BOOK OF PROCEEDINGS

1st International Conference on Built Environment

ICBE 2026

MAY 08th-09th, 2026
POLIS University, Tiranë

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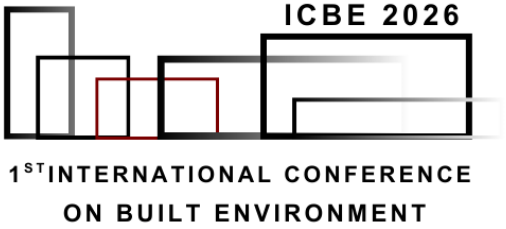
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1st International Conference on Built Environment

ICBE 2026

Conference Theme and Rationale

The 1st International Conference on Built Environment (ICBE 2026) was conceived as an international and interdisciplinary forum for advancing knowledge, critical discussion, and innovation across architecture, urban planning, engineering, construction, materials, design, and the wider built environment. Organized by POLIS University in collaboration with the National Agency for Scientific Research and Innovation in Albania (AKKSHI), the Academy of Sciences of Albania and the University of Ferrara in Italy, the conference brought together academics, researchers, practitioners, students, and industry representatives to exchange research findings, professional experience, and emerging perspectives on the transformation of contemporary cities and territories.

The conference theme reflected the increasingly complex challenges shaping the built environment, with particular attention to sustainability, resilience, technological innovation, heritage preservation, and socially responsive design. Contributions addressed sustainable architecture and green building, innovative construction technologies and materials, climate-responsive and energy-efficient design, disaster risk reduction, circular approaches to construction, and the integration of renewable energy. Equal emphasis was placed on digital transformation through Building Information Modeling, Geographic Information Systems, artificial intelligence, data analytics, automated solutions, digital fabrication, and advanced manufacturing.

ICBE 2026 also recognized that the future of the built environment cannot be approached through technological innovation alone. Urban transformation, cultural heritage, adaptive reuse, inclusive design, ecological thinking, art, and interdisciplinary research were therefore integral to the conference rationale. The scientific sessions examined topics ranging from seismic resilience, geotechnical engineering, and structural safety to urban fragmentation, public space, heritage conservation, adaptive environments, and new relationships between human and non-human systems.

Through keynote lectures, scientific presentations, case studies, and interdisciplinary debate, the conference encouraged connections between research and practice while promoting approaches capable of responding to environmental, social, cultural, and technological change. The breadth of contributions demonstrated the value of bringing engineering, architecture, urbanism, design, heritage, and emerging technologies into a shared academic framework for more resilient, sustainable, adaptive, and human-centered environments.

Held on 8-9 May 2026 at POLIS University in Tirana, with in-person and online participation, ICBE 2026 welcomed guest speakers and participants from Albanian and international universities, research institutions, professional organizations, and industry. Its sessions established a platform for presenting current research, exchanging expertise, strengthening meaningful collaboration, and identifying future directions for the built environment.

The event

The **1st International Conference on Built Environment (ICBE 2026)** is an interdisciplinary academic and professional forum dedicated to exploring contemporary challenges, emerging research, and innovative approaches shaping the future of the built environment. Bringing together researchers, academics, architects, engineers, urban planners, designers, practitioners, and industry professionals, the conference promotes the exchange of knowledge and encourages collaboration across traditionally interconnected disciplines. Its thematic scope encompasses sustainable and resilient construction, technological innovation, advanced building materials, urban transformation, cultural heritage, and interdisciplinary design approaches. Particular attention is given to the growing role of digital technologies, data-driven methodologies, intelligent design processes, and advanced analytical tools in supporting more informed and responsive approaches to architecture, engineering, and urban development. At the same time, ICBE 2026 recognizes the importance of environmental responsibility, cultural identity, social needs, and human-centered design in shaping contemporary cities and territories. Through keynote lectures, scientific sessions, case studies, and interdisciplinary exchange, the conference provides a platform for presenting current research, discussing professional experiences, and developing new perspectives capable of contributing to **safer, more sustainable, adaptive, inclusive, and resilient built environments**.

Objectives

- Promote interdisciplinary collaboration among researchers, academics, practitioners, and professionals in architecture, engineering, urban planning, construction, design, heritage, and related fields of the built environment.
- Advance the use of digital technologies and innovative methodologies, including BIM, GIS, artificial intelligence, data analytics, digital fabrication, and parametric approaches, in research and professional practice.
- Encourage sustainable, resilient, and climate-responsive approaches to architecture, construction, and urban development through innovative materials, energy-efficient strategies, and environmentally responsible design.
- Address contemporary challenges affecting cities, buildings, and infrastructure through scientific research, applied case studies, evidence-based approaches, and innovative design solutions.
- Promote the conservation, transformation, and adaptive reuse of cultural heritage, balancing cultural identity, contemporary needs, structural safety, and responsible urban development.
- Support human-centered and socially responsive urban transformation, considering public space, mobility, ecological systems, community needs, and the wider social and economic impacts of the built environment.
- Provide a platform for knowledge exchange and emerging research, enabling scholars, young researchers, professionals, and students to present innovative ideas, strengthen international collaboration, and contribute to future directions in the built environment.

