#7645

Thermal Performance of Solid Ground Floor Slabs

P J Jones
Welsh School of Architecture
University of Wales College of Cardiff

Synopsis

This paper describes the application of a two-dimensional finite element computer program for predicting the temperatures and heat flux in the floor-slab and ground of industrial buildings. The model was constructed from the SERC's Finite Element Library. The model has been used to predict the steady state heat flux for different ground conditions and floor-slab insulation options, and results are presented. The paper presents measurements over time of the floor-slab and ground temperatures for a factory and these have been used to test the time-dependant operation of the model. Results are also presented relating to slab warm-up and the time dependant performance of slabs with edge-insulation. The paper concludes that the model performs well in comparison with measured data, and that there are significant differences between steady-state and time-dependant solutions for industrial buildings.

1. Introduction

Modern industrial buildings typically consist of a well insulated lightweight wall and roof cladding construction and a thermally 'massive' floor-slab. The slab can have a major impact on the thermal performance of the space, and in the design of the heating system. However there is still some degree of uncertainty concerning how the floor-slab should be considered in relation to the sizing of heating systems and the significance of floor insulation.

This paper considers these issues, and in particular it :

- describes a floor slab model which is able to operate in steady-state and time-dependant modes.
- considers steady-state applications relating to ground conditions and slab insulation.
- tests the time-dependant performance of the model against measured data and considers the difference between steady-state and time-dependant solutions.

2. Floor Slab Model

The floor slab model was developed from the Finite Element Library (FEL)[1], initially compiled by Smith and Greenhough, which is currently available through NAG. The FEL is contained in two levels of computer software. The first level (LEVEL 0) consists of a set of subroutines which perform most of the basic numerical operations required during a finite element solution. The second level (LEVEL 1) consists of a set of example programs which access the relevant subroutines in LEVEL 0 and which cover a range of application areas. A combination of two of these example programs, namely 'Steady State Potential' and 'Time Dependent Potential', were used as a basis for the development of the Floor Slab Model.

The model is constructed around a two-dimensional grid (although it could be extended to three-dimensional grids with minor modification). The solution domain and boundary conditions for a typical two dimensional floor slab problem are presented in Figure 1. The solution domain includes three main regions, namely :

(i) the half slab and ground beneath, to a depth where heat losses normal to the boundary are insignificant (symmetry is assumed about the floor centre).
(ii) the ground outside, to a distance such that heat losses normal to the boundary are insignificant.
(iii) a portion of the external wall to a height, where heat losses normal to the boundary are insignificant.

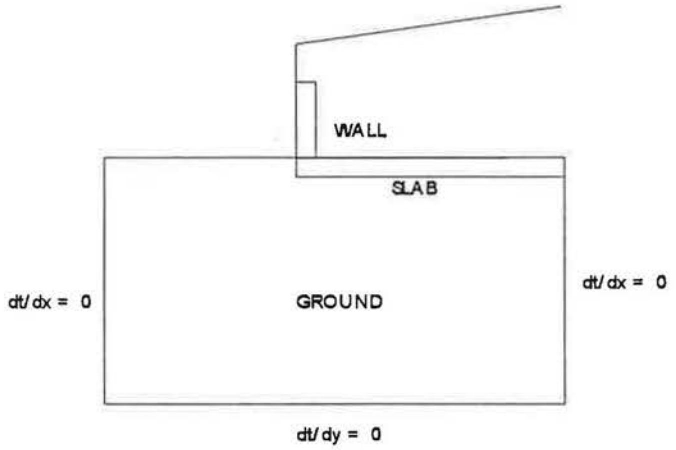

Figure 1 : Schematic of solution domain with ground boundary conditions shown.

The Floor Slab Model can be operated in either a steady-state or time-dependent mode. A major consideration when performing a time-dependent solution is the long initialisation time needed before the slab and ground temperatures assume realistic values after which a solution can be started. This is due to the large thermal capacity of the slab and ground. Typically the model has to be run for between four to seven years over the same cycle of annual boundary condition input data before changes from one year the next in predicted slab temperatures are within 1%. Figure 2 illustrates the change in yearly cycle slab heat loss during a seven year initialisation period. To speed up run times when in the time dependent mode, the model can be 'switched' to a steady state mode for the first 'time step' in order to provisionally initialise temperatures to reasonable values. Alternatively temperatures from previous runs can be used for initialisation. The Floor Slab Model has the facility to include the initialisation procedure with the solution conditions (including being able to vary the time step) as a run-time menu.

