

Dynamic Heat and Moisture Transport Modeling of Industrial Floors on Different Climates

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Abstract. In this paper a conjugated heat and moisture transport investigation of industrial floors is presented. We have analyzed 2D general segments of wall and foundation connections in three different climatic conditions: Budapest (Hungary), Lisbon (Portugal) and Espoo (Finland). We also modeled the component with horizontal or vertical edge insulations with various thicknesses and lengths, and two different soil compositions under the floors. The design of the floor and wall components was performed according to the current standards. We examined 126 combination of the segment and the results shows difference both in relative humidity across the components and heat losses through the internal faces. In conclusion, the simulations and results can improve the energy efficient design of industrial buildings across Europe.

Introduction

In recent years, our goal is to construct residential and even industrial halls in the most energy-efficient way. In building energy calculations, it is fundamental to know the hygrothermal aspects of a structure, therefore we need to know the component and material performances as well. These performances can be calculated from material properties and boundary conditions using partial differential equations of heat and moisture transport. However, the conditions and properties are continuously changing over time, depending mostly on the temperature and moisture effects.

In this paper, we have analyzed 126 combinations of a general segment of wall and foundations connection of a heated industrial hall. We did not cover freezer rooms in our study, which building have interesting building physical effects in other respects [1].

The old Hungarian standard MSZ-04-140-2:1991 [2] regulated the size and the locations of the insulation in case of ground contact structures. The standard committee withdrew this standard in 2012, nowadays there are now standardized or legislative requirement to perimeter insulation in ground contact structures, yet it is very often used. Therefore, we decided to examine the models with three different lengths of floor insulation (50 cm, 100 cm and 150 cm).

To determine the most important properties (moisture and temperature dependent thermal conductivity, specific heat capacity, vapor diffusion coefficient and resistance, moisture storage functions, water absorption coefficient and liquid transport coefficient) of the steel fiber reinforced concrete, we used our measurements from a previous researches [3, 4].

We evaluated the results according to the effect of the heat loss on the internal surfaces of the floor and the walls and relative humidity across the components. With these results, in the field of building structures and energy design we are able to calculate more accurately and closer to reality in European conditions.

Conjugated Heat and Moisture Transport

While studying conjugated heat and moisture transport of buildings or components, we know the temperature and moisture distribution on the boundaries on hourly basis, and we want to know the temperature and relative humidity changes inside the structures or the heat fluxes on the boundaries of the layers, which are changing dynamically over the time. Especially we are curious for the results from the internal faces of the components, since Hungarian building physical calculations

based on internal dimensions. The heat and moisture transport is always a conjugated physical phenomenon, since material properties affected by both temperature and moisture and the phenomena is not separable in the real life, since there are no permanent steady-state conditions in the reality. In some structures, (e.g., mineral wool insulated components), air transfer can have observable effect on heat transfer [5], but in soil contact structures, there are mainly heat and moisture transport dominates the energy flows for dynamic simulations. If the boundary conditions are periodic (e.g., same weather file repeated every year), consider heat transfer only is sufficient to represent heat fluxes on boundaries [6]. Therefore, we neglected the effects of air transport, which simplifies the simulations as well.

We used WUFI 2D simulation tool for the conjugated heat and moisture transport analyses, which are based on equations presented in [7, 8]. These differential equations are discretized by means of an implicit finite volume method and are iteratively solved. The accuracy of the numerical solutions depends on the mesh widths of the grid and the size of time steps and the choice of the convergence criteria. Understanding the changing material properties in these equations are essential for hygrothermal simulations, therefore, if we want to model a building or a component we need to know all the important hygrothermal properties. Without proper set of boundary conditions and material properties, the results can be interesting but technically useless.