Main Conference Themes

- Sustainable architecture and green building practices.
- Innovations in construction technologies and materials.
- Heritage preservation and adaptive reuse in the built environment.
- Digital tools and smart technologies in architecture and construction (e.g., BIM, GIS).
- Climate-responsive and energy-efficient design.
- Disaster risk reduction and resilience in the built environment.
- Circular economy approaches in construction and material usage.
- Integration of AI and data analytics in building design.
- Acoustic and thermal performance in building design.
- Renewable energy integration in building systems.
- Advanced manufacturing techniques in construction, such as 3D printing.
- Innovations in construction technologies and materials.
- Heritage preservation and adaptive reuse in the built environment.
- Disaster risk reduction and resilience in the built environment.
- Digital tools and smart technologies in architecture and construction.
- Advanced manufacturing techniques in construction.
- Geotechnical Engineering for Sustainable Development.
- Cartography and Geographic Information System.
- Computer Automated Solutions for Built Environment.
- Reliability in Civil Engineering.
- Urban planning strategies for resilient cities.
- Climate-responsive and energy-efficient design.
- Regulatory frameworks and policies impacting construction and urban development.
- Design in the Era of Anthropocene (Rethinking the Relation between Human and Non-Human Species)
- Speculative Design (with Attention to “Discursive” and “Critical” Design)
- Design and Cross-Disciplinarity (with Emphasis on Processes rather than Design Outputs)
- Inclusive Design
- Art and Urban Regeneration (Focus on Participatory, Collaborative, and Research-Based Practice)
- Relational Art and Architecture
- Monuments and ‘Anti-Monuments’ (Particular Attention to the Process of Designing and Building the City)

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The conference is structured around six thematic sessions, each addressing a specific area of research and practice within the built environment.
Each session is coordinated by experts in the relevant disciplinary field and is open to professors, researchers, PhD candidates, and other scholars and professionals contributing to the conference themes.

SESSION I
Urban Planning and Societal Impact

Chair: Dr. Gent Avdija

This session examines the relationship between urban transformation, spatial development, and their social implications within contemporary cities. Contributions address rapid urbanization, urban fragmentation, the transformation and loss of public space, informal and spontaneous development, and the challenges associated with balancing growth and modernization with human-scale urban environments. Particular attention is given to the evolving conditions of Albanian cities and to planning approaches capable of supporting more inclusive, sustainable, socially responsive, and livable urban environments.

SESSION II
Sustainable Materials, Resilient Construction & Smart Design

Chair: Dr. Endri Duro

This session explores innovative approaches to sustainable construction, resilient structural systems, and environmentally responsive design. Particular attention is given to sustainable materials, energy-efficient and climate-responsive strategies, prefabricated and lightweight construction technologies, and human-centered approaches to structural and architectural design. The session investigates how material innovation, technological development, and responsible design practices can contribute to safer, more efficient, adaptable, and environmentally sustainable built environments.

SESSION III
Technological Advancements and Seismic Design for Resilient Places

Chairs: Dr. Seyyed Behrad Emadi & Dr. Ornela Şen

This session examines the role of technological innovation and advanced engineering methodologies in developing safer, more resilient, and adaptable built environments. Contributions address seismic hazard and risk assessment, digital fabrication, parametric and computational approaches, transformations of building envelopes and prefabricated housing systems, and emerging concepts for future urban mobility. The session highlights how the integration of engineering knowledge, digital technologies, and resilience-oriented design can strengthen the capacity of buildings, infrastructure, and urban environments to respond to contemporary and future challenges.

SESSION IV

Cultural Heritage

Chairs: Dr. Nikolla Vesho & Dr. Marsela Demaj

This session addresses the preservation, interpretation, and transformation of cultural heritage within contemporary architectural and urban contexts. Contributions explore conservation strategies for historic buildings and sacred architecture, seismic assessment and strengthening of heritage structures, adaptive reuse, and the social implications of urban regeneration and heritage loss. Particular emphasis is placed on achieving a responsible balance between conservation ethics, cultural identity, structural safety, and the evolving functional requirements of historic buildings and urban environments.

