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A review of solar assisted radiant heating system: experimentation and simulation approach

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Abstract

The rate of energy consumption on the household level for heating and cooling is increasing annually. Due to economic growth and improved living standard, there is a sense of urgency of heating and cooling system for thermal comfort. Considering the thermal comfort, energy consumption, and impact on the environment, researchers and engineers need to focus on innovative heating and cooling solutions. The radiant heating system, which is popular among the Nordic countries, can be a promising future heating solution for Nepali buildings. This paper provides a brief overview of the solar-assisted floor heating system (SAFHS), experimentation, and simulation approach. Three types of paper included for review, the first type- experimental investigation on the floor heating system (FHS), the second type- simulation using ANSYS, and the third type- numerical analysis using TRNSYS. Out of forty-two papers selected for the study. The maximum papers used an experimental approach (11 articles) or TRNSYS (13 documents) to conduct temperature measurement, performance analysis, economic analysis, and estimate the solar fraction. ANSYS Fluent for the simulation of heat flux out of the system (9 papers), temperature field (11 articles), and the thermal comfort analysis (9 documents). 13 articles performed experiments combined with simulation under a standard protocol to validate the model. Both tools provide accurate results with an error below 10 %. The experimental study should be under the standard protocol, while TRNSYS should study the energy performance analysis, economic analysis, etc. The ANSYS Fluent simulates the thermal performance, temperature field, velocity field and conducts thermal comfort analysis. Based on the review, future research should be on taking combined advantages using the coupled-simulation approach.

Keywords: TRNSYS; ANSYS; Temperature distribution; Thermal analysis

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1. Introduction

The energy consumption in building shares one of the most significant portions of total energy demand in Nepal. Among which the maximum amount of energy for cooking and a small percentage for heating and cooling. People use electrical appliances like air conditioners and heaters for thermal comfort with improved living standards and economic growth. The heating and cooling sector consumed 10% of energy consumption on Nepal's household level [1]. The rate of consumption is increasing annually. Thus, to meet the future heating and cooling energy demand in the building sector, SAFHS might be an appropriate and urgent technology. The FHS consists of piping arrangements embedded within a radiant surface through which hot water flows and heat transfer occurs. The FHS maintains the desired indoor temperature through heat transfer between a radiant surface and room by conduction, convection, and radiation [2]. The Radiant heating and cooling systems deal with the sensible load. Combi-systems having ventilation with radiant heating and cooling systems have proven to be feasible in a hot and humid climate as it requires a continuous supply of fresh air [3].

Korea installed a floor heating system in almost all buildings. The percentage is 85 in Northern China and 35-50 in the EU nation's buildings [4]. The curve of installation is increasing rapidly. The residential and commercial buildings such as hotels, banks, educational institutions, and airplane hangar use this system. Applications of FHS have been steadily increasing because of its exciting features and advantages. The FHS system has low investment cost, low energy consumption, better thermal comfort, maintained the desired temperature up to human height, and quiet operation [5]. It avoids temperature fluctuation and reduces unnecessary indoor adjustment requirements [6]. These merits have motivated numerous studies on the FHS regarding thermal performance, heat transfer phenomena, energy simulation, system performance, control strategy, pressure drop, friction loss in pipe surfaces, and system arrangement.

SAFHS essentially consists of a solar collector, thermal storage, water pump, control valve, control system, and radiant surface, also called an active layer [8], as depicted in Fig. 1. A radiant surface is a heat emitting surface with complex phenomena as all heat transfer modes occurred together with thermal capacitance [9]. Thermal performance mainly depends on a collector size, thermal storage performance, and active layer's properties [10]. The integration of auxiliary heating systems with the plan enhances energy reliability. Occasionally, SAFHS is combined with a ground source heat pump, sometimes with a passive heating system, to get optimal system benefits. Solar integrated combi-system has a minimal operating cost [11], higher electric COP [7], higher energy and exergy efficiency [12], and better thermal performance [13]. Better thermal performance, maximum energy efficiency, the uniform temperature distribution for thermal comfort, and energy conservation are the primary design considerations for the designer and the consumers. Heating systems need to provide consistent temperature distribution that ensures better thermal comfort. Several simulation approaches analyze the system to know the system's en-

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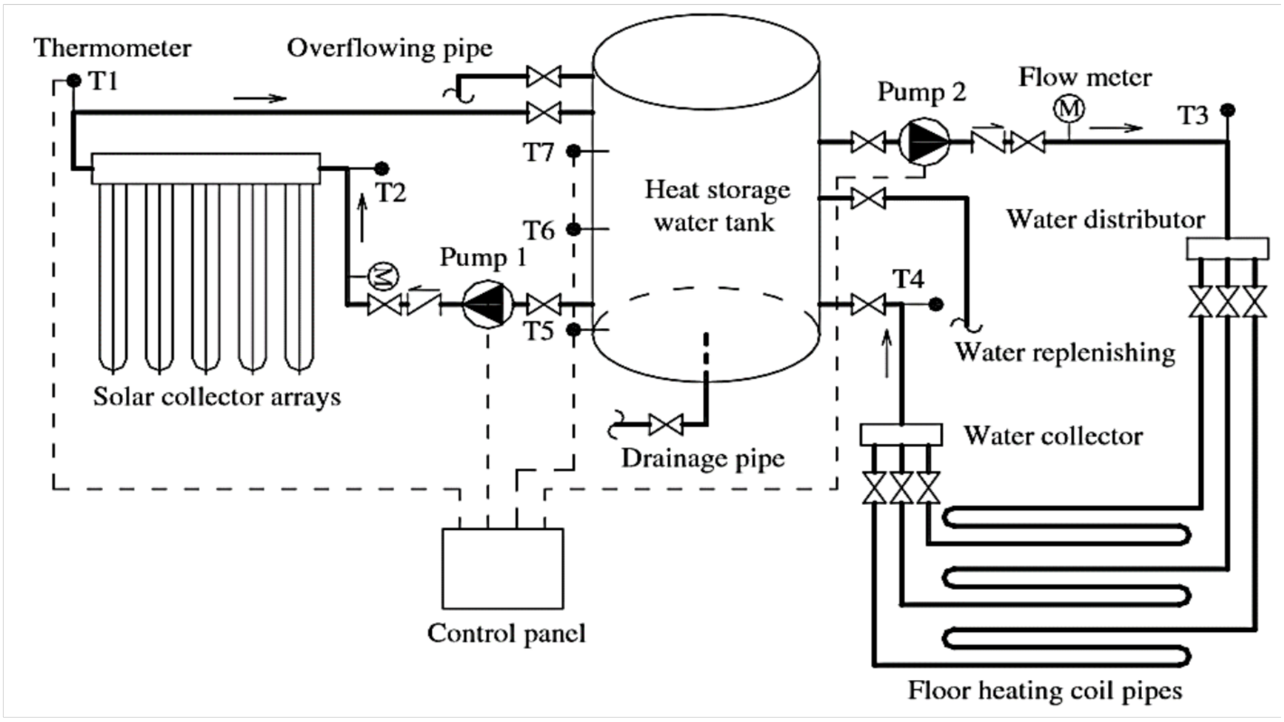