Industrial Floor Models

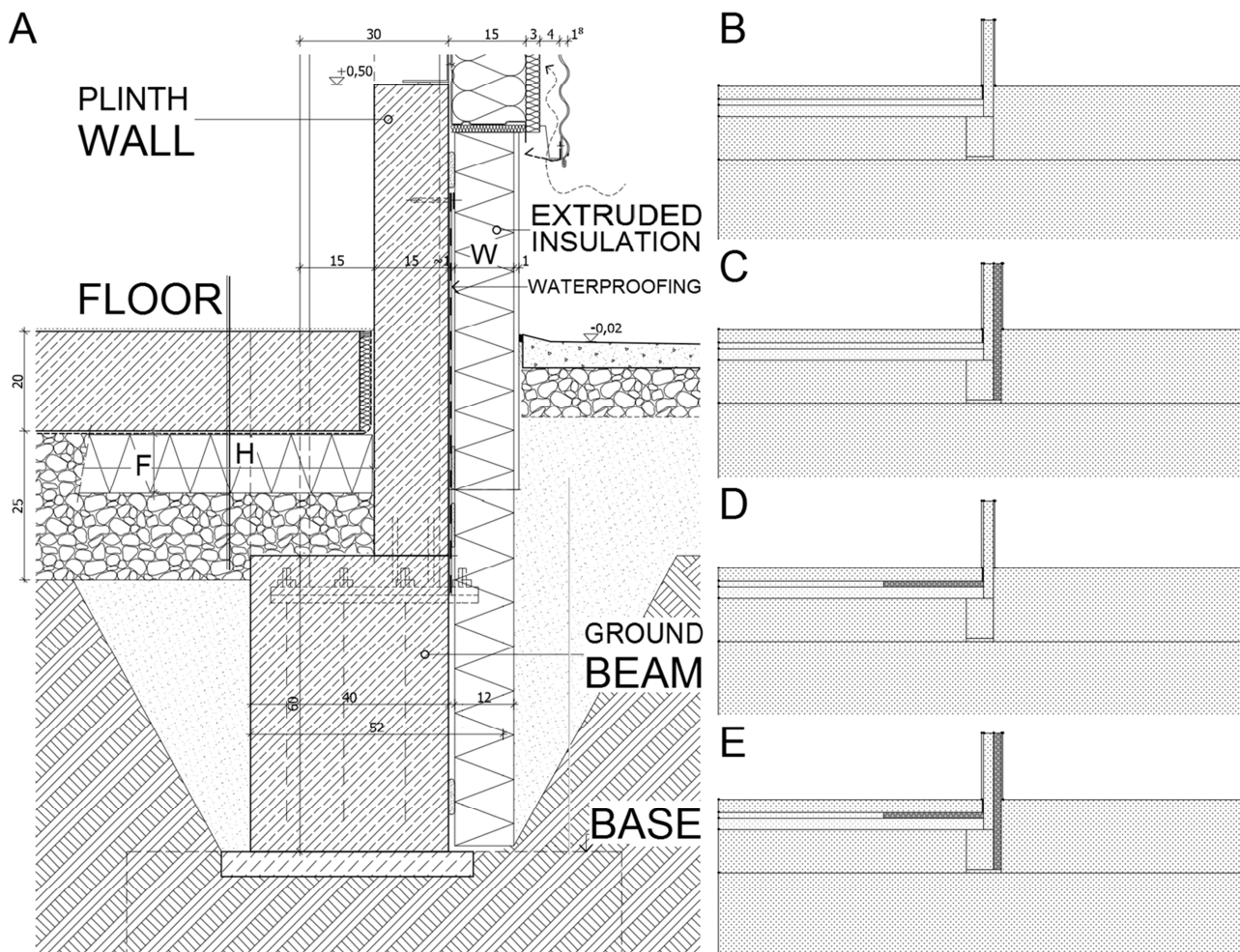


Figure 1. A) General section of an industrial floor and ground beam joint; Right side: Geometrical models of simulated joints: B) without insulation, C) with vertical wall insulation, D) with horizontal floor insulation, E) insulated wall and floor.

Sections. In this paper we have analyzed two dimensional general sections of industrial floor and ground beam joints shown in Figure 1 A), using parameter “W” for the thickness of the extruded insulation of plinth wall and ground beam, “H” for the length of the horizontal insulation and “F” for the thickness of the horizontal underfloor insulation. The four basic geometrical model created using WUFI 2D is shown in Figure 1 B)-E).

Details. Based on Figure 1 A), we used 2 cm inner and outer plaster on the geometry models. We placed extruded polystyrene foam insulations on the plinth walls, ground beams and under the floor with different parametrized thicknesses expressed later. We placed one layer polyethylene foil for waterproofing under the 20 cm steel fiber reinforced concrete floor, which is common in industrial floor constructions. We applied polystyrene expansion tape between the floor and the plinth wall. Under the floor construction, we have a 25 cm layer of gravel.

Parameters. With these parameters, we created 21 different geometry models based on the permutation of four basic geometrical model shown in Figure 1 B)-E).

Table 1. Parameters used in dynamic simulations.

Parameters	Values
“F” Thickness of underfloor insulation	0 cm, 5 cm, 10 cm
“H” Length of underfloor insulation	0 cm, 50 cm, 100 cm, 150 cm
“W” Thickness of wall & beam insulation	0 cm, 6 cm, 12 cm
Soil	Sandy Clay (SC), Loamy Sand (LS)
Climate	Budapest, Hungary (B), Espoo, Finland (E), Lisbon, Portugal (L)

The thermal design of the floor and wall components was performed according to the operative Hungarian regulation (TMN Decree No. 7/2006). The Decree have two levels of prescribed U-values over the wall and floor structures, general values and “cost optimized” values. The latter values are considerably lower, and indicates the construction of energy efficient buildings. The prescribed and designed U-values are observable in Table 2.