SESSION V

Spaces of Connection: Art and Design for an Interspecies and Interdisciplinary Environment

Chair: Dr. Francesco Scasciamacchia

This session explores the intersections of art, architecture, design, technology, and the built environment through interdisciplinary and experimental perspectives. It investigates changing relationships between human and non-human systems, spatial perception, adaptive reuse, post-industrial landscapes, urban representation, digital heritage, and environmentally and socially engaged design practices. Through critical, speculative, participatory, and research-based approaches, the session examines how art and design can generate new forms of connection, reinterpret existing environments, and contribute to emerging cultural and spatial narratives within contemporary cities.

SESSION VI

Next-Generation Pioneers of the Built Environment

Chair: Dr. Flogerta Krosi

This session provides a dedicated platform for emerging researchers and students to present innovative, experimental, and forward-looking approaches to the built environment. Contributions span architecture, engineering, urban planning, environmental resilience, design, and related creative disciplines, reflecting the interdisciplinary character of a new generation of researchers and practitioners. Through projects addressing topics such as bioclimatic design, flood-risk management, structural technologies, architecture-inspired design, and critical interpretations of objects and social space, the session encourages critical inquiry, experimentation, and new perspectives on the future of the built environment.

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Sustainable Materials, Resilient Construction & Smart Design

Sustainable and resilient construction: Innovative construction systems / Sustainable building materials / Resilient structural solutions / Environmentally responsible construction.

Climate-responsive and energy-efficient design: Passive design strategies / Energy efficiency / Climate adaptation / Environmental performance.

Smart construction and material innovation: Lightweight construction / Prefabricated building systems / Advanced material applications / Resource-efficient technologies.

Human-centered design: Structural design for human needs / Performance-oriented architecture / Adaptable building systems / Integration of architecture and engineering.

Numerical assessment of the thermal performance of a heated and cooled floor containing upgraded phase change materials

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Abstract

A two-dimensional numerical model of a radiant floor heating system integrating phase change material (PCM) microcapsules microencapsulated in polyethylene spheres was elaborated to estimate its thermal performance. The outcomes point that ideal incorporation of the microcapsules directly above the heating pipes, with a 15% concentration in the cement mortar layer, meaningfully increases heat transfer to the upper floor surface. The parametric study highlights that increasing the pipe space extends the PCM melting time, stabilizes the surface temperature during the heating and cooling phases, and allows for a decrease in the number of pipes, thus improving the system's economic performance. A heating start-up temperature of 35°C is within the limits of thermal comfort, while higher temperatures generate discomfort, primarily during the heating phase. Evaluation between organic and inorganic PCMs shows that inorganic PCMs, particularly S27 hydrated salts, exhibit the best thermal performance, with a 4°C increase in temperature range and a 5,5-hour phase shift assessed to a floor without PCMs. The addition of conductive nanoparticles to form enhanced phase-change materials (NePCMs) achieves a total phase shift of 6.5 hours, ensuing significant cost savings. Finally, in cooling mode with water circulating at 19°C, a 4.5°C reduction in internal surface temperature is achieved.

Key words: *latent heat storage, microcapsules, NePCM, phase shift, thermal comfort.*

1. INTRODUCTION

Underfloor heating is a low-temperature heating system in which hot water (35–45 °C) circulates through pipes embedded in the floor. The heat spreads across the floor surface and warms the indoor space. According to the DTU 65.14 standard (NF DTU 65.14, 2021), the floor surface temperature should remain around 28 °C to ensure thermal comfort. This system can operate with different heat sources such as solar energy, boilers, or heat pumps and can also be used for both heating and cooling. Several studies have examined the performance of underfloor heating systems. Mokhtari et al. (Mokhtari et al., 2021) studied a solar underfloor heating system consisting of copper tubes (15 mm diameter) embedded in concrete and insulated with a 50 mm polystyrene layer. Their results showed that the fluid temperature stabilized at around 40 °C after 60 hours and maintained indoor temperatures between 20 °C and 25 °C, which satisfies thermal comfort requirements. Similar work by Zaheer-Uddin et al. (Zaheer-Uddin et al., 1997) used a gas boiler instead of solar collectors. Their results showed that the system required approximately 50 hours to reach stable operation and could maintain the indoor temperature close to the desired setpoint even when the outdoor temperature reached −6 °C. In another study, Mokhtari et al. (Mokhtari et al., 2021) explored the use of underfloor systems for summer cooling without air conditioning. The results showed that solar floors could cover up to 60 % of building energy needs in Maghreb climates and reduce indoor temperature by about 4 °C when circulating water at around 22.5 °C while avoiding condensation risks. Belkacem et al. (Belkacem et al., 2015) also evaluated a solar floor heating system without a storage tank and suggested combining reversible floor heating with night ventilation to improve comfort and reduce energy consumption. Control strategies also play an important role in system efficiency. According to the EN 12098 standard (NF EN 12098-5, 2021), intermittent operation with scheduled control can optimize energy use, particularly during periods when buildings are unoccupied. To further improve energy efficiency, several researchers have proposed integrating phase change materials (PCMs) into underfloor heating systems. PCMs store thermal energy during the heating phase and release it when the system stops. González et al. (González and Prieto, 2021) conducted a 2D numerical study comparing floors with and without PCMs. Their results showed that PCM integration increased stored thermal energy from about 445–552 Wh/m² to 1141–1245 Wh/m², although heat transfer decreased slightly. Other researchers have explored different PCM configurations. Wenlong Cheng et al. (Cheng et al., 2015) introduced PCM panels made of paraffin, polyethylene, and expanded graphite into a test room with underfloor heating and observed improved energy efficiency and reduced insulation thickness. Devaux et al. (Devaux and Farid, 2017) investigated the integration of PCMs in walls, ceilings, and floors, achieving energy savings of 32 % and cost reductions of 42 %. Farid et al. (Farid and Kong, 2001) tested macro-encapsulated PCMs integrated into concrete slabs with a melting temperature of around 28 °C. The results showed reduced floor temperature fluctuations and allowed heating to operate only during off-peak electricity hours. Similarly, Huang et al. (Huang et al., 2014) studied a floor