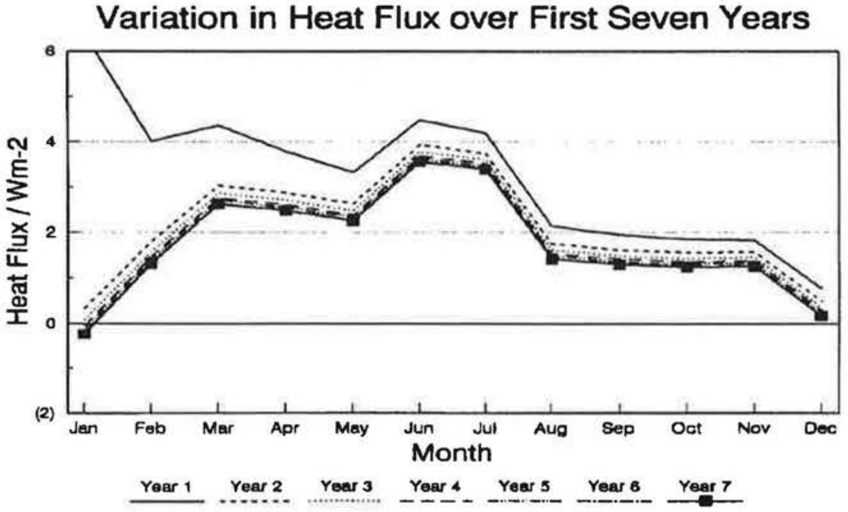

Figure 2 : Monthly variation in heat flux from the space into the slab surface over the first 7 years following building construction.

3. Steady State Application

The model was use to estimate the U-value of ground floor slabs for different ground conditions (ground k-values of 0.7, 1.4 and 2.1 W/m/°C) and for different insulation configurations (none, edge and total). Figure 3 shows that for dry soil conditions, the largest reduction in U-value is achieved by applying edge insulation, whilst for moist soil conditions totally insulating the slab provides more relatively significant benefits. This indicates that the performance of insulation is considerably affected by the ground conditions, and that whole slab insulation is probably not worthwhile unless the ground conditions are particularly moist. Figure 4 shows the heat loss profile at the slab surface, from edge to centre, for different insulation options (k:1.4 W/m/°C). This indicates that horizontal edge insulation is more effective than vertical and that if perimeter insulation is to be used then extending the horizontal insulation to a 2 metre perimeter strip is probably the most effective width to reduce the edge losses.

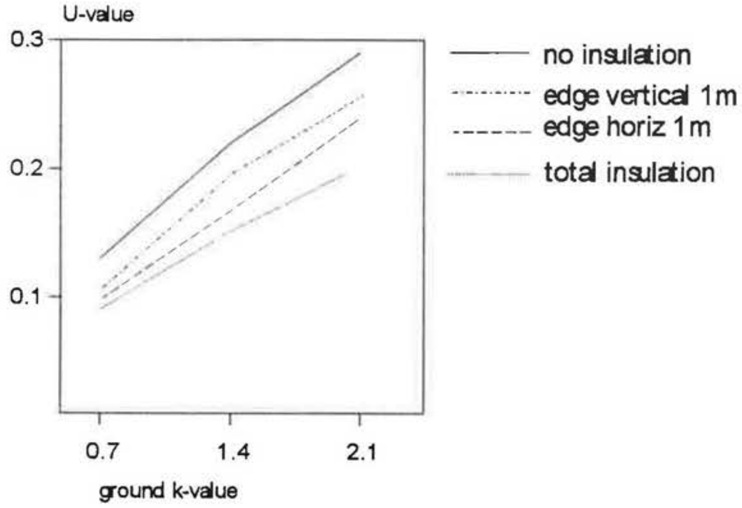

Figure 3 : Variation of U-value with ground condition and insulation options.

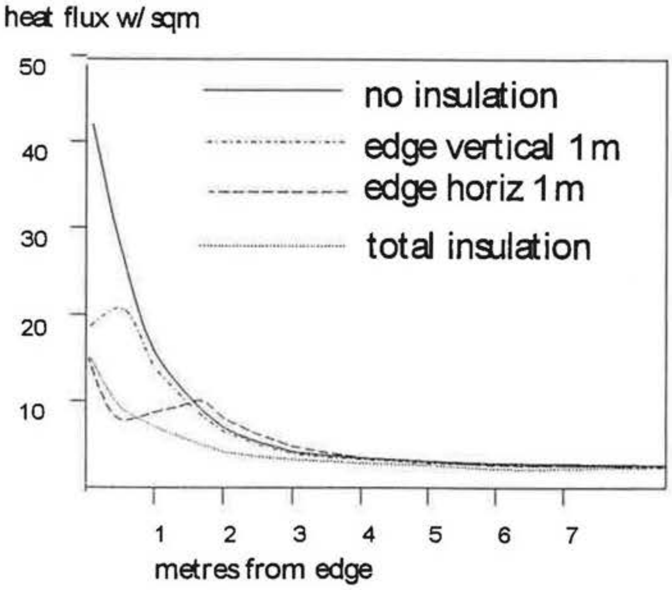

Figure 3 : Floor-slab heat flux along surface from edge to centre for different insulation options.