Figure 1: Flow diagram of solar-assisted floor heating system [7].

ergy consumption and performance.

Thermal simulation software for building allows for determining the appropriate heating-cooling devices, analyzing and simulating energy consumption, and performing economic analysis among several energy sources. It also enables evaluating the thermal performance of devices and provides the best measures adopted in the building. Simulation software also calculates the building variables like zone temperature, infiltration rate, heating and cooling load, ventilation level, thermal comfort level in the zone, and energy gain from occupants and equipment. This paper aims to provide a brief overview of solar-assisted radiant floor heating systems, the solar binary system, and their simulation technique in energy simulation and system performance.

1.1. Review method

For the review, papers published in scientific journals via google scholar were searched using the keywords: radiant heating system, floor heating system, solar-assisted floor heating, hydronic heating system, the capillary heating system, thermal analysis, thermal performance, thermal comfort, experiment solar heating system, energy simulation, CFD Analysis, TRNSYS simulation, ceiling heating, and cooling system, numerical study heating system, performance analysis. Further, we gathered some relevant papers using the reference section of the collected articles. In total, 160 documents, research articles, and conference papers were gathered, out of which 60 papers were selected that directly related to the topic of study.

We classified the research articles based on research approaches used: (1) laboratory test, (2) simulation using TRNSYS, and (3) simulation using ANSYS. We used this approach to highlight the research methodology under these topics.

2. Experiment method

The experiment method is the most effective analysis method, carried under standard test conditions for the heating and cooling system's rating and certification purposes. But it is not always feasible to create a test rig in the laboratory environment due to physical and financial connotations [14]. However, the experimental methods are as per ASHRAE standard or other protocol to validate the simulation result and investigate the system's real performance [15]. Experiments in a test rig have several units that define the desired plan. The components may be a solar collector, hot water storage tank, temperature controller, water pump, control valve, temperature sensor, as shown in Fig. 1. The test room may have the same dimension as the actual heating room or be scaled down.

The parameters like indoor air temperature and relative humidity, outdoor temperature and relative humidity, solar irradiance, radiant surface temperature, non-heating surface temperature, air velocity, etc., can be measured directly from the building integrated with the heating system. A new test method for two different floor heating systems that can perform simultaneous measurement was developed by Cho et al. [13], as shown in Fig. 2. Floor surface temperature, indoor air temperature, the heat transfer rate, etc., were measured to compare the system's thermal performance. Zhao [16] developed the experimental procedure for dual-source: (1) Solar, (2) Air Source Heat Pump (ASHP) radiant system as depicted in Fig. 3. The test rig measures the temperature distribution over the floor, vertical temperature gradient, non-heating surface temperature. The indoor thermal comfort, optimization strategy of the system, etc., were analyzed based on experimental data.

Weibin et al. [17] experimented with investigating the capillary radiant heating system assisted by ASHP as an additional heating source. The measured data gives an idea about thermal behavior and indoor thermal condition. Yu et al. [18] experimented following ASHRAE standards [15]. The test chamber consists of a flow meter, pump, bypass valve, electric heater, ceiling Radiant cooling panel, etc., as shown in Fig. 4. The system's heat capacity was determined and was equal to the electric heater's capacity after achieving thermal equilibrium. According to the ASHRAE standard, [19] constructed the test chamber with a ceiling radiant panel to study the heat transfer mechanism's radiant surfaces. The electric heater under EN14240 standard with a temperature controller provides the thermal energy. The temperature controller controls the supply water temperature to maintain a stable indoor climate.

Apart from test rig experiments, Imanari et al. [20] carried out seven subjective experiments to investigate the various radiant ceiling heating system characteristic. Radiant heating reduces energy consumption by 10%, having a payback period ranging from 1 to 17 years, and also, more than 80% of voters favor radiant heating. Thalfedt et al. studied the effects of internal load on room temperature and heat pump efficiency by monitoring room temperature, floor temperature, and heat output from the system [21]. It reported that temperature fluctuation during off-hours was below 0.2°C, but instability increased with unbalanced gain.

2.1. Experiments on SAFHS

While designing the FHS system, thermal performance, thermal comfort, energy efficiency, temperature distribution, energy consumption, etc., are the crucial parameters. All the experiments in the SAFHS focused on investigating these parameters. Table 1 presents the summary of experiments conducted under these parameters in SAFHS. Henning et al. studied and discussed possible solar system uses for heating and cooling the building. The study highlighted that solar thermal collectors are the most common and economical way to cover hot water loads [22]. Solar-based heating is a possible solution for places with high solar radiation. The proportion of the solar system's energy for solar assisted air source heat pump was studied, which showed that solar power to the total energy consumption of heat pump was 60 %. This ratio implied that solar-assisted systems are a more viable alternative energy source [23]. Performance of solar air source heat pump (SASHP) and Air source heat pump (ASHP) was evaluated, and results stated that the COP of SASHP was 109.43 % higher than that of ASHP and had 9.7 % lower operating cost [24]. The study on Radiant Heating and Cooling (RHS) 's feasibility in Iran indicates less risk of condensation in dryer regions. The RHS system saves the heating energy by 11.3 % and the cooling energy by 9.1 % [25]. Energy consumption for two SWHS located in Chifeng and Tianjin was studied by Hongbin et al. and found that average energy consumption from solar was higher. It is beneficial to use a solar-assisted system. The experiment on performance analysis of solar capillary heating system found that the system can dissipate enough heat to meet the demand [26]. The temperatures at different room coordinates and heat-dissipating capacity from the capillary showed that the delivered energy was larger than the building's heating load. An assessment of solar-based heating and cooling system for Italian buildings suggested that proper design is crucial for better heating and cooling circuits for better performance [28].