system with two layers of heating tubes and a PCM layer containing capric acid, which released 37,677.6 kJ of heat over 16 hours, representing 47.7 % of the supplied solar energy. Sung Ho Choi et al. (Choi et al., 2019) analyzed the thermal delay introduced by PCM layers in floor heating systems. Their results showed that PCMs increased the heat release period during discharge by more than 5 hours, improving peak load management. Zhang et al. (Zhang and Zhaosheng, 2021) also developed a numerical model to study the influence of PCM properties, concluding that phase change temperature and thermal conductivity significantly affect indoor comfort. However, PCMs generally suffer from low thermal conductivity (Al-Maghalseh and Mahkamov, 2018), which can limit their performance. To overcome this limitation, researchers have proposed enhancing PCMs with nanoparticles, creating nanoparticle-enhanced phase change materials (NePCMs). Al-Kayiem et al. (Al-Kayiem and Lin, 2014) showed that adding copper nanoparticles increased the thermal conductivity of paraffin PCM by 24 % and improved solar collector efficiency. Similarly, Karunesh et al. (Kant et al., 2017) demonstrated that graphene nanoparticles enhance PCM melting rates, although excessive concentrations may increase viscosity and reduce natural convection.

Sarrafha et al. (Sarrafha et al., 2021) investigated the use of carbon nanotubes (CNTs) in organic PCMs and found that they improved thermal comfort in winter and moderate seasons but could increase heat transfer during summer. Tian-Hu Wang et al. (Wang et al., 2020) also improved PCM thermal conductivity by mixing microencapsulated PCM with expanded graphite, increasing thermal conductivity from 0.22 W/m·K to 0.51 W/m·K and enhancing heat storage and release performance. In this study, it was numerically investigated the integration of PCM microcapsules. The objective is to exploit the thermal storage capacity of PCMs to reduce heating energy consumption and stabilize indoor temperatures near the comfort level. A two-dimensional model based on the enthalpy method and the finite volume approach is used. To address the low thermal conductivity of PCMs, nanoparticle-enhanced PCMs (NePCMs) are considered. The system is analyzed for both winter heating and summer cooling by circulating hot or cold water through the floor pipes.

2. METHODOLOGY

Our system is a heated floor consisting of five layers. The system described is based on a typical full-scale configuration taken from the literature (Abdellatif et al., 2019). The first layer consists of a 4 cm cement screed followed by 4 cm of cork and EPS thermal insulation. The next layer contains heating pipes and phase-change material microcapsules, and finally, a 2 cm marble top layer. In this study, it was specifically investigated the performance of nanoparticle-enhanced phase change materials (NePCMs). The enhanced PCM is composed of S27 hydrated salts integrated with 1% copper (Cu) nanoparticles and 4% Al_2O_3. This specific fraction was selected to overcome the inherently low thermal conductivity of organic and inorganic PCMs.

Figure 1 illustrates the composition of the heated floor under study. The water temperature

circulating in the pipes is taken from an experimental study in the literature (Larwa et al., 2021). The thermophysical properties of the materials used are shown in Tables 1 and 2.

