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A COMPREHENSIVE REVIEW OF THERMAL PERFORMANCE CHARACTERISTICS IN WET AND DRY RADIANT FLOOR HEATING SYSTEMS

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Abstract: This paper reviews the thermal performance of wet and dry radiant floor heating systems. Wet systems provide stable operation but suffer from high thermal inertia, while lightweight dry systems offer significantly faster heating and cooling response. The study summarizes research findings on heat transfer behavior, pipe installation methods, and the influence of radiant sheet materials on surface temperature distribution. The review highlights the need for further optimization of lightweight configurations to improve uniformity and overall energy performance.

Keywords: radiant floor heating, lightweight dry systems, wet screed systems, thermal performance, radiant sheet materials, surface temperature uniformity.

Introduction. Radiant floor heating systems function as an effective heat exchange technology and have become one of the most widely implemented heating solutions in modern construction practices. Their application is especially prevalent in residential buildings, including single-family houses and multi-unit housing complexes, due to their energy efficiency and improved indoor comfort. In recent decades, these systems have also gained strong relevance in non-residential infrastructures-such as office buildings, educational facilities, airports, and railway terminals-demonstrating their adaptability to diverse architectural environments [1].

Literature review. Radiant floor heating remains a subject of active scientific investigation, particularly in the field of thermal performance assessment and numerical modeling. Merabtine et al. [2] developed a two-dimensional numerical methodology to evaluate the transient heat transfer behavior of floor heating equipped with an anhydrite screed. The reliability of their approach was confirmed through both experimental measurements and finite-element simulations, allowing the influence of pipe diameter variation and volumetric flow rate on surface temperature uniformity and system response time to be quantified. In a further contribution, Merabtine et al. [3] proposed a semi-analytical model capable of predicting transient heat transfer more efficiently than fully numerical approaches, offering faster computation while maintaining sufficient accuracy. In addition, Zheng et al. [4] formulated a mathematical representation for estimating heat output and surface temperature distribution in radiant floor heating systems, providing engineers with a simplified but practical analytical tool.

Radiant heating is widely acknowledged as an energy-efficient indoor thermal environment solution due to reduced distribution losses and enhanced user comfort [5, 6]. This improvement in comfort conditions is primarily attributed to the relatively low vertical temperature gradient within the occupied zone, typically remaining below 0.07 K/m, which ensures more homogeneous thermal sensation throughout the space [7].

Wet (heavyweight) radiant floor systems, in which heating pipes are fully embedded in a screed layer, represent the most traditional and commonly used configuration. This approach is generally integrated during the initial construction phase, enabling pipe installation on top of a thermal insulation layer before screed casting. Despite their widespread use, wet systems are characterized by high thermal inertia, which limits the ability to rapidly adjust indoor temperatures, particularly in overheating situations [8]. To address this drawback, lightweight dry radiant floor systems have been introduced as an alternative solution. These configurations provide significantly faster thermal response, allowing heating and cooling rates up to six times quicker than those achieved by wet systems [9]. The assembly is finalized by applying a load-distributing layer such as dry screed panels or wood-based boards, followed by the chosen floor finishing material (tile, carpet, laminate, etc.). The elimination of a heavy screed layer results in considerably lower heat storage capacity, thereby improving controllability and reducing system inertia. Furthermore, installation time can be shortened because no curing period is required prior to finishing the surface. Due to these advantages, dry radiant floors are particularly suitable for buildings with joisted floor structures, which explains why recent research continues to explore their operational performance under both transient and steady-state conditions [10].

Qiu and Li [11] conducted a comparative assessment of surface temperature uniformity in both dry and wet radiant floor heating systems. In the evaluated dry configuration, pipes were installed within profiled insulation panels and covered by an aluminum radiant sheet; however, the exact sheet thickness was not provided. Their findings showed that the dry system exhibited pronounced temperature non-uniformity, with recorded variations reaching up to 4.64 K at a supply water temperature of 45 °C. In contrast, the wet system demonstrated substantially improved uniformity, presenting a maximum surface temperature difference of only 1.69 K under identical operational conditions. Zhang et al. [12] examined the effect of pipe spacing and supply water temperature on the thermal efficiency of lightweight systems. Their investigation revealed that reducing pipe spacing and increasing water temperature enhanced heating performance. In their experimental setup, pipes were placed above a non-profiled insulation layer within an air gap created by the floor's keel structure, and an aluminum foil layer-of unspecified thickness-served as the heat spreader. Despite improved heat transfer, considerable surface temperature fluctuation was reported, with amplitude values reaching up to 9 K. Liu et al. [13] investigated a lightweight radiant floor design with a pipe spacing of 0.075 m. The system featured pipes inserted into profiled EPS insulation and covered by a continuous aluminum sheet with a thickness of 0.12 mm. By eliminating gaps between radiant sheets, the authors reported improved thermal uniformity compared to configurations employing segmented aluminum clips.