Table 2. Calculated U-values and insulation thickness of structures.

Regulation	Component	Prescribed U-value [W·m ⁻² ·K ⁻¹]	Designed U-value [W·m ⁻² ·K ⁻¹]	Insulation thickness [cm]
General	wall	0.45	0.431	6 cm
	floor	0.5	0.458	5 cm
“Cost Optimized”	wall	0.24	0.232	12 cm
	floor	0.3	0.285	10 cm

Material Definitions. To assign the materials, we used the built-in material database, except for the industrial floor. Those floors constructed using steel fiber reinforced concretes, which materials’ hygrothermal properties were measured in a previous research [4] and we used that data for the simulations. We examined two different soil composition (loamy sand and sandy clay) during our research also. We selected those soils because their differences in thermal conductivity, loamy sand is 70-90% sand combined with 10-15% clay and 0-30% silt, while sandy clay is based on 35-55% clay combined with 45-65% sand and 0-20% silt. Since the sand component have generally higher thermal conductivity than the clay or silt components [9], we expect to get lower heat losses on loamy sand than sandy clay. The most important data in the boundary conditions is the climate. To compare the models we analyzed the sections in three dissimilar climates (Lisbon, Budapest and Espoo). During the simulations, it was set to constant 10 °C in the depth of 20 m, and we neglected the different and changing geothermal gradients on each climate as well.

Results

Effect of Different Climates. As seen by comparing Figure 2 and Figure 3, that if we did not insulate the industrial floors, then we will get significantly larger heat fluxes in Budapest or Espoo. Even a 5 cm thick and 150 cm wide horizontal insulation below the steel fiber reinforced concrete floor can reduce the hourly heat flux maximums to one third. On the other hand, insulating the floor can reduce the heating season length as well, because we can see in Figure 3 the negative heat flux period will develop later, which we consider as heating season.

Observing both floor constructions in Budapest or Espoo climate, the effect of hourly changing weather losses its dominance in the internal heat fluxes if the floors were insulated next to the base on the perimeter, the dataset is “clearer”.

However, on the climate of Lisbon, there are no observable heating season according to the simulations, because there are no visible constant negative heat fluxes on the internal faces of components. A well-insulated residential or industrial building can be heating system free on those climates, and people only need to design their buildings for avoiding the summer overheating.

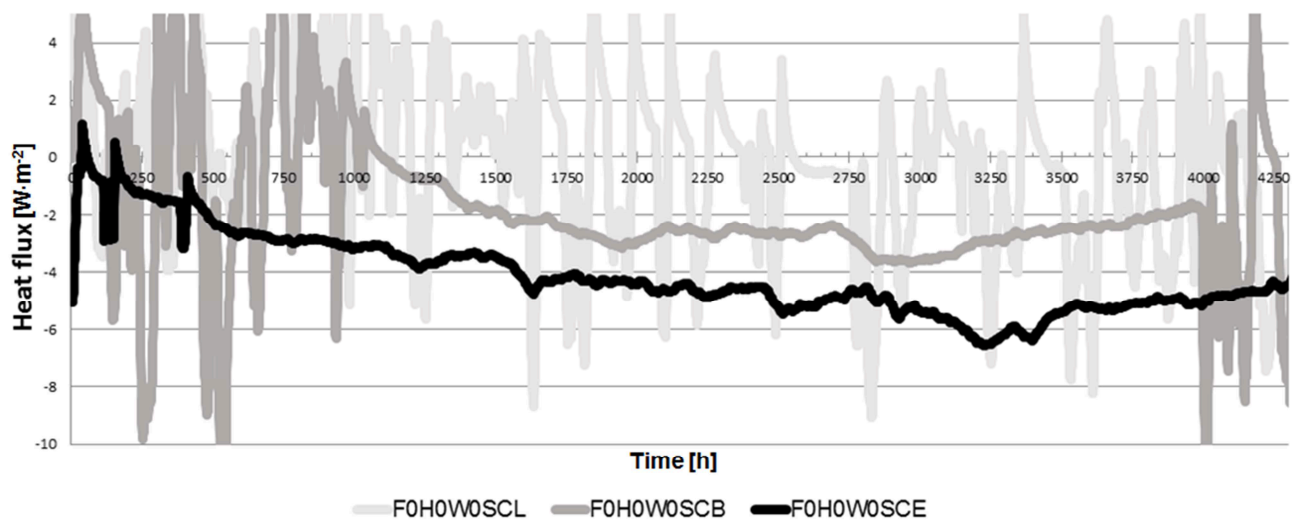


Figure 2. Heat flux densities on internal faces of uninsulated floor on different climates.