The results for different insulation options can be summarised for heat loss calculation purposes in Figure 5 (for a 20 metre wide slab), and the floor U-value can then be estimated from the following procedure.

Floor Transmittance =

Exposed Perimeter x 1m U-value
\+ Exposed Perimeter x 2m U-value
\+ Remaining Area x Central U-value (W/°C)

This provides the basis for a useful 'simple to use' method for estimating the floor transmittance and comparing different insulation options (the 'Remaining Area' component of the U-value will vary according to slab width, ground condition and whether it is insulated or not).

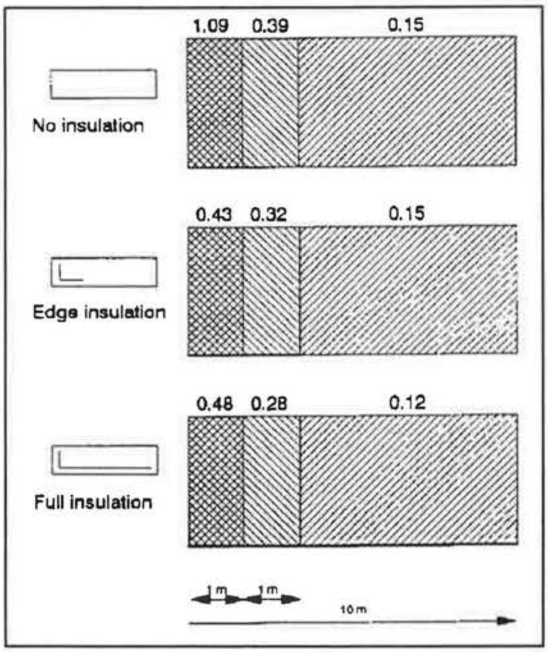

Figure 5: Breakdown of U-value into components for estimating the U-value of different insulation options

4. Measurements of Ground and Slab Temperatures

Measurements of slab and ground temperatures at depths down to 5 metres were carried out over the period May 1986 to January 1987 in factory Unit 7 Dafen Industrial Estate, Llanelly, South Wales. Measurements were taken at three locations, namely, centre slab, 1m in from the external wall and 1m outside of the external wall at the centre of the wall.

At each location a hole was drilled through the slab and down to a depth of 5 metres. The drilling work was carried out under contract by a firm of specialist soil engineering consultants.

Temperature sensors were placed into a continuous sealed plastic tube at depths of 0.0m (surface), 0.25m, 0.5m, 1.0m, 2.0m, 3.0m and 5.0m. The sensors were adhered to the inside surface of the tube to maximise thermal contact with the slab and ground. The tube was filled with sand to ensure no connective heat transfer up the tube. The tubes were then placed in the holes . Bentonite was used to pack around the tube in order to avoid any vertical moisture transfer which would give rise to temperature measurements not representative of depth.

5. Comparison of Measurements with Time Dependant Predictions

Figures 6 a,b present the time variation of slab surface and depth temperatures for measured (Fig 6a) and predicted (Fig 6b) data.

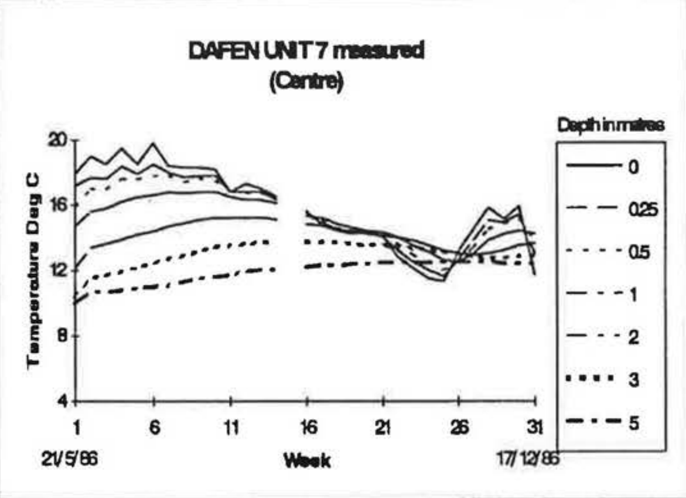

Figure 6a : Measured slab and ground temperatures over 31 weeks.

