Optimization of Dynamic Embedded, Water Based Surface Heat (and Cold) Emitting System for Buildings

S. Thomas*, P-Y. Franck, P. André
University of Liège, Department of Environmental Sciences and Management
* 185 Avenue de Longwy, 6700 Arlon, Belgium, sebastien.thomas@ulg.ac.be

Abstract: This paper presents the heat flow model and the experimental test bench developed to optimize a new kind of heating floor. In the first part of the text is described the new kind of high reactivity emitting device for building heating and cooling. A second part illustrates the numerical model developed to evaluate the device efficiency. Finally experimental test bench implementation and results are presented. Both computational and experimental results support the use of colder water in comparison to other heating devices. This implies energy savings for building heating.

Keywords: heating floor, heat transfer, experimental validation.

1. Introduction

Among heat emitting systems (like radiators, air convectors, air handling units, local stoves,…) for buildings and dwellings, radiant water floor heaters are considered to be the most energy efficient and to provide the best comfort conditions for occupants. Standard warm water floor heating systems usually consist of serpentine or double spiral pipes that are drowned in a screed mortar on which final floor covering (like tiling, parquet floor,…) is laid.

New kind of emitting devices are developed to overcome the main drawback of the standard heating floors (low reactivity) and reduce as much as possible the supply water temperature. Attempts have been made to reduce respectively the thermal inertia of the whole heat emitter and the thermal resistance between water and the final floor surface. Ultimately, these improvements will allow both an increase in global heating system efficiency and in ambient comfort conditions.

The purpose of this simulation work is to help to optimize a particular heat emitting arrangement in terms of heat transfer, constitutive materials choice, weight, size (and cost) reduction.

2. Heating device layout

The emitting device basic arrangement is presented in figure 1. Load carrying material like MDF planks (2) are fixed on a thermally isolated, flat and stable support (1) at 16 mm intervals. Between them, pipes (4) transporting hot or cold water, are suspended by means of aluminium clips (3) that draw the heat upwards to a grid consisting of a spread out metallic sheet (5). Tiles or a similar covering material (6) are fixed on top of the arrangement by means of cement glue that also drown the metallic grid in such a way that it efficiently spreads the heat inside the glue and conveys it upwards to the final floor cover. In the same time, the grid improves the fixing of the tile and increases the strength of the whole arrangement.

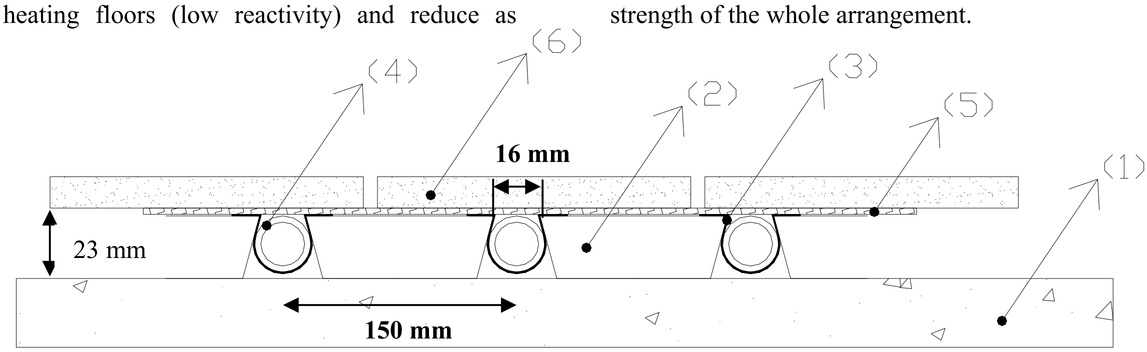

Figure 1. Heating floor description

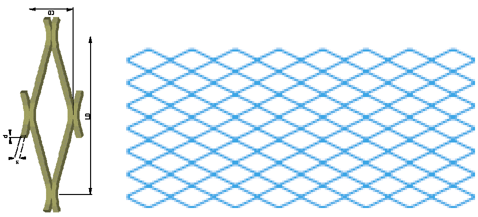

Figure 2. Grid = Spread out aluminium sheet (5).

In case of wood flooring, grid and glue are not necessary, wood planks are directly lain on the aluminium clips.

3. Numerical implementation

Heating floor modeling consists in computing the heat equation [1] on the whole simulation domain (defined below). The problem is studied under steady-state conditions, the aim is to reduce the thermal resistance between water and floor surface.

$$\rho c_p \frac{\partial T}{\partial t} = r + \nabla \cdot (k \nabla T) \quad [1]$$

Simplification is done (steady-state, no internal heat generation r = 0), the only parameter used is *k* which is the thermal conductivity [W/(mK)] of a material (defined in table 1). As the floor geometry is quite complex, analytical resolution is not feasible. A Finite element method has been chosen to compute the temperature field in the domain. The "Heat transfer" module of COMSOL 3.5 (steady-state) has been used.