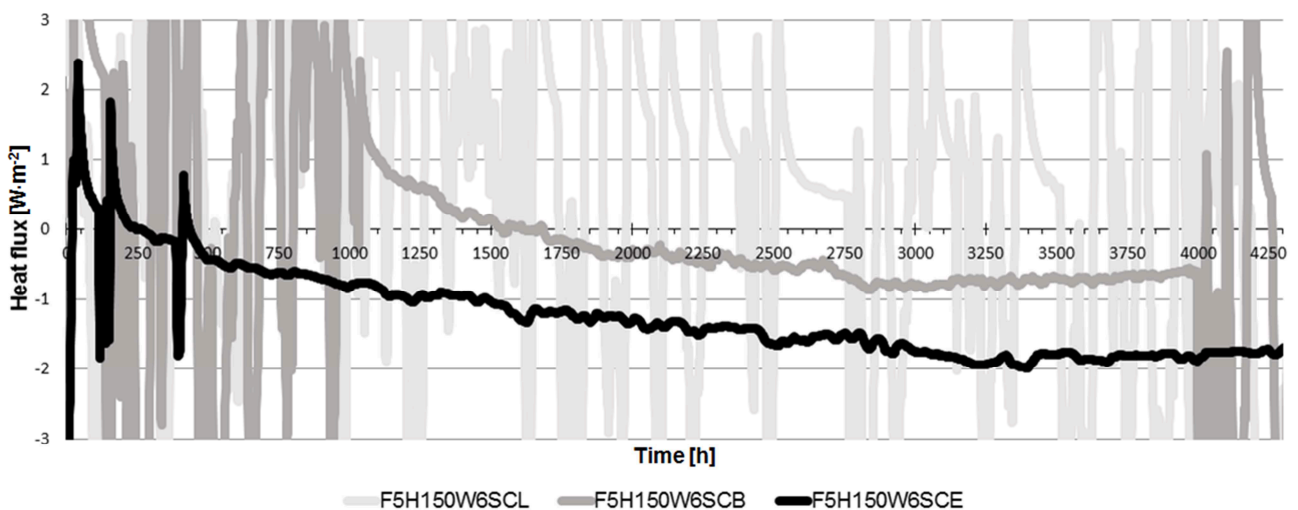


Figure 3. Heat flux densities on internal faces of insulated floors on different climates.

Periodic Relative Humidity Changes. For ground contact structures, the question of relative humidity in the components are essential. In Figure 4 a 10 year long simulation shows, that if we set the initial relative humidity to 80% in the floor or plinth wall, we need to consider really long

simulation time till we get periodic results. Interesting, that we get the developed periodic humidity changes earlier for the floor, than the air contact walls. It can be, because the moisture content of the ground is more permanent, than in air over time.

If we only want to compare the structures against each other (not considering the research on drying time or not including real initial moisture data into the components), setting the initial moisture content of the components regarding to their average of periodic values over a long term simulation is the only way we can manage the simulation times efficiently. After we set the initial relative humidity in the walls around 63% and for the floors around 50%, we get periodic results after only five years of simulation.