The use of renewable energy sources is not only the solution to the energy crisis. The system's best choice and efficient operating strategy can reduce its operating cost and solve the energy field issue. Zhai et al. investigated a solar-powered floor heating system's performance integrated into a Shanghai research center's green building. The solar-assisted system has essentially higher COP and has excellent energy saving potential than the ASHP [7]. The performance of a solar-ground water heat pump unit associated with radiant floor heating was evaluated [29]. The water-sourced heat pump unit and radiant heating with an adequate switch between solar energy and geothermal energy have better performance. Yu et al. tested hybrid solar air heating systems under different operating strategies. It was better to have a plan with passive heating for southern rooms and active solar heating for northern rooms [30].

3. TRNSYS features and simulation approach

Building energy simulation is a very complex task. All three modes of heat transfer conduction, convection, radiation, and their combination occurred, which is very difficult to address. The boundary conditions consist of weather and occupants challenging to predict and measure [9]. The designers and the researchers need to calculate the heating and cooling load to size the heating and cooling equipment. Different programs are available to simulate building models based on algebraic and differential equations to describe the problem.

TRNSYS is a transient simulation software designed in 1935 by Duffy and Beckman [32]. It uses the sequential computational approach for solving algebraic and differential equations [33]. It can solve the differential equation based upon the system, determine its convergence after the iteration, and plot the system variable. TRNSYS consists of two elements: (1) Kernel, which is just like an engine that reads and processes the input file, (2) Type. The prefix Type defines the whole system as a mathematical model that can function independently or in assembly, similar to real cases [34]. The Basic principle of TRNSYS is modeling the individual components of the desired system as a black box.

As depicted in Fig. 5, Input parameters refer to the deck file generated based upon the types' arrangements. The output managers: an online plotter, printer, integrator, etc., organize the simulation result after the solution converges.

TRNSYS provides a Graphic user interface, upon assembly of components, to solve transient systems like solar, HVAC, electric system and multi-zone building, etc. It consists of several built-in interfaces like simulation studio, the multi-zone building called TRNBUILD, and an editor interface called TRNSED [36]. Simulation studio allows a user to build a project by dragging and dropping a component called the type. The type consists of equations that require a number of the input parameter and constant value. These sets of the equation help to get the solution. The linkage between types transfers the output of a kind as an input for the next. The TRNSED allows performing the parametric study. TRNSYS type 56 takes the building data to model the building. It divides building into different zones, is further divided into air nodes. It utilizes the heat balance method and calculates heat transfer to and from surfaces and between the node type [9]. It is a widely used Type by engineers and researchers for simulation of building.

The SAFHS consists of the collector, hot water storage tank, controller, auxiliary heating devices, and radiant surfaces, as shown in the figure. The active layer facilitates the creation of radiant/capillary heating or cooling surfaces. The active layer needs input parameters such as mass flow rate, specific heat fluid, the inlet temperature of fluid, pipe diameter, and pipe spacing, which need to define initially. Mehdaoui et al. presented a descriptive diagram of the TRNSYS model [8], as shown in Fig. 6. The hot water stored in the thermal storage tank circulates via an active layer for room heating based on the heating load. A differential temperature controller controlled the supply to attain the setpoint temperature of the room.

3.1. Energy simulations on SAFHS using TRNSYS

This section presents the studies on evaluating energy consumption, energy performance, and the SAFH system's thermal environment using TRNSYS. Table 2 shows the investigations on the heating system for assessing these parameters. The number of validated simulation studies on the SAFH system showed that the FHS saves abundant energy, ensures desirable thermal comfort, and reduces operating costs.

The FHS installed in the lab in the mechanical faculty at Damascus University was tested and compared with simulated results.

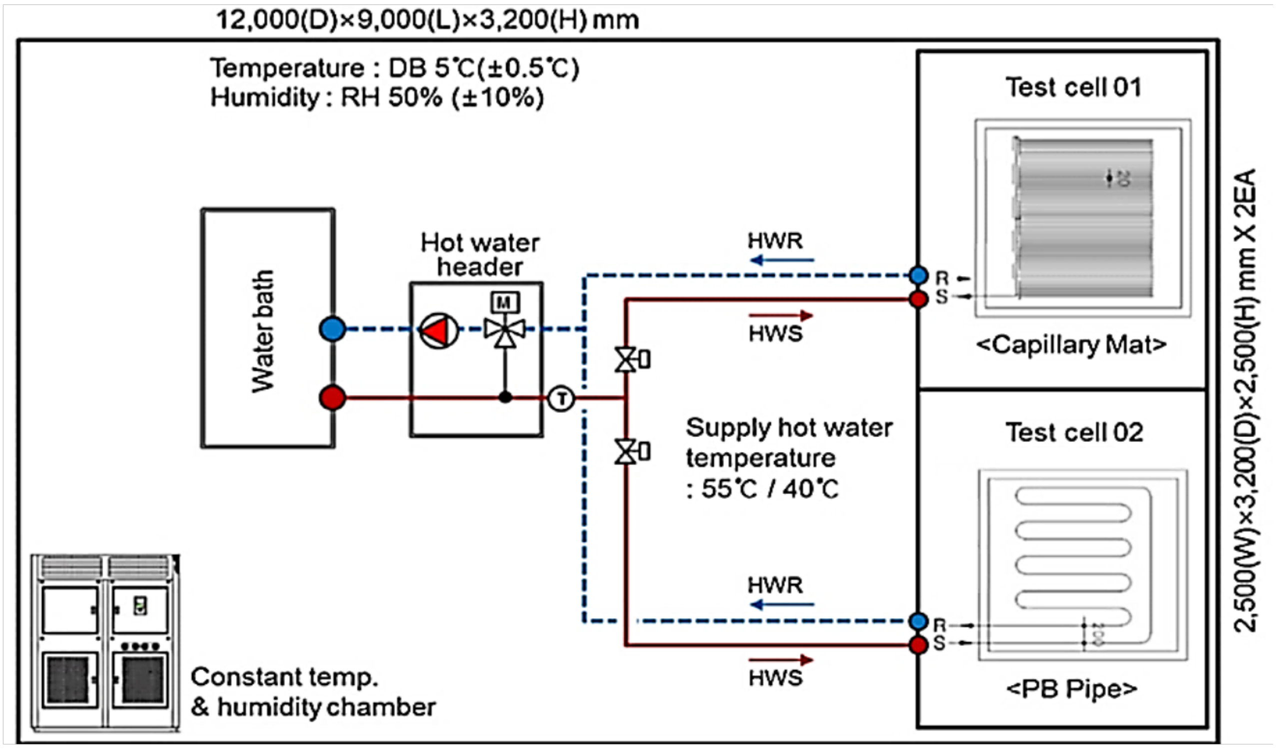

Figure 2: Diagram representing the proposed test chamber [13].