A representative domain of the heating floor has been defined. When doing a cross section into a spiral heating floor (kind of floor studied in this paper), the shape is the same as shown by figure 1. The computation domain is reduced to the one presented in figure 3 (where boundary conditions are also defined). This reduction has sense because of the pipe sequences (supply-return-supply-return….). It is assumed that supply pipes have all the same water temperature. It is also the case for return pipes. So this configuration allows temperature symmetry on both sides of the vertical planes that include axes located in the center of the pipes. No normal heat flux is than considered through this axes. Temperature is fixed in the lower part of the domain. Stable support described in figure 1 consists in 3 successive slices respectively Wood-fibre – Insulation – Wood-fibre.

To model the heat transfer from floor to room, convection coefficient is fixed for upper part : 11.63 W/(mK) heating floor (ref 1); 7 W/(mK) cooling floor (ref 2).

Two floor covering are investigated :

- Wood flooring : planks floating directly on large aluminium clips.
- Tile flooring : Mix of glue and aluminium sheet is considered as a homogeneous material. Thermal conductivity is weighted by materials volume.

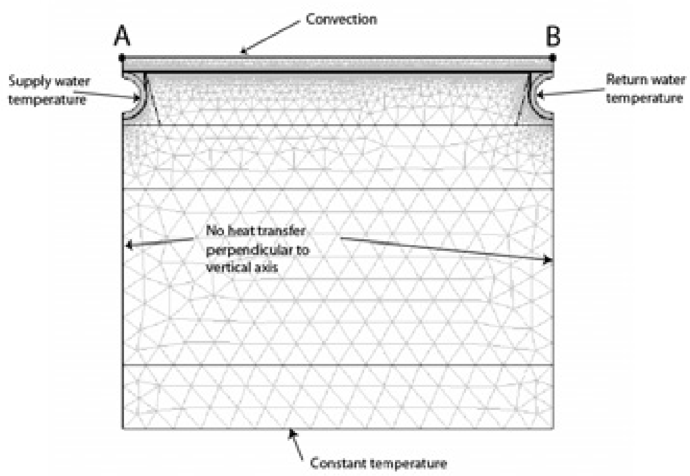

Figure 3. Domain definition and boundary conditions.

Material	Thermal conductivity [W/(mK)]
Insulation *(Extruded Polystyrene)*	0.034
Aluminium	222
Static air	0.025
Parquet	0.143
MDF (wood)	0.18
Wood fibre up	0.14
Wood fibre down	0.14
Pipe	0.38
Mix Glue-Aluminium sheet	45.4

Table 1 : Material properties

Air gap exists in the cavity under pipe, conduction heat transfer is only considered (no air replacement so no convection ; temperatures differences and low-emissivity of the materials lead to negligible radiation).

4. Test bench implementation

The Test bench (figure 4) has been designed to validate the optimized configuration simulated with COMSOL. To do this, it must meet the assumptions done here :
Vertical Symmetry plan axis → four pipes in a cross section of the test bench.
No depth effect (it is a 2D problem) → 1 meter depth test bench is considered.

Four parameters (boundary conditions) are mandatory to run a simulation and compare to measurements :

- Water temperature in the two circuits (hot–cold)
- Air temperature
- Temperature under the floor

A Laboratory facility let us control these four parameters. Figure 4 shows the wood floor covering test bench. Tile floor covering is very similar. To verify the model, the measured variable is the floor surface temperature. It is done with 5 temperature probes put on a cross section representative of the mathematical model.

5. Results

As mentioned before, tests are done with fixed boundary conditions and surface temperatures are measured in five points. Heat transfer rate is computed by multiplying the difference between mean surface temp and air temp with heat transfer coefficient defined before. Different cases were identified; care has been taken to have measurements done under steady state conditions. Example of floor temperature profile is showed on figure 5. Some of the test cases are listed in table 2. Comparison is done on power transferred to room.

Figure 4 Wood flooring test bench

Test case #	Mean surface floor temp	Supply hot temp (pipe)	Supply cold temp (pipe)	Air temp	Floor bottom temp	**Measured power (h = 11.63 W/m/K) [W/m²]**	**COMSOL power result [W/m²]**	COMSOL losses bottom [W/m²]	**Difference [%]**
11	27.37	39.35	35.53	19.95	9.91	**86.30**	**86.55**	10.30	**-0.29**
12	26.91	39.31	33.52	19.97	9.87	**80.66**	**81.30**	9.98	**-0.80**
13	27.32	37.23	37.64	20.02	9.89	**84.96**	**86.16**	10.32	**-1.40**

Table 2 : Results for some test cases (wood flooring)

5.1 Wood floor covering

Results of tests are very interesting, experimentation is really closed to model. For all common cases (around 20 cases were recorded where water temperature is >33°C) the variation between model and experimentation is less than 2.5%. These cases can provide the total heat transfer coefficient from hot water to floor surface (which is important for heating floor design).

$U_{water \rightarrow floor\ surface}$ = 8.54 W/(m²K) standard deviation is 0.12 W/(m²K)

For cooling mode, results are also significant but are not detailed here.