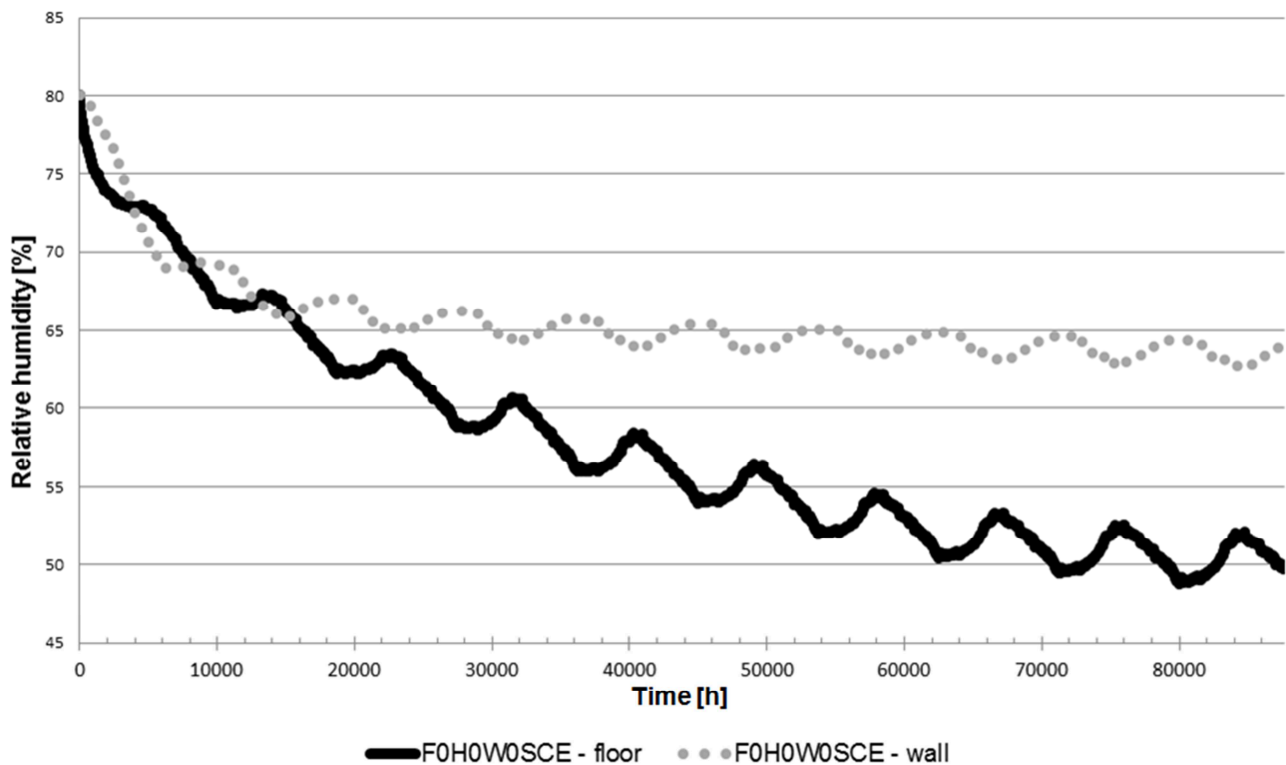


Figure 4. Simulation sets presented on relative humidity in the floor and in the plinth wall.

Comparison of Structures with Different Insulations. We can compare the different insulation scenarios around the model. In Figures 5, 6 and 7, there are four different approaches. All the models were simulated using sandy clay soil and Espoo climate, the difference between them is the position of the insulation. From right to left on the images there are fully uninsulated, plinth wall insulated, only underfloor insulated and fully insulated datasets shown.

Comparing the heat fluxes measured on the internal faces of floors (Figure 5.), it is clearly visible, that insulation next to the plinth wall and the ground beam are more efficient than insulating horizontally under the industrial floor. Using the vertical insulation method can reduce dramatically the heat losses through ground contact structures. Designers should notice that horizontal and vertical insulation not equal to each other latter is a much more effective solution.

If we observe Figure 6 represents the relative humidity changes in the industrial floor get from the last heating season of a 6 year simulated period, we can see that the relative humidity of the fiber reinforced concrete layer decrease as the section is better insulated. This can be explained by if we using insulation under the layer, than we separate it from dynamic climatic conditions.

On Figure 7 we can see the effects of the above mentioned different insulation approaches against the heat losses from the internal faces of the plinth walls. It is observable, that the heat losses are dramatically big, when we did not insulate the walls, and insulating only the floor have almost no effect on reducing the heat losses through the walls. If we insulate the wall, the heat fluxes will be less, however, we should highlight the fact that if the walls have insulation and the

floor is insulated as well, the heat losses reduced by an observable quantity as well. This phenomena can be explained by if we insulate both the floor and wall, we reduce the linear thermal transmittance (thermal bridging) of the section as well.