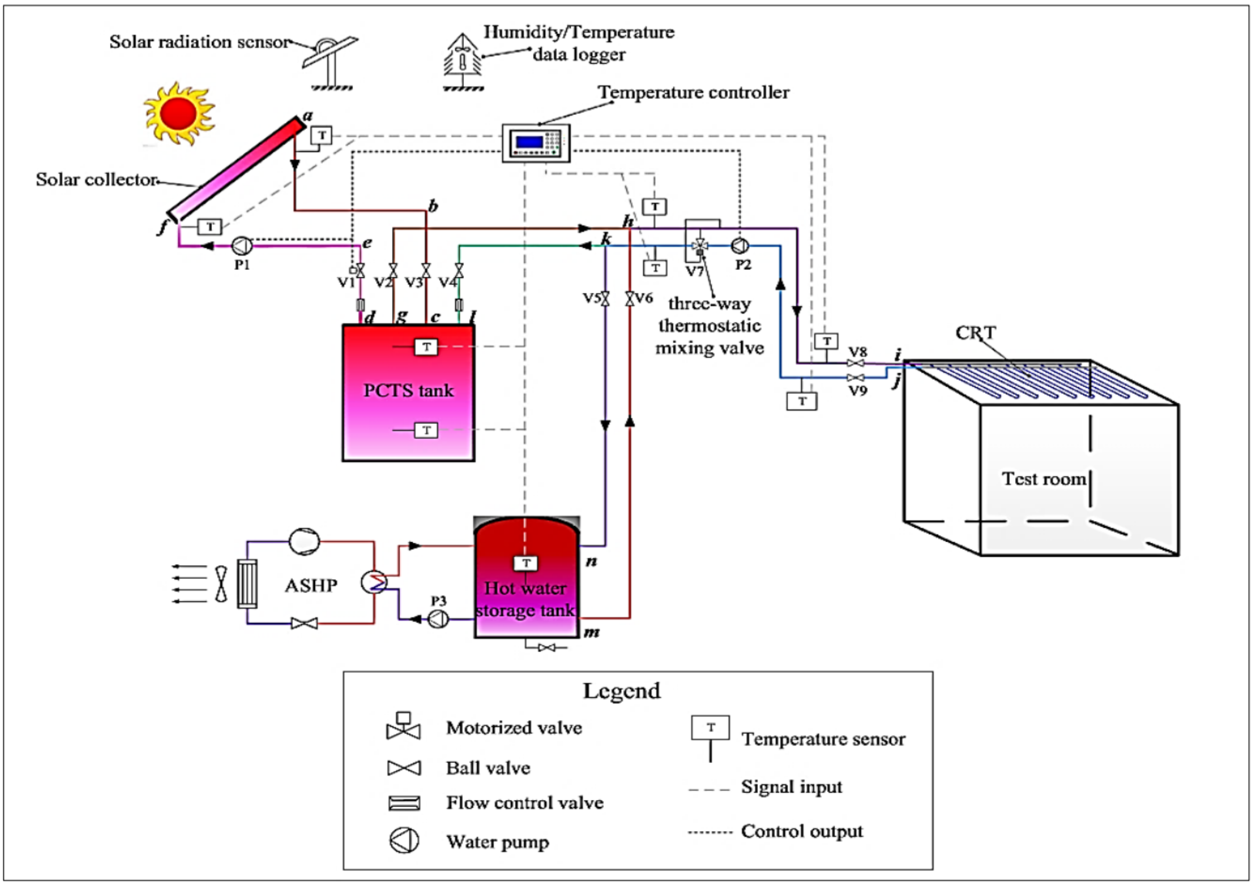

Figure 3: Flow diagram of the integrated system [16].

Table 1: Experimental research on SAFHS.

Author	System Features				Observations
	Country	Building	Area	System	
[22]	Germany	Hotel	3050 m^2	Solar Heating Cooling	Solar thermal collectors are the most common and economical way to cover the hot water load in the building, with those places having high solar isolation
[23]	China	Residential		Local Heating System	Solar energy is a feasible alternative having a ratio of solar energy to the total energy consumption of heat pump is 60 %
[31]	China			Hot Water System	Found that average energy consumption from solar was higher and it was beneficial to use solar assisted system
[21]	Estonia	Lab test room	100 m^2	Floor Heating System	Temperature fluctuation during off-hours was below 0.2°C but change increased with unbalanced gain
[3]	China	Residential	72 m^2	Floor Heating System	The air temperature had no impact on vertical air temperature distribution for FHS+DV or CHS+DV
[26]	China	Office	21 m^2	Capillary Heating System	Heat dissipating capacity from the heating system is 79.6W/m^2, which is higher than the heat load of 55W/m2
[19]	China	Test Room	15.12m^2	Radiant Cooling Panel	Obtained the value of heat transfer coefficient of 8.5W/m^{2}K
[27]	Iran	Standard flat	160m^2	Heating System	The heating loads are 8837 and 8757watt in Tehran and Yazd, respectively
[28]	Italy	Office	172m^2	Solar Heating System	Suggested that for better operation of the system more care should be given to design better heating and cooling circuit
[29]	China		30m^2	SGWHP with RFH	SGWHP has an energy saving of 30.55 % as compared with the conventional heating system. Also, an increase in solar fraction increases the COP of the heat pump by 6.44 %. Floor heating again has an energy-saving rate of 18.96 % compared to the traditional system.
[16]	China	Residential	11.88m^2	Capillary Radiant Heating	The supply water temperature has a significant impact on energy consumption. A temperature below 35°C can improve energy-saving potential.
[7]	China	Green Building	460m^2	Floor Heating System	The average electric COP of FHS was 19.76, and the system's solar fraction was 56 %. The system has great potential in energy conservation.
[18]	China	Office Building	265m^2	Active Solar Heating System	The experimented data shows that the time constant of the radiant panel is about 30min. The system has a comparatively smaller time lag as compared with the traditional concrete floor.
[17]	China	Residential	11.88m^2	Capillary Radiant Heating	Heating capacity from the radiant ceiling system satisfied the thermal load of the room
[24]	China	Residential	93.84m^2	Solar Air Source Heat Pump and ASHP	The radiant heating room has a uniform temperature distribution and a vertical temperature gradient of less than 3.2. The comfort level is of class A.
[20]	Japan	Office	33m^2	Radiant Ceiling Panel	The study shows that the radiant ceiling panel system reduced energy consumption by 10 %, having a payback time of 1 to 17 years, depending on market price.