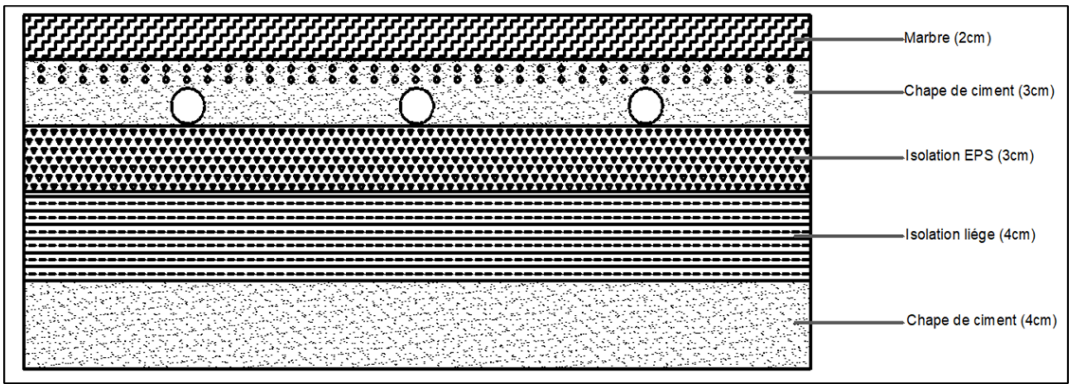


Table 1. Thermophysical properties of the slab construction materials

Construction materials	Density [kg/m³]	Thermal conductivity [W/ (m K)]	Specific heat capacity [J/(kg K)]
Liege	400	0.065	1500
Marber	2800	3.5	1000
cement	1600	0.85	1000
EPS	29	0.04	1450

Table 2. Thermophysical properties of the PCM

Melting point [°C]	**27**
Latent heat of fusion [J/kg]	185 000
Density (solid / liquid) [kg/m³]	1500
Thermal conductivity [W/(m·K)]	0,54
Specific heat capacity (solid) [J/(kg·K)]	2200

Simplifying assumptions

The heat balance of heat diffusion within the heated slab is developed using the following simplifying assumptions:

- The physical properties of the materials are assumed to be constant.
- Heat transfer within the slab and the fluid is unsteady and two-dimensional (2D).
- The heated slab is assumed to be adiabatic on all sides, except for the upper surface in contact with the internal environment.
- Contact is perfect at the interfaces.

• Convection is negligible in the molten phase of the PCM: Convection is neglected in the molten phase of the PCM. This simplification is justified by the fact that the PCM is microencapsulated within polyethylene spheres. The small diameter of these microcapsules physically restricts the mobility of the liquid phase, thereby suppressing buoyancy-driven natural convection

• The tubes are surrounded by a conductive material such that the water temperature is equal to the surface temperature of the heating tubes.

• Heat transfer within the layer containing the tubes and microcapsules is symmetrical.

Mathematical formulation

The heat transfer within the radiant floor is governed by the energy conservation equation. Based on the assumptions stated previously, the mathematical model is formulated using the enthalpy method in order to account for latent heat storage in the PCM layers.

For the standard layers (cement screed, insulation, and marble), the transient heat conduction equation is expressed as:

$$\left(1-\epsilon\right)\rho C_p\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)\right) \quad (1)$$

For the layer containing the heating tubes and the microencapsulated PCM, the governing equation incorporates the PCM volume fraction $\epsilon$and the total enthalpy $H$to describe the phase change process:

$$\epsilon\,\rho\frac{\partial H}{\partial t}=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) \quad (2)$$

The total enthalpy $H$is defined as the sum of sensible and latent heat contributions:

$$H=C_pT+fL \quad (3)$$

Where:

- ρ is the density of the material $\left(kg/m^3\right)$
- C_p is the specific heat capacity at constant pressure $(J/kg.K)$
- T is the local temperature (K)
- t is time (s)
- k is the thermal conductivity $(W/m.K)$
- ϵ is the volume fraction of microencapsulated PCM
- H is the total specific enthalpy (J/kg)
- f is the liquid fraction of PCM (1)
- L is the latent heat of fusion of the PCM (J/kg)

Boundary conditions

- $-\alpha\left(\frac{\partial h}{\partial y}\right)_{y=h}=h_{int}(T_{(y=h,t)}-T_{int})$

$$h_{int}=10\ \text{W/ (m².K)}\ et\ T_{int}=20°C$$

- $-\alpha\left(\frac{\partial h}{\partial y}\right)_{y=0} = 0$

$T|_{(x+l/2)^2+(y-R)^2=R^2} = T|_{(x-l/2)^2+(y-R)^2=R^2} = T_{eau}$

Initial condition

- $T(x, y, 0) = T_{int}$

Solution using the finite volume method

An implicit time integration scheme was employed to ensure numerical stability, and the resulting nonlinear system was solved iteratively using the Gauss–Seidel method, where the coupling between temperature and enthalpy was updated at each time step until convergence was achieved with normalized residuals below 10^{-6}.