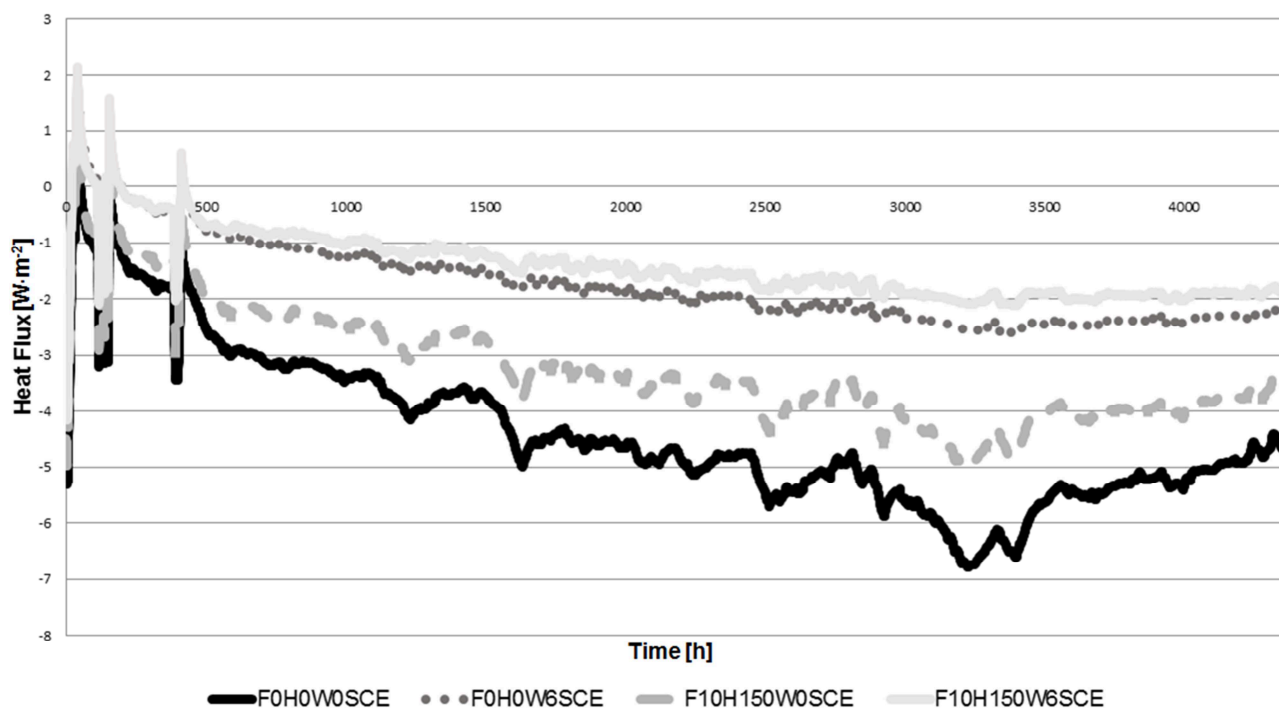


Figure 5. Heat flux densities on internal faces of floors with different insulations.

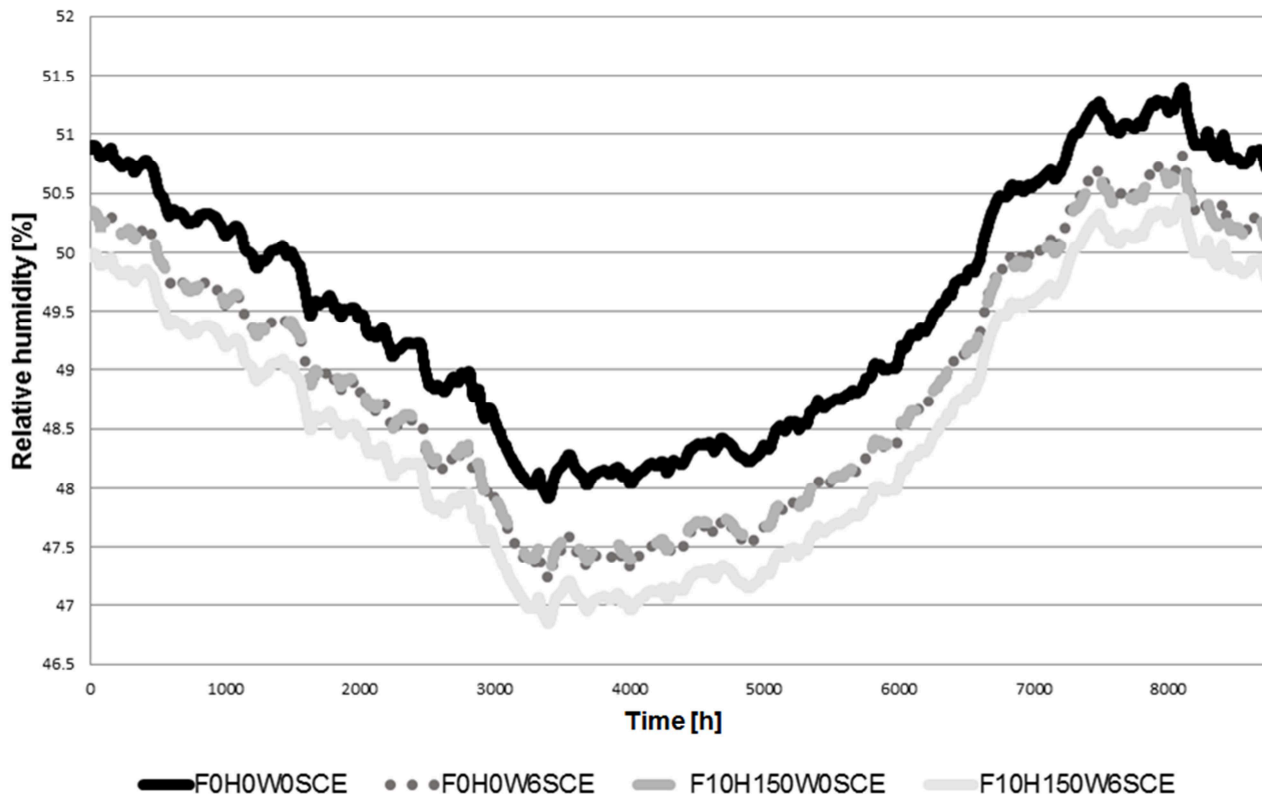


Figure 6. Relative humidity in floors with different insulations.