It appears that the heat transfer coefficient between floor and air has significant impact on results and strongly influences the comparison between experimentation and model. Up to now, a common value was fixed but it is useful to analyze this parameter more in details.

Floor temperature profile (figure 5) is different between experimentation and model. An explanation could be that the probes themselves are diffusing heat on the surface. Another hypothesis is the modification of the convection factor along the floor surface. These aspects should also be investigated. Nevertheless, the average floor temperature is similar, and that's the reason why experimental heat flow is closed to computed heat flow.

5.2 Tile floor covering

For a better heat transfer, it is recommended to use tile floor covering when installing a heating floor. For this kind of floor covering, mix of glue and aluminium has been modeled in COMSOL (see paragraph 3). Large differences are encountered between experimental and computational results. Experimental heat flow is around 20% less than computation. For experimental results, the heat transfer computation gives :

$U_{water \rightarrow floor\ surface}$ = 13.08 W/(m²K) standard deviation is 1.26 W/(m²K)

High standard deviation can be due to test disturbance or convection coefficient variation. Difference between computation and experimentation can come from the modeling of the glue-aluminium mix. In the finite element model, it has been considered as a homogeneous material. Moreover, real mix of these two components can unfortunately encapsulate air bubbles. Another explanation could be the variation of the heat transfer coefficient from floor to air between wood and tile covering tests. During both sets of tests, room temperature, wall temperature and ventilation were nearly the same.

Currently no clear explanation of these differences has been found. It is important to find out this problem especially because heat transfer of experimentation is less than computation. Low heat transfer implies use of higher supply water temperature thus lower efficiency of heating floor.

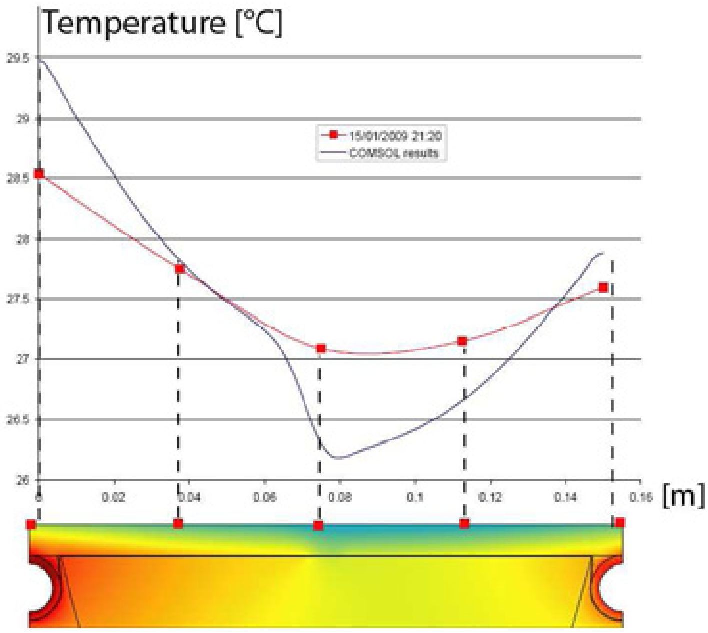

Figure 5 Floor surface temperature : Red curve is experimental (with boxes at the probe positions), Blue is COMSOL curve.

6. Further developments

The following issues mentioned above in the text should be investigated :

- Temperature profile smoother in experimentation than in computation.
- Variation between experimentation and computation for tile flooring.
- Heat transfer definition between floor and air. A more precise value should be taken than a normative figure.

For the second point, a first approach will be to compare the experimental results with a new test bench built soon. It is a way to assert if differences are coming from the glue-aluminium mix implementation.

For the third point, semi empirical correlations (ref. 3) have been used to find a more accurate floor to air heat transfer correlation. These have lead to values generally lower than 10 W/(m²K). A new way to identify this coefficient should be investigated.

Moreover, one of this new heating floor asset is the high reactivity. To verify this, transient simulations should be run. New test bench is in progress to compare reactivity of light versus heavy heating floor. A model will be developed to predict the two floors behavior.

7. Conclusions

In this paper was presented a method to model the heat transfer through a floor emitting device. Due to complex geometry, a finite element numerical model has been built for optimization. Validation has been made with two test benches (wood and tile covering) but only one test bench experimental results matches with the computation.

Even if the model developed here has not always been able to predict accurately floor surface temperature, it has been very useful to evaluate the impact of the emitter geometry and material composition on its efficiency. This is necessary to optimize the emitter design in terms of heat transfer efficiency and cost.

The comparison between heavy and light floor emitting systems will also be interesting and helpful to improve the model in its steady state and dynamic behaviors.

8. References

1. Vasco – chauffage par le sol – information technique. http://www.vasco.be/downloads/vloerverwarming_techinfoFR.pdf

2. Draft prEN 15377-1 – Heating systems in buildings – Design of embedded water based surface heating and cooling systems – Part 1 : Determination of the design heating and cooling capacity. (October 2005)

3. W.M. Rohsenow, J.P. Hartnett, *Handbook of heat transfer*, 6-14 to 16. McGraw-Hill, New-York (1973)