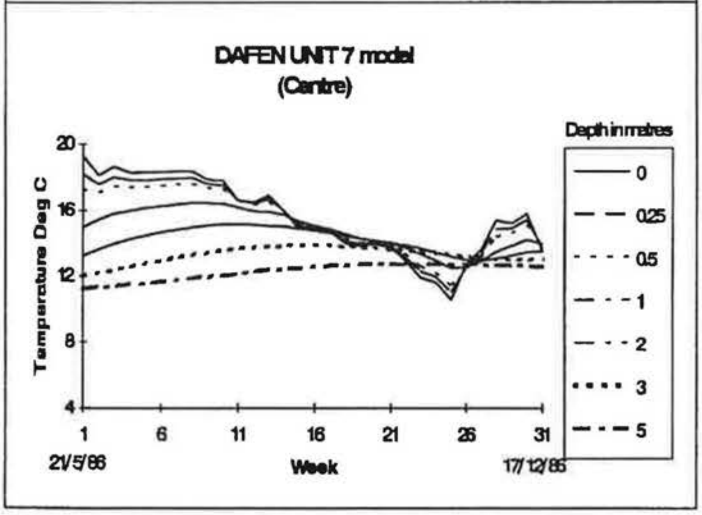

Figure 6a : Predicted slab and ground temperatures over 31 weeks.

Figures 7(a,b,c) presents the direct comparison of measured data with predictions for the surface and for three depths, namely, 0.5m, 2.0m and 5.0m, for the centre slab location. These show a good agreement between measured and predicted values. Results are also available for the inside and outside edge locations. The largest differences between measured and predicted data are for the outside edge surface values, which was probably due to the some uncertainty over modelling ground surface conditions.

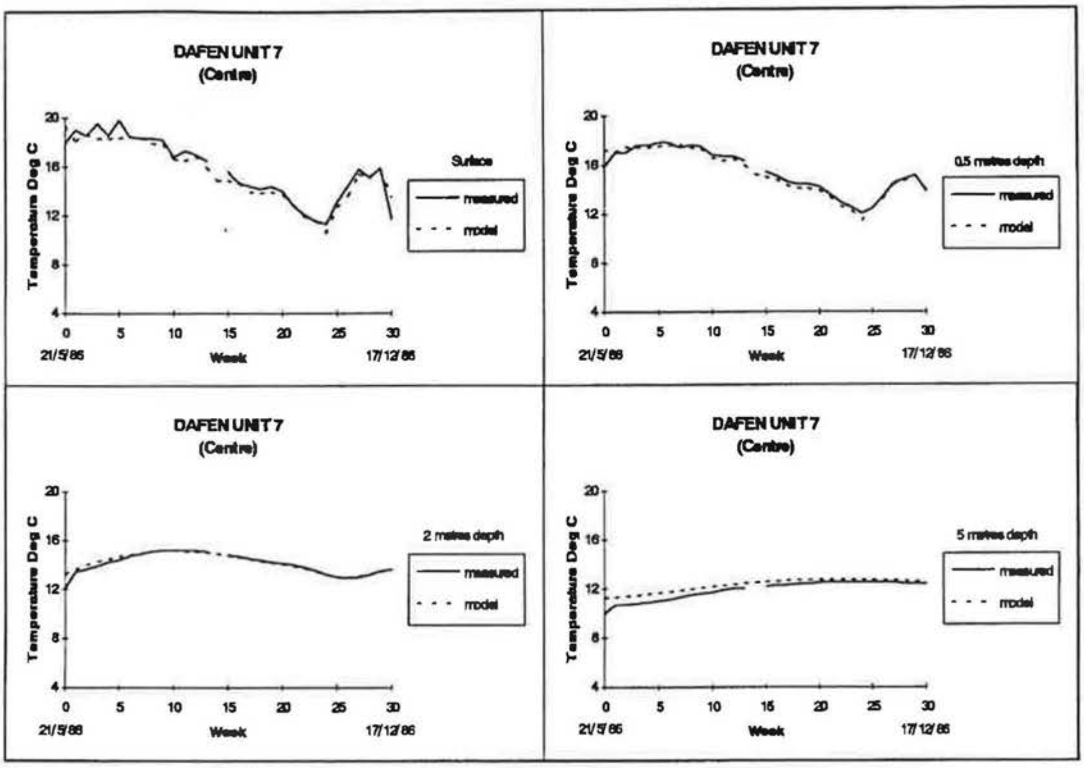

Figure 7 a,b,c,d : Comparison of measured and predicted temperature variation at the surface and 3 depths.