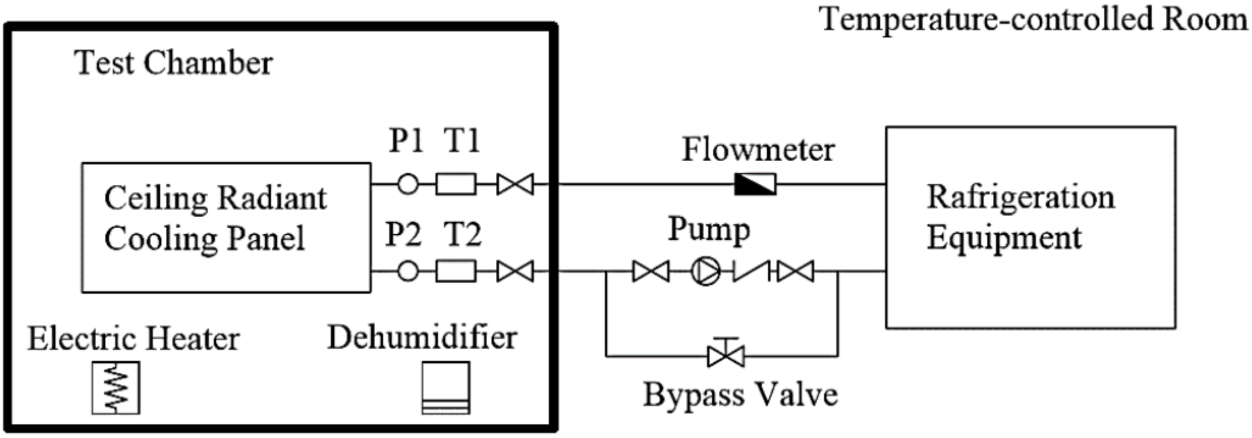

Figure 4: Flow diagram representing the cooling performance test [18].

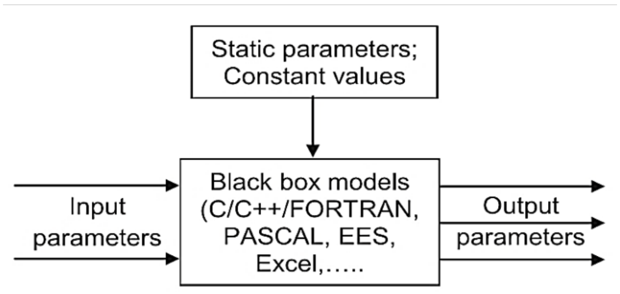

Figure 5: Black Box model of TRNSYS [35].

TRNSYS results showed closed relation between simulated and experimented results. Maleh et al. [5] found that thermal insulation saved energy by about 40 % of consumed fuel annually. They mentioned that radiant panels reduced local discomfort and draft rate. Maleh et al. [37] calculated the heating and cooling load of low flow systems in the renewable energy lab at Damascus University. The whole system was simulated using TRNSYS. The result showed that reducing the flow rate from optimum to minimum value reduced the room temperature by 2°C. A low flow rate system required a small pipe diameter, which is economical. Korkmaz et al. [10] examined the effects of different factors on the energy consumption of SAFH. The housing units have an area of 120 m^2 and 3 m high. Results showed that rising set point temperature by 1 increased energy consumption by 9.56 %. Likewise, increasing the volume of Heat Storage Tank (HST) reduced energy consumption by 3.96 % for every 1 m^3 volume increment. Also, increasing the collector area decreased the energy consumption by 0.12 % for every 1 m^2 increased in volume.

Occasionally, SAFHS is integrated with a heat pump and absorption chiller to improve the combined system's performance. It is a common practice to increase the COP of the system and also to reduce electricity consumption. Plytaria et al. [38] compared the three different SAHP underfloor heating systems' energy performance. The FHS with PCM reduces system capacity requirement by 40 % and electricity consumption between 42 % and 67 %. The simple payback period was from 9.61 to 22.06 years. O Ayadi et al. [39] developed a methodology for comparing different systems with the solar-assisted system. It was found that non-renewable energy saving for solar was 29 %, and the Levelized cost for the design was 15 %. Bellos et al. [11] proved that the SAHP saved energy consumption up to 40 % and had a COP of 4, which was essentially higher than all conventional air-source systems (2.5). Also, SAHP had an electricity-saving potential of about 35 % because the system has a higher COP. Tamasauskas et al. [40] developed a model to determine the heating and cooling loads using TRNSYS and concluded that solar energy could be the best option among combined systems. Operating strategies play a crucial role in enhancing performance and efficiency. The different operation strategies of a hybrid solar heating system were applied. Results showed that operation having passive heating for the southern room and active solar heating for the northern room proved to be superior in COP, solar fraction, and system efficiency [30].

The radiant system operates in both heating and cooling modes. The evaluation of the performances, thermal comfort and energy consumption highlighted that they had better cooling than heating. The system ensured better thermal comfort in cooling mode with minimal vertical temperature asymmetry [41]. Solar heating with an active and passive heating system (PHS) was studied using TRNSYS; the results showed that incorporating an active heating system improves the indoor air temperature [42]. A TRNSYS model of an absorption chiller operated by hot water from an evacuated tube collector was developed and found that the evacuated tube collector of 12m2 was enough to meet the system's thermal energy requirement during winter [43]. Another simulation model for a solar house in Brasov, Romania, to study the energy supplied by a solar collector. It was found a solar-based system saved extra heater energy consumed by auxiliary heating during summer and winter when solar isolation was minimal [44].