The discretization of the energy equation using the finite volume method is performed by integrating the equation as follows for the general case:

$$\iiint (1-\varepsilon)\left(\frac{\partial h}{\partial t}\right)dxdydt = \iiint (1-\varepsilon)[\alpha\frac{\partial}{\partial x}\left(\frac{\partial h}{\partial x}\right) + \alpha\frac{\partial}{\partial y}\left(\frac{\partial h}{\partial y}\right) - \rho L\left(\frac{\partial f}{\partial t}\right)]dxdydt$$

- $(1-\varepsilon)\frac{h_p - h_p^0}{\Delta t} = \alpha(1-\varepsilon)\frac{h_e - 2h_p + h_w}{\Delta x^2} + \alpha(1-\varepsilon)\frac{h_S - 2h_p + h_N}{\Delta y^2} - \rho L(1-\varepsilon)\left(\frac{fp - fp0}{\Delta t}\right)$
- $(1-\varepsilon)(h_{(i,j)} - h^0_{(i,j)}) = (1-\varepsilon)\alpha\frac{\Delta t}{\Delta x^2}\left(h_{(i-1,j)} - 2h_{(i,j)} + h_{(i+1,j)}\right) +$
- $(1-\varepsilon)\alpha\frac{\Delta t}{\Delta y^2}\left(h_{(i,j-1)} - 2h_{(i,j)} + h_{(i,j+1)}\right) - (1-\varepsilon)\rho L(f_{(i,j)} - f^0_{(i,j)})$
- $(1-\varepsilon)\left(-\alpha\frac{\Delta t}{\Delta x^2}\right)h_{(i-1,j)} + (1-\varepsilon)\left(1 + 2\alpha\frac{\Delta t}{\Delta x^2} + 2\alpha\frac{\Delta t}{\Delta y^2}\right)h_{(i,j)} + (1-\varepsilon)\left(-\alpha\frac{\Delta t}{\Delta x^2}\right)h_{(i+1,j)} = (1-\varepsilon)h^0_{(i,j)} + (1-\varepsilon)\alpha\frac{\Delta t}{\Delta y^2}\left(h_{(i,j-1)} + h_{(i,j+1)}\right) - (1-\varepsilon)\rho L(f_{(i,j)} - f^0_{(i,j)})$

The liquid fraction for the general case is zero and the equation will take the following form:

$$(1-\varepsilon)\left(-\alpha\frac{\Delta t}{\Delta x^2}\right)h_{(i-1,j)} + (1-\varepsilon)\left(1 + 2\alpha\frac{\Delta t}{\Delta x^2} + 2\alpha\frac{\Delta t}{\Delta y^2}\right)h_{(i,j)} + (1-\varepsilon)\left(-\alpha\frac{\Delta t}{\Delta x^2}\right)h_{(i+1,j)} = (1-\varepsilon)h^0_{(i,j)} + (1-\varepsilon)\alpha\frac{\Delta t}{\Delta y^2}\left(h_{(i,j-1)} + h_{(i,j+1)}\right)$$

The discretized equation takes the following form:

$$a_e h_{(i+1,j)} + a_p h_{(i,j)} + a_w h_{(i-1,j)} = b$$

3. RESULTS AND DISCUSSIONS

Mesh and Time Step Optimization

The mesh chosen for the layers not containing the PCM microcapsule lightly coarse at 0.5 cm. Mesh optimization was performed for the layer incorporating the microcapsules, using three finer meshes of 0.1, 0.2, and 0.3 cm. The transition from a 0.2 cm to a 0.3 cm mesh resulted

in a 1.09% change in the surface temperature and a 9% change in the liquid fraction. Therefore, a 0.2 cm mesh will be considered, given that the transition from 0.1 cm to 0.2 cm results in a 0.885% change in surface temperature and a 1.329% change in the liquid fraction, respectively. Regarding the effect of the different time steps (Δt = 5, 2, and 1 s) on the internal surface temperature, the following table presents the relative variations in internal surface temperature for the chosen time steps. As can be seen, the transition from Δt = 2 s to Δt = 1 s resulted in a relative variation in internal temperature of approximately 0.003% and a difference of 1.0 x 10^{-3}°C, in addition to a variation in the liquid fraction of 0.991%. Finally, the chosen mesh size is 0.2 cm for the layer incorporating the PCM microcapsules and 0.5 cm for the other layers, with a time step of 2 seconds. The obtained results are in good agreement with previously reported studies in the literature, confirming the validity of the numerical model (Larwa et al., 2021).

Table 3. Effect of the mesh on the internal temperature.

dx(cm)	dy(cm)	T(i=N)	V.R[%]	Différence	fr(i=N)	V.R[%]	Différence
0,1	0,1	28,342			0,668		
0,2	0,2	28,595	0,885%	0,253	0,677	1,329%	9,0E-03
0,3	0,3	28,911	1,093%	0,316	0,744	9,005%	6,7E-02

Table 4. Effect of time step on internal temperature.

dt	T(i=N)	V.R[%]	Différence	fr(i=N)	V.R[%]	Différence
5s	28,911			0,9988		
2s	28,902	0,031%	9,0E-03	0,9987	0,010%	1,0E-04
1s	28,901	0,003%	1,0E-03	0,9889	0,991%	9,8E-03

Validation with experimental results from literature

The system on which we validated our mathematical and numerical model is an improved radiant floor with macro-encapsulated salt hydrate phase change materials (PCMs) in a layer of wet sand [21]. Our two-dimensional validation model of the radiant floor was implemented in a computational fluid dynamics (CFD) software using the finite volume method.