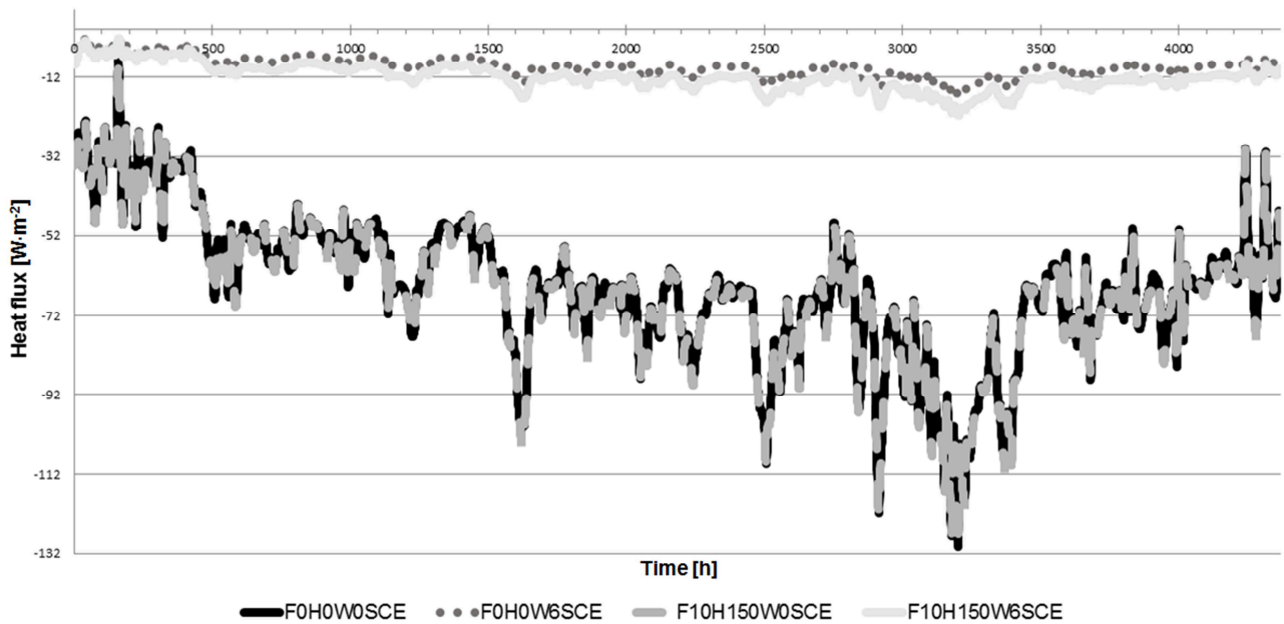


Figure 7. Heat flux densities on internal faces of plinth walls with different insulations.

Effect of Different Insulation Lengths and Thickness Under the Floor. Using thicker insulation with smaller width (10 cm/50 cm) next to the base wall than thinner insulation with longer width (5 cm/150 cm) leads to higher heat losses as shown in Figure 8. 50 cm insulation length gives significantly less heat loss reduction, than 100 cm or 150 cm, even if it will be 10 cm thick.