Evren et al. [14] investigated lightweight hydronic radiant heating systems installed in floors, walls, and ceilings. In their studied configuration, Pe-Xa pipes were embedded within profiled insulation boards placed over chipboard panels, and a 0.5 mm aluminum radiant layer fully covered the insulation surface. The lightweight system was evaluated both as the primary heating source and in combination with electric fan heaters. Their results indicated that the hybrid operation not only reduced total energy consumption but also improved indoor thermal comfort compared to radiant heating alone. Thomas et al. [15] further analyzed the transient performance of a lightweight floor system operating in both heating and cooling modes. Pipes were mounted in aluminum clips fixed into wooden planks, with a parquet layer serving as the final surface finish. Despite the presence of discontinuities between the radiant sheets, the system exhibited a significantly faster thermal response than conventional wet systems. However, the authors cautioned against the use of wooden flooring finishes when applying radiant heating due to potential issues regarding durability and thermal performance. A novel lightweight radiant configuration was proposed by Karpiesiuk [16], demonstrating sufficient mechanical load-bearing capacity without the need for a screed layer. In this design, heating pipes were embedded in a reinforced tile adhesive layer, and ceramic tiles were installed directly above, resulting in a reduced build-up height and simplified installation. Werner-Juszczuk [17] examined the influence of incorporating a 0.4 mm metallized polyethylene radiant sheet on the thermal output of lightweight systems. The study found that including this sheet increased surface heat flux by as much as 105% compared with systems lacking a radiant layer. Even though both aluminum and polyethylene sheets improved heat transfer, the latter delivered 43–66% lower surface heat flux and exhibited less uniform surface temperature distribution than aluminum. Wang et al. [18] introduced an enhanced-convection overhead floor heating design, classified as a lightweight dry system. Pipes were located above insulation covered with aluminum foil, and an air cavity was formed beneath the wooden floor surface installed on support brackets. Two variations-one with ventilation openings and one without-were compared. The enhanced-convection configuration achieved faster temperature rise in both floor surface and indoor air relative to the standard overhead installation. A review of the body of literature confirms that most studies have focused on evaluating different radiant sheet materials, thicknesses, and installation arrangements. Aluminum has predominantly been employed as the thermal spreading layer, either fully covering the insulation surface or applied segmentally depending on the configuration.

Discussion. The reviewed studies collectively demonstrate that while radiant floor heating systems are highly attractive due to their comfort and energy-efficient operation, different construction approaches significantly influence their thermal behavior and controllability. Wet screed-embedded systems offer superior temperature uniformity and long-term stability but suffer from high thermal inertia, limiting their suitability in buildings with dynamic heating demand. Conversely, dry lightweight systems have emerged as a promising alternative because their reduced thermal mass enables considerably faster response time during both heating and cooling modes. Despite this progress, several thermal design challenges persist in lightweight configurations. A recurring limitation observed in multiple studies is insufficient heat spreading, which leads to non-uniform surface temperatures—especially in cases where aluminum layers are discontinuous or installed with air gaps. Research findings indicate that improving contact between pipes, insulation, and radiant sheets is crucial for enhancing heat flux distribution. Pipe spacing, material conductivity, and finishing floor type also exert considerable influence on overall performance and comfort perception. Furthermore, although dry systems have demonstrated performance improvements under experimental setups, more investigations on durability, acoustics, and long-term operational reliability are required before large-scale adoption in diverse building structures. Advanced numerical modeling continues to play a key role in identifying design optimizations, enabling more accurate prediction of transient heat transfer phenomena and system efficiency.

Conclusion. Radiant floor heating represents a technically and economically viable heating solution capable of providing both energy efficiency and enhanced thermal comfort in residential and commercial buildings. The comparison of construction strategies highlights that:

- Wet systems provide high thermal stability and uniform heat output but exhibit slow thermal response due to large heat storage mass.

- Dry systems offer rapid response and improved controllability, reduce installation time, and are suitable for refurbishment applications or joisted floor structures.

- Surface temperature uniformity remains the most critical performance factor for lightweight radiant floors.

- The use of continuous aluminum radiant sheets, reduced pipe spacing, and optimized water temperature settings yield considerable comfort and efficiency improvements.

- Future development efforts should focus on thermal homogenization techniques, enhanced analytical modeling tools, and material innovations that balance response speed with uniform heat distribution.

Overall, dry radiant floor heating technology continues to evolve through improved heat spreading solutions and optimized design practices. Continued experimental and simulation-based research will further enhance energy performance and support wider integration into modern sustainable building systems.

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