JNBC, 2009).

Stage 2 Results: A parametric investigation undertaken to ascertain the time delay of Phase Transition Substance integrated with Mycelium in residential apartments situated in Amman.

Each material in the envelope layers exhibits a distinct time-lag under identical climatic conditions and with equal thickness (Swiety, D.S., 2023). Table 5 (Time lag exhibited by the current envelope materials) presents the calculated time lag per millimeter. Additionally, Table 6 (Time delay observed with PSTF in envelope layers) demonstrates the efficacy of PSTFas a thin layer with robust thermal performance. Time lag values for each material were sourced from the literature. Each layer corresponds to a specific material, and the time lag is influenced by the thickness and characteristics of each material.

Table 5: *Time Lag Exhibited By the Current Envelope Materials*

Envelop Component		Material Name	Thickness (mm)	Time Lag (hr/mm)	Time Lag (hr)
1	**W01**	Jordanian Stone	60	0.016667	1

2		Castin-Site Concrete	70	0.037143	2.6
3		Extruded Polysterne	30	0.05	1.5
5		Hollow Concrete Block	100	0.01	1
6		Cement Plastering	20	0.0065	0.13
		Total	**280**		**6.23**
1	**R01**	Ceramic Tile	8	0.0175	0.14
2		Cement Mortar	20	0.013	0.26
3		Sand & Gravel	70	0.002429	0.17
4		Water Proofing (bi-tumen roll)	4	0.0075	0.03
5		Light Weight Concrete	100	0.027	2.7
6		Re-inforced Concrete Slab	300	0.01	3
8		Cement Plastering	20	0.0065	0.13
		Total	**522**		**6.43**
1	**S01**	Ceramic Tile	8	0.0175	0.14
2		Cement Mortar	20	0.013	0.26
3		Sand & Gravel	70	0.002429	0.17
4		Re-inforced Concrete Slab	300	0.01	3
6		Water Proofing (bi-tumen roll)	4	0.0075	0.03
7		Light Weight Concrete	100	0.027	2.7
		Total	**502**		**6.30**

***(Source:** Illustrated by the Researcher)*

Table 6: *Time Delay Observed With PSTF in Envelope Layers*

Envelop Component		**Material Name**	**Thickness (mm)**	**Time Lag (hr/mm)**	**Time Lag (hr)**
1	**W01**	Jordanian Stone	60	0.016667	1
2		Castin-Site Concrete	70	0.037143	2.6
3		Extruded Polysterne	30	0.05	1.5
4		Phase Change Material with Mycellium Integration	10	0.17	1.7
5		Hollow Concrete Block	100	0.01	1
6		Cement Plastering	20	0.0065	0.13
		Total	**290**		**7.93**
1	**R01**	Ceramic Tile	8	0.0175	0.14
2		Cement Mortar	20	0.013	0.26
3		Sand & Gravel	70	0.002429	0.17
4		Water Proofing (bi-tumen roll)	4	0.0075	0.03
5		Light Weight Concrete	100	0.027	2.7
6		Re-inforced Concrete Slab	300	0.01	3

7		Phase Change Material with Mycellium Integration	10	0.17	1.7
8		Cement Plastering	20	0.0065	0.13
		Total	**532**		**8.13**
1	**S01**	Ceramic Tile	8	0.0175	0.14
2		Cement Mortar	20	0.013	0.26
3		Sand & Gravel	70	0.002429	0.17
4		Re-inforced Concrete Slab	300	0.01	3
5		Phase Change Material with Mycellium Integration	10	0.17	1.7
6		Water Proofing (bi-tumen roll)	4	0.0075	0.03
7		Light Weight Concrete	100	0.027	2.7
		Total	**512**		**8.00**

***(Source:** Illustrated by the Researcher)*

Stage 2 Discussion: A parametric investigation undertaken to ascertain the time delay of Phase Transition Substance integrated with Mycelium in residential apartments situated in Amman.

The method used to determine the time lag of materials involved parametric simulations of a residential building. Two adaptive nodes were simulated: Node A, representing an external heating point with adjustable temperatures, and Node B, acting as an internal sensor. Tables were used to illustrate the parametric analysis, demonstrating the effects of the envelope materials both before and after integrating the PTSF layer.

5. Conclusion

This research delved into exploring the time lag of envelope materials, both with and without PTSF, emphasizing their crucial role in regulating heat transfer. In the absence of PTSF, the average time lag was approximately 5.2 hours, indicating the delay in transferring external heat to the interior. Conversely, integrating a 25mm layer of PTSF improved the time lag across all components. For instance, W.01 exhibited a time lag of 6.7 hours, while W.02 (with PTSF) demonstrated a time lag of 8.5 hours, indicating a 1.8-hour enhancement. Similar improvements were observed for the roof and ground floor slab. Given the limited existing research on PTSF in Jordan, this study pioneers its investigation in residential buildings within Amman's climatic conditions. The findings suggest that PTSF effectively enhances thermal performance, meeting regulatory codes and reducing U-Values. Despite challenges associated with software utilization, such as DYNAMO, this study recommends a reassessment of local building insulation codes, promotion of energy reduction education, and adoption of PTSF, particularly salt-hydrates, to surpass energy demand standards.

This investigation utilized digital simulation to compare the thermal performance of a residential building envelope with and without PTSF integration in Amman (32.0°N, 35.8°E). The outcomes indicated that integrating PTSF significantly improved thermal performance, leading to reduced U-Values meeting regulatory standards. This research contributes to understanding PTSF application in residential buildings in Jordan, particularly in the highland climatic zone.

The study concluded that PTSF, specifically salt-hydrates, when utilized as an envelope layer, effectively reduces energy demand, and meets regulatory codes. Time-lag analysis indicated that introducing PTSF, even with a small thickness of 25mm, notably improved the heat transfer delay within envelope components. These enhancements ranged from 1.8 hours for external walls (W.01 to W.02) to improvements in the roof and ground floor slab.

Despite its contributions, the study faced challenges, including limited existing research on PTSF in Jordan as an envelope material. However, this limitation turned into an advantage, positioning this study as the first of its kind in Jordan. The utilization of specific software tools, like DYNAMO, posed challenges due to the learning curve and time consumption. Based on the findings, the study recommends a review of local building insulation codes, enhanced public awareness about energy reduction, and adoption of PTSF, particularly salt-hydrates, to enhance building envelope performance in Jordan's climatic conditions.

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