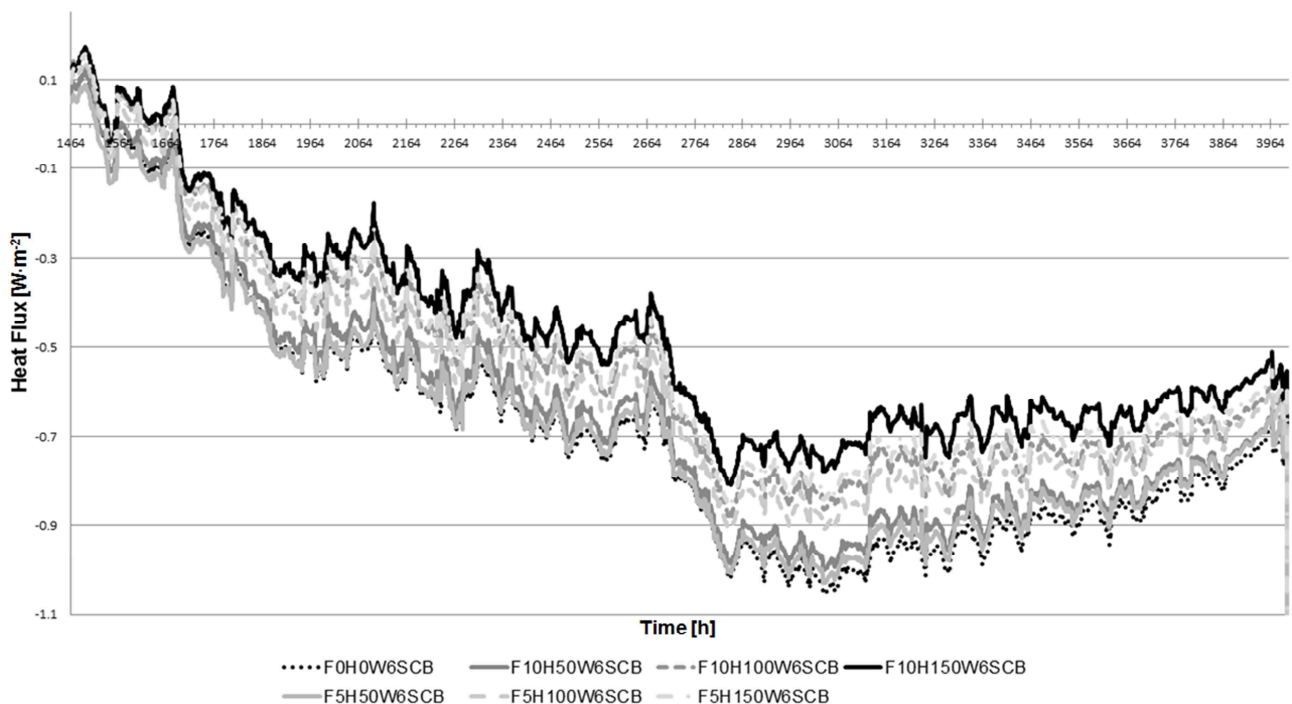


Figure 8. Heat flux densities on internal faces of floors with different insulations.

Effect of Different Soils. There is a visible connection between different soils and heat losses on Figure 9 but the effects of different soil types reduced when we used insulated floors and walls.

Besides that, Figure 9 clearly shows that we get the heat flux from internal faces of floor in the heating season in an inverted natural logarithmic function form as [6] prevented.

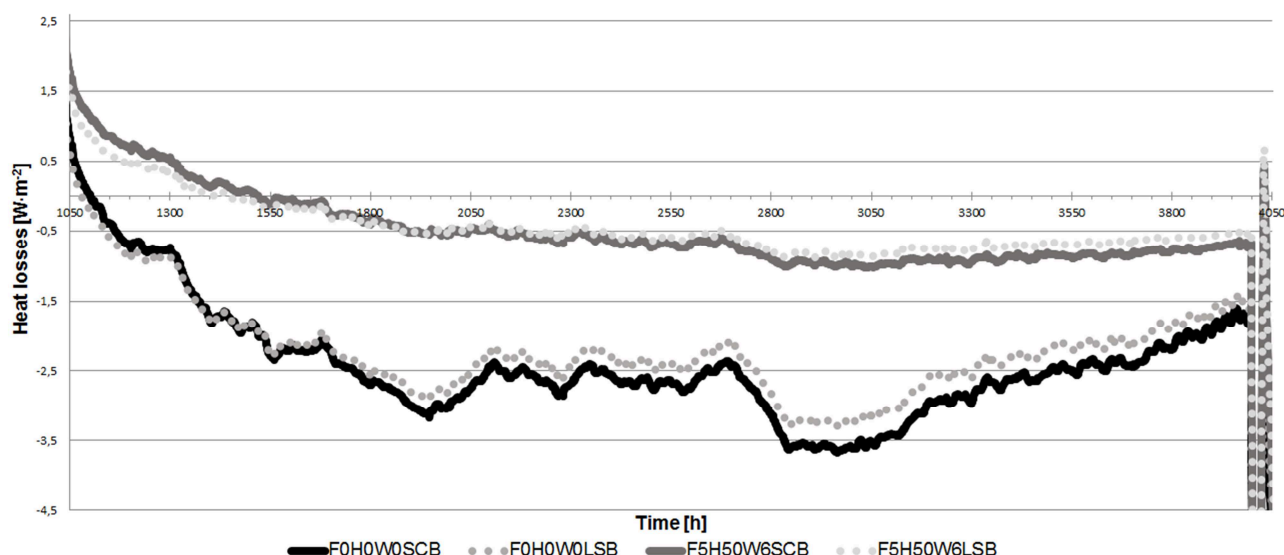


Figure 9. Heat flux densities on internal faces of floors with different insulations and soils.

Summary

In the presented paper, we examined different approaches on insulating floors of an industrial floor section on different climates, soils or structures. We showed that climate differences across Europe should result different insulation techniques as well, insulating the plinth walls could be very effective, floors should be insulated at least 1 m from their edge, and soil type under the floor could affect the heat loss through industrial floors. In short, the conclusion is that keeping in mind the presented results can improve the energy efficiency of industrial buildings across Europe.

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