To minimize numerical errors and accelerate the calculation, the mesh size was refined for the area near the PCM containers and coarse for the area further away. The full mesh is limited to 0.5 cm to reduce computation time, with a 0.2 cm mesh reserved for the layer incorporating the PCM microcapsules. The comparison between our numerical results and those obtained experimentally on the temperature variation of the underside of the floor covering with PCMs.

Comparing the two solutions yields a numerical curve very close to the experimental curve, with a mean error (ERR) of 0.5%. This can be explained by neglecting the phenomenon of natural convection in our assumptions.

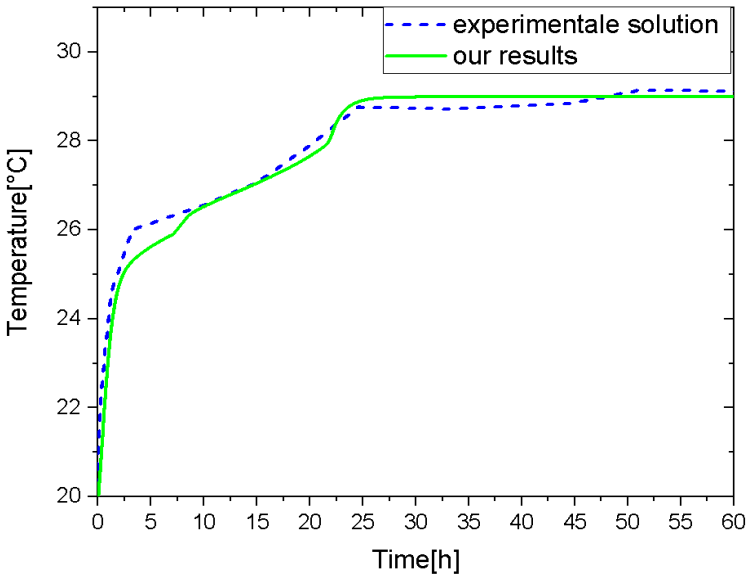


Figure 2. Validation of the digital and experimental solution for underfloor heating.

In general, we conclude that the numerical results are consistent with the experimental values, allowing us to affirm that the developed model is valid for predicting results closer to reality for this type of underfloor heating system.

Evaluation of heating and cooling Floor

To ensure climate control for year-round thermal comfort, this section proposes applying a cooling mode to the selected configuration during the winter months. This allows the floor to function as a conditioned hydraulic circuit for cooling during the summer. To prevent condensation of the fluid in the heating pipes, we will set the temperature to 19°C to ensure indoor comfort. The following figure illustrates the temporal variation of the internal surface temperature for the heating floor without cooling and the heating floor with cooling (cooling floor).

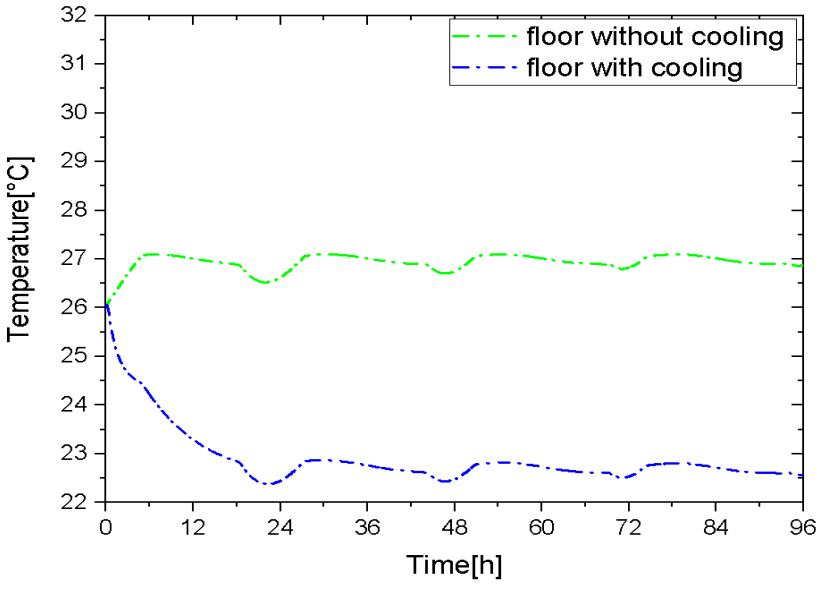


Figure 3. Variation of internal surface temperature for the floor with and without cooling.