Krarouch et al. [45] analyzed the bathroom's energy performance located in Marrakech using TRNSYS. The results showed that solar collectors supplied whole energy during sunny days, and the study examined the applicability of copper tubing and PEX tubing. The results showed no significant impact on piping materials on surface temperature. So PEX pipes are more economical to use. Similarly, A model to determine the heating and cooling load using TRNSYS was developed and concluded that solar energy could be the best option among combined systems [40]. A simulation model to optimized the operation of SAFHS by regulating the supply temperature of the working fluid was studied [30]. This study proved to be an attractive way to monitor the indoor temperature within the comfort range. The effect of direct integration of solar heat into the room heating system was investigated. It was found that combining the system with Thermal Activation (TA) results in lower energy consumption. Other heating systems like the FHS and radiator did not significantly impact energy consumption [46]. A study and comparison on the low-temperature heating system in terms of energy consumption and energy efficiency with a conven-

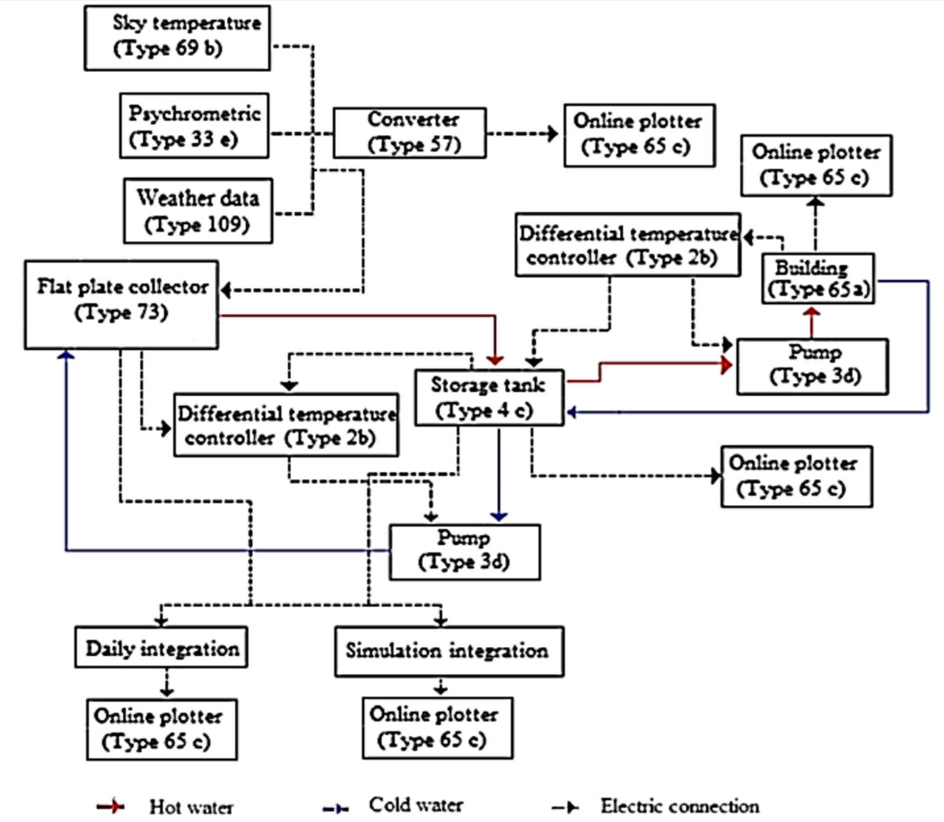

Figure 6: Descriptive flow diagram of TRNSYS model [8].

tional system and showed that lower temperature heating systems (LTHS) are more energy and efficient than traditional heating systems (CHS) [47].

3.2. Simulation approach using CFD

Finite volume code ANSYS Fluent is used for the simulation of a radiant heating system. Mass, momentum, and energy equations are set as the governing equation to define the physical problem. It is common to use experimented data like wall temperature, surface temperature, heat transfer coefficient, etc., as boundary conditions [48]. An appropriate turbulence model is used based upon system requirements. Since the radiant heating system is associated with convective and radiative heat transfer, it is sometimes desirable to obtain the radiation field as an output. For this, an appropriate radiation model needs to apply and thus gives more realistic results. The discrete ordinate method is a standard method because of its accuracy[49]. In the end, model validation is vital to ensure the accuracy of the model. In such a case, the experimented data and the simulated results are compared and should have an acceptable error below 10 %.

An experiment and simulation to evaluate the thermal comfort for a room with a cooling ceiling provide a general procedure to experiment, simulate, and validate simulated results, especially thermal comfort [48]. As depicted in Fig. 7, the necessary boundary conditions like temperature, relative humidity, non-heating surface temperature, etc., were provided as boundary conditions. A numerical method that coupled CFD with a semi-analytical radiant panel model was proposed [50]. Initially, the boundary condition was the panel temperature for solving a governing equation. The simulation results were input for the semi-analytical model, and the model could compute the new temperature field. The temperature was a boundary condition for CFD. This model helps to calculate energy consumption, thermal environment, the temperature distribution in different cases.

3.3. Analysis of the FHS using ANSYS

The radiant heating system is associated with the air system for ventilation, which causes uneven temperature distribution velocity and pressure in the room. The CFD analysis is crucial to investigate indoor parameters such as airflow pattern, air distribution, air quality, and temperature. Many CFD analysis studies for FHS simulation focused on getting temperature distribution, velocity field, and pressure field and analyzing the heat transfer mechanism from the radiant surface. This section presents researches conducted on simulation and analysis of the FHS using ANSYS (Table 3).