6. Time-Dependant Thermal Performance

The thermal storage capacity of the slab and ground causes the thermal performance of the floor to vary from the steady-state approximation in a number of ways, some of which are discussed below.

(i) Initial Warm-up : As indicated in Figure 2, the heat loss to the floor slab in the first year a building is constructed can be increased significantly due to the slab 'warming-up'. This can effect heat load calculations in low energy buildings where the heat loss to the floor is a greater proportion of the total heat loss, and the effects could be more pronounced in radiant heated factories where the floor surface is a secondary, but significant, source of heat.

(ii) Seasonal Performance : The results in Figure 2 also indicate that for industrial buildings the time of greatest heat loss to the slab does not correspond to the coldest part of the year. With the heating turned off at night during the heating season there is a heat gain from the slab back into the space. During the colder part of the heating season the night cool-down will be greater, and therefore so will the heat gained back from the slab. Figure 8 presents a 24-hour profile of the heat flow between the space and the slab for a day in January. In this case the heat gain to the space from the slab at night is greater than the heat loss to the slab during the occupied day.

(iii) Insulation Performance : Also shown in Figure 8 is the 24-hour profile for the case where perimeter edge insulation is included. The benefits of edge insulation for this day are less than a steady state calculation would predict. Although the total heat loss is not greatest during the coldest time of the year, the edge losses are high because they are more closely coupled to the external conditions.

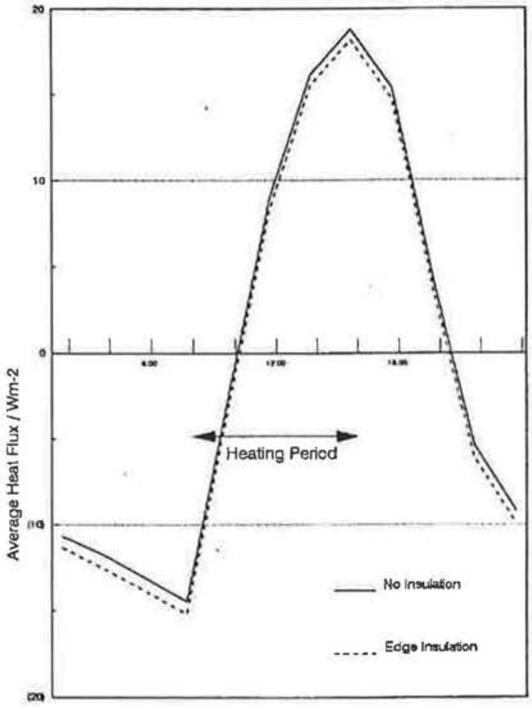

Figure 8 : Daily profile of heat flow into the surface of a floor-slab for a January Day. The situations are shown for insulated edge and no insulation.

7. Conclusions

The model used in steady-state mode can be used to provide useful data on floor U-values and a method of presenting steady-state floor U-values for different insulation configurations has been shown to provide the potential for a simple design tool.

The steady state applications are probably suited to design heat loss calculations although an allowance may be needed the first year of operation when the slab is 'warming up'. The slab may take some time to warm up after construction and this could have a bearing on heating system capacity during the first year of operation, especially for radiant heating systems.

The model has been shown to produce results which compare favourably with measured data.

The predicted performance of the floor-slab indicates that the period of minimum heat loss is in the when conditions are coldest outside and moreover there could be a net heat gain to the slab from the space during this time.

The time-dependant performance of edge insulation is less beneficial than a steady state application would indicate.

This Floor-Slab model is currently being incorporated into the building energy model HTB2 to allow more accurate predictions of floor losses to be carried out.

Acknowledgements

The model development was funded by SERC, and the author wishes to acknowledge the considerable advice provided by Dr C Greenhough of RAL during the model development stage. The measurement experiments were funded by the Welsh Development Agency who also provided access to the building. The author also wishes to acknowledge the work of G Powell and R Drayton for their assistance in the measurement and data analysis stages of the work, the latter part of wish was funded by the Welsh School of Architecture Research Group.

References

1. Smith and Greenhough, Finite Element Library, SERC (Now available through NAG).