According to the results shown in the figure, when circulating cold water at 19°C through the pipes to cool the indoor environment in the case of the cooling floor, the floor surface temperature varies between 22.3°C and 22.7°C. However, when using the floor without cooling, we observe that the surface temperature of the floor varies between 26°C and 27.2°C. We therefore emphasize that the use of cooling floors has shown that the process can indeed provide satisfactory results with a maximum reduction of 4.5°C in the ambient temperature, provided that a relatively high hydraulic circuit temperature of around 19°C is used to both provide a feeling of comfort for the occupants and to avoid the risk of condensation.

Regarding the liquid fraction, the following figure shows the temporal variation of the liquid fraction for the floor with and without cooling.

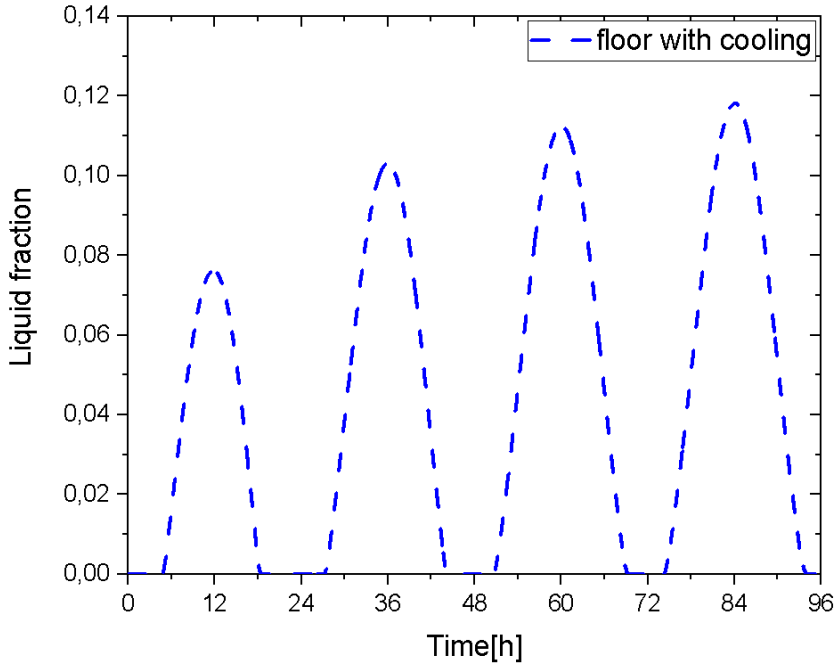


Figure 4. Variation of the liquid fraction of MCP microcapsules for the floor with and without cooling.

We observe that the liquid fraction of the PCM microcapsules exhibits a maximum liquefaction of 12% during the daytime period. This liquefaction is related to the imposed perceived temperature, which is slightly higher than the melting temperature (27°C) and which enabled the solid-liquid phase change of the microcapsules (f=0.12). However, the PCM remains in the solid phase during the nighttime period. This is related to the PCM's melting temperature (27°C), which is significantly higher than the imposed cooling temperature (19°C) and higher than the imposed temperature of 26°C during this period. In this case, the PCM microcapsules act as thermal insulation and can increase the temperature at the top surface of the floor, but the circulation of cold water at 19°C in the tubes cools the internal environment. We conclude that underfloor heating can be used as a heat diffuser during the winter period and can also be used as a heat absorber during the summer period; this is referred to as reversible underfloor heating.

4. CONCLUSIONS AND RECOMMENDATIONS

A two-dimensional physical model is used in this chapter to evaluate the thermal behaviour of a radiant floor heating system incorporating phase-change material microcapsules microencapsulated in polyethylene spheres. This prevents leakage into the liquid phase of the phase change material (PCM).

In this study, we evaluated the impact of adding simple and hybrid NePCMs on the floor's thermal performance and compared their respective effects.

Through this integration of phase-change material microcapsules enhanced with 1% copper and mixed with 4% Al2O3, we achieved a 4°C temperature increase with a 6.5-hour phase shift compared to conventional underfloor heating. Next, we performed a numerical simulation during the summer period using the same configuration as during the winter period. The results showed that integrating the PCM microcapsules into the floor provides improvements in thermal performance during both summer and winter periods, using the S27 hydrated salt PCM. Finally, we performed a numerical simulation for a cooling floor using the best configuration selected for the underfloor heating system during the winter period. By circulating cold water through the pipes at a temperature of 19°C, we achieved a cooling of the internal floor environment with a decrease in the internal surface temperature of 4.5°C. The main limitation of this study lies in the neglect of natural convection within the PCM during the melting process. Future work will focus on incorporating convective effects and experimental validation to further improve the model accuracy.

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