The thermal performance of indoor airflow in the heated room via the radiator, air conditioners, and the FHS were analyzed [51]. The numerical model was for simulation of temperature, pressure, and velocity field for a residential building of 20 m^2 area with an indoor temperature of 18 °C and an outdoor temperature of -9 °C. The simulated room was located on the building's middle floor, assuming zero radiation effect, incompressible airflow in a steady-state turbulent flow. The basic equation of mass momentum and energy was solved by applying boundary conditions for the heating system. The model has a hexahedral structure created using Hex and submap in GAMBIT with the grid independence study. The pressure velocity coupling is solved using the SIMPLE algorithm. Simulation results showed that FHS provides a more uniform temperature field and lower airflow velocity [51]. Instead of numerical simulation for the room, a two-dimensional model for floor heating and concentrated heating for an enclosure was developed [2]. The results showed a more uniform temperature for floor heating than localized heating. The CFD model that predicted surface temperature in the heating of a farrowing house found that alternative heating systems efficiently maintained the floor temperature required for thermal comfort. Geometry has a tetrahedral mesh

Table 2: Research on simulation of SAFHS using TRNSYS.

Author	System Features				Observations
	Country	Building	Area	System	
[37]	Syria	Lab Room	18m^2	Low flow Heating System	The result showed that reducing the flow rate from optimum to minimum value reduced room temperature by 2°C which can be balanced by pipe spacing
[5]	Syria	Lab Room	18m^2	Floor Heating System	Thermal insulation saved energy consumption by 40 %.
[10]	Turkey	Residential	120m^2	Floor heating Ceiling Cooling	Energy consumption by Auxiliary heater decreased with increasing collector area.
[42]	China	Residential	72m^2	Radiant Heating System	The system can be optimized using simulation techniques. The increase in collector area and the tank volume cannot increase the indoor temperature. It is the solar guarantee rate that enhanced the indoor thermal environment.
[43]	Pakistan	Family Building	14m^2	Solar Cooling System	The evacuated tube collector of 12m^2 was enough to meet the thermal energy requirement
[45]	Morocco	Hybrid Bath	36m^2	Combine Solar/Bio System	During sunny days, the energy was supplied by solar, and using the PEX pipe is economical compared with copper pipe.
[40]	Canada	Office	14240m^2	Solar Driven Absorption Chiller	Solar energy could be the best option among the combined system.
[46]	Switzerland	Residential	180m^2	Solar Thermal Combi- System	Combining the direct system with Thermal Activation results in lower energy consumption
[38]	Greece	Office	100m^2	Under Floor Heating System	The results showed that the use of PCM in the building envelop reduces the heating demand by 40 %, and electricity consumption reduced in the range of 42 % - 67 %. Solar-driven heating has a payback period of 9.61 years.
[39]	Jordan	Dormitory	1246m^2	Solar Thermal Heating Cooling	The solar source thermal and electric systems have a non-renewable primary energy savings of 29 % and 100 %, have a Levelized cost of Energy Saving of 15 % and 62 %, respectively.
[11]	Europe		100m^2	SAHP Heating System	The study shows that the COP of the solar-assisted system is closed to 4, and it proved to be a financially optimum solution.
[8]	Tunisia	Living Building	12m^2	Solar Assisted Floor Heating	The result showed that the solar-assisted system has a solar fraction of 78 %. The use of SAFHS reduced the relative humidity in the room by 35 %.
[41]	France	Laboratory	14m^2	Radiant Ceiling Panel	It is better to install radiant heating and cooling in the low thermal load building. The system gives good results with meeting the setpoint temperature in the heating mode than in cooling mode.
[30]	China	Office Building	265.6m^2	Active Solar Heating System	The solar fractions of the system in Hefei and Nyingchi were 39.5 % and 69.0 %. The values are above average during the heating season.

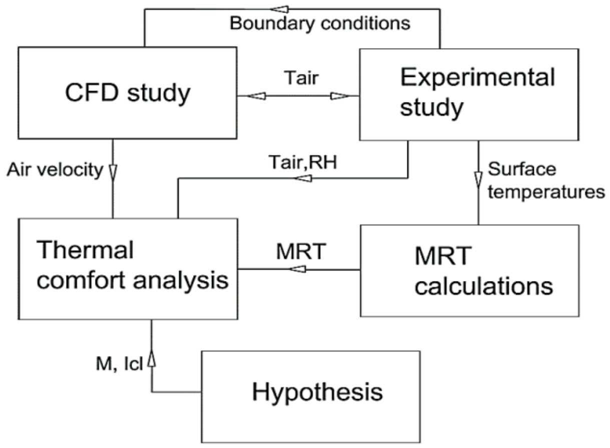

Figure 7: Flowchart for thermal analysis using CFD [48].

of 149503 and 32364 nodes and convergence criteria of less than 10^{-4}. The results showed that measured and predicted value has normalized mean square error of 0.002 and 0.0005 for conventional and alternative treatment [52].

A model to calculate the FHS's surface temperature and heat output was proposed, air as incompressible, the heat transfer process in a steady-state was assumed. The three-dimensional numerical model in fluent solved continuity, momentum, and energy equation using RNG, K-E model for turbulence, and DO for radiation model. The results showed that radiant floor heating gives the temperature of 27.8, which is the required temperature for thermal comfort [53]. A dome-shaped house was simulated by solving a governing equation, K-W model for turbulence model, and DO for radiation model assuming all surface as diffused grey. Results showed that heat transfer from the floor for dome shape is 6.5 % more in dome shape room than the cubic form, and floor heat transfer area decreased by 23 % with uniform temperature distribution was obtained in the dome-shaped room [54]. Temperature distribution for two layouts was simulated. The governing equation was solved using the RNG K-E model with second-order upwind discretization having convergence criteria of 10^{-4}. Simulation results showed that the spiral loop generated uniform temperature distribution used in the FHS. Some parameters, like velocity at the inlet, inlet temperatures, the pattern of tubing form, etc., were studied by Oubenmoh et al. [56] to examine the FHS's thermal performance simulation technique. The results showed that uniform temperature was for spiral configuration, and grid-independent study had no impact on the floor's surface temperature [55].

An application of solar air collector and air supply heating system in winter in the room of 20 m^2 area was studied. Governing equations: energy and momentum equations with two order accuracy difference scheme and rest were solved using the first-order upwind difference scheme. The three-dimensional double-precision pressure-based solution method was applied using the standard k- turbulence model and DO radiation model. The results were monitored for floor air supply system in fluent for 500 times showed that the change of outlet temperature was 328 K, meeting the standard for winter [57]. Zukowski et al. [58] conducted a numerical analysis of air underfloor heating systems and built a model to predict velocity and temperature distribution. Governing equations were solved in the finite element method using a two-equation- K-E model for modeling of turbulence and the Radiation matrix method for the radiation model. The algebraic equations were solved line by line using the Tri-Diagonal matrix algorithm having convergence criteria of 10^{-5}. There was a good agreement between simulated and experimented data and the uniform profile of the temperature in the middle from floor to ceiling. The location of the outlet vent had no impact on temperature distribution.

4. Discussion

This study is a review of the previous researches conducted on the experiment and the simulation of SAFHS. The objective of the study and system requirement defines the research approach. Experiments usually have a test rig under standard test conditions. It is not always feasible to conduct experiments due to lots of technical and financial implications. In such a case, the simulation could be an alternative technique to evaluate system performance. The philosophy behind the simulation technique is solving the mathematical equation using numerical methods. The result of the simulation depends on the simulation model and solving techniques.

The solar-assisted heating system is the transient system. Weather conditions, occupancy, internal load, etc., are the necessary boundary conditions that are difficult to predict. TRNSYS provides a simulation environment for building energy systems like HVAC, solar thermal, and electrical systems. It can incorporate weather files, schedules for the internal load that is transient, and essential boundary conditions. Apart from energy simulation, it is sometimes necessary to study temperature, velocity and pressure, thermal environment, and comfort. In that case, ANSYS Fluent shall solve the approximate form of governing equations to provide a solution field for a particular domain. Simulation results are of higher-order accuracy but required high simulation time, effort, and cost.

Table 4 summarizes the researches under different parameters like performance, thermal analysis, load study, temperature measurement, economic analysis, and solar fraction using experimental and simulation approaches. Research methodologies are selected based on the parameters under study. TRNSYS has features for energy performance analysis. Out of 16 papers selected for review on TRNSYS simulation, 13 of them studied the radiant heating system's energy performance, 4 of them performed economic analysis. ANSYS predicts the thermal performance, temperature distribution, pressure field, and velocity field inside the room. Model validation is crucial to ensure the accuracy of the model. The experiments for a similar system helps to check the accuracy of the model. Based on the review, whatever the simulation approach, the radiant heating system has equal benefits compared to all conventional heating cooling systems.

4.1. Future research

The market for solar energy is growing worldwide, making it a promising alternative energy source. There is a considerable reduction in the PV modules' price and the growing demand for heating and cooling requirements. It is urgent to introduce advanced technologies that can meet future heating and cooling load. Regular updates of simulation tools are mandatory for addressing changes in boundary conditions such as weather, occupancy, and internal gain. The coupled simulation using TRNSYS and ANSYS will be a possible future simulation approach. Future researches should be the focus on co-simulation of the heating and cooling system.

5. Conclusion

This study reviewed the general research consideration on SAFHS in terms of experimentation and simulation approach. The review shows that researcher used TRNSYS, TRNSOL, MATLAB, and energy plus for energy simulation. TRNSYS is a powerful tool that can perform energy simulation. Validating the TRNSYS results by testing on actual performance proves the above statement. At the

Table 3: Researches on FHS using ANSYS.

Author	Features				Observations
	Country	Building	Area	System	
[51]	China	Residential	$20m^2$	Floor Heating System	There was a more uniform temperature field and lower air velocity for floor heating. Mean temperature for model A 16.68°C with surface temperature 57°CModel B: 23.63°C with outlet temperature 28°CModel C: 21.42°C and having 1.84°C the temperature gradient between floor and heat.
[2]		Test Enclosure	$9m^2$	Floor Heating System	74 % of heating transfer from floor to wall and the air by radiationUniform temperature distribution for the FHS
[52]	Brazil	Farrowing House		Heating System	Measured and predicted value has NMSE of 0.002 and 0.005 for conventional and alternative treatmentCFD is an efficient tool for the design and simulation of the heating system.Low-temperature fluid can produce the same temperature using an alternative system
[53]		Test Room	$12m^2$	Floor Heating System	The average temperature for the three conditions is 24.5°C 27.8°C and 33°C respectively.27.8°C provides better thermal comfort.
[56]		Residential Building	$4.86m^2$	Radiant Floor Heating System	The modulated spiral configuration allows a more homogeneous temperature distribution of the floor.
[58]			$10m^2$	Air Under Floor Heating system	Uniform temperature distribution profile from floor to ceiling with a minimum temperature gradient
[54]		Dome House	$28m^2$	Floor Heating System	Heat transfer from the floor is 6.5 % more in the dome-shaped room, and the heating area is reduced by 23 %. The uniform temperature in the room using the FHS
[55]	Nepal	Hotel Building	$89.7m^2$	Solar Under Floor Heating	Spiral loop generates uniform temperature distribution in the floor, which produces consistent temperature in the room too.
[57]	China		$20m^2$	Floor Air Supply Heating System	The room temperature maintains at 292KThe measured temperature at different coordinates gives temperature, which was closed to the simulation temperature.
[59]	Turkey	Residential Building	$7.8m^2$	Floor and Wall Heating System	The simulation results showed a uniform temperature distribution for the FHS. The system has better thermal performance and thermal comfort conditions.
[60]				Floor Heating System	The volume flow rate and the diameter have a significant impact on the surface temperature. Similarly, the slab thickness, density, and specific heat influenced the thermal time constant.

Table 4: Summary of numbers of researches and their main findings.

Parameter	Number of research		
	Experiments	TRNSYS	ANSYS
Performance	11	13	4
Thermal analysis	7	4	9
Temperature measurement	8	9	-
Load study	9		-
Solar fraction	5	5	-
Economic analysis	4	4	-
Thermal comfort	5	1	5
Experimentation		6	7
Temperature field	-	-	11
Velocity field	-	-	1
Validation	-	6	7

same time, TRNSYS assumes air temperature in each zone to be uniformly constant; the CFD analysis helps to study the stratification in radiant heating systems.

Based on a review of research carried out on SAFHS, it is evidence that the SAFHS proved to be the right solution for improved thermal comfort and energy consumption. Solar assisted low-temperature heating system is more energy-efficient and beneficial to the commercial heating system. In a nutshell, a solar-assisted radiant floor heating system is one of the most promising and urgent technologies that provide a uniform temperature field in the room, better thermal comfort at the expense of lower energy consumption. The basis of the research approach depends on the system considerations and research objectives. It needs to explore the possibility of a co-simulation approach to analyze further energy saving potential and thermal comfort to meet the energy standards.

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