Application of a Computer Model for Integrated Hygrothermal Building Analysis

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Abstract

An existing building energy analysis tool, *BSim2000*, has recently been expanded with routines for calculation of transient moisture transfer in building constructions as well as in the indoor climate. The moisture conditions of the indoor environment and the materials in adjacent structures depend very much on each other. Thus, the combination of the calculations in one integrated analysis yields much better possibilities for analysis of both the indoor humidity conditions and the moisture conditions in the exterior envelope and in interior furnishing of buildings. Also, the moisture conditions are highly dependent on the thermal conditions in all parts of the building, on the use of the building, and on the system for heating, cooling and ventilation. All these aspects are covered in the integrated model.

The paper will show an example that demonstrates the use of the new integrated model for analysis of the use of building materials to moderate indoor humidity fluctuations.

Introduction

Humidity in indoor spaces is one of the most important factors influencing indoor air quality. Many health-related problems in the indoor environment, e.g. the Sick Building Syndrome (SBS), can be associated with high indoor humidity and "damp buildings" (Clausen et al., 1999). The humidity level in a building depends on a combination of factors such as moisture sources, ventilation and air movement, reservoirs and sinks, heating, insulation, external conditions, as well as building materials and occupants. Among these, the moisture buffering effect of the materials in a building is an important factor. There is a general interest in exploiting the moisture buffering effect of building materials to dampen the cyclic variations of indoor humidity. However, this effect is often disregarded by building designers and engineers.

Several attempts have been made to model the indoor humidity condition. Such modelling may cover the simultaneous prediction of moisture condition in the whole building – its indoor climate and all constructions of the building envelope. Some references to attempts of modelling the indoor or whole-building moisture conditions are given in (Wang, 2000) and (Rode et al, 2001).

Moisture conditions cannot be predicted without knowing the thermal conditions. It is quite obvious therefore to develop a model for prediction of whole building moisture conditions as an extension to an existing model for detailed, thermal analysis of buildings. Such a model already predicts the thermal condition of the indoor environment and all the adjacent building components. Normally, the thermal calculation models are rather elaborate themselves, their thermal predictions have already been validated, and they already have a user interface. One such model is *tsbi5*, which is included in the integrated building simulation tool *BSim2000* (Wittchen et al., 2002).

Furthermore there is a great need to experimentally verify the predictions of whole building hygrothermal models. Some relevant experimental investigations are reviewed in Mitamura et al., 2001 and Virtanen et al., 2000.

Building Simulation 2000

BSim2000 is a computational design tool for analysis of indoor climate, energy consumption and daylight performance of buildings**.** *BSim2000* integrates different computer models that make it possible to carry out a complete thermal and daylight analysis of a building. The core of the system is a common building data model shared by the design tools, and a common database with typical building materials, constructions, windows and doors. Figure 1 illustrates the user interface of *BSim2000.*

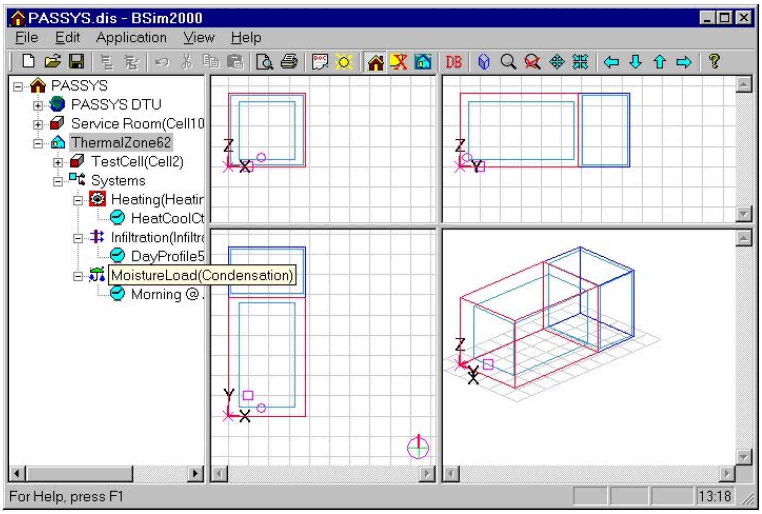

Figure 1. Graphical user interface of the BSim2000 program showing the model of a test cell that has been used previously to provide data for model validation (Rode et al., 2001).

The following computational analyses can be made on most buildings using *BSim2000*:

- Heat gains from solar radiation, people, lighting, and equipment

- Solar radiation through windows
- Heating, cooling and ventilation
- Power and energy balance
- Steady state moisture balance
- Temperature conditions
- Heat and air exchange between zones
- Shading conditions
- Daylighting conditions
- Variable infiltration and venting
- Several different ventilation systems simultaneously
- Surface temperatures
- Air exchange in connection with infiltration and opening of windows
- Air exchange between rooms
- Heat and refrigeration recovery in ventilation plants
- Supply and exhaust air temperature in ventilation plants
- Power from heating and cooling coils in ventilation plants
- Humidification in ventilation plants

Whole Building Moisture Model

A transient moisture model for the whole building - its indoor climate and its enclosure - has been developed as an extension to the thermal simulation model (*tsbi5*) in *BSim2000*. *BSim2000* sees a building as consisting of a number of zones, separated from each other and from the outside, by constructions of different kinds. A humidity balance is set up separately for each zone. The balance equation expresses that humidity is exchanged by infiltration, ventilation and air change with the outdoor air and with adjacent zones. Furthermore, humidity is exchanged by convection between air in the zone and the surfaces of adjacent constructions, and moisture is released to the zones as a result of activities in the zone. The balance equation is dynamic, so it takes into consideration the buffer capacity of the zone air.

The new moisture model makes simultaneous calculations of transient moisture conditions in all interior and exterior constructions of the building. The zones on the sides of the constructions constitute the boundary conditions.

The following influences on the air's humidity condition are considered:

- Humidity transfer from adjoining constructions
- Contribution of humidity from various sources and activities, e.g. person load, laundry and drying, bathing, cooking, industrial processes, humidification/drying, and other
- Penetration of humidity from outdoor air (by infiltration and venting)
- Supply of humid air from ventilation systems
- Humid air transferred from other zones (mixing)

The model for moisture transport in the constructions considers moisture transport in the form of vapour diffusion. The moisture transport internally in the constructions is described in a transient way, i.e. by considering each layer's moisture buffering capacity. A calculation is carried out for each control volume and time step of the balance between moisture gained and lost by vapour diffusion. The sum of these contributions causes a change of the moisture content from one time step to the next. Using the sorption curves of the materials, the new moisture contents can be recalculated into new relative humidity and vapour pressures. For the sake of numerical stability in all situations, an implicit calculation procedure is used in the model.

The moisture model is described in details in (Rode et al, 2001).

Test in practice

During the autumn 2001 three major Danish consulting engineering firms have tested the moisture model in *BSim2000* on real building design projects.

The consulting firms' main conclusions after the testing are that the new moisture model will provide possibility to:

- Study the relative humidity in rooms taking into account the ability of building materials and furniture to absorb and desorb moisture.
- Analyse the moisture level of constructions.
- Analyse energy consumption in relation to construction moisture in building elements.
- Analyse consequences of the indoor air quality by selecting different building materials.
- Estimate risk of condensation.
- Perform more realistic analysis leading to reduced cost of the building.

BSim2000 with the moisture model has now (in June 2002) been officially released under the name *BSim2002*, and thus the new features are available to users of the program in general. The companies now use the model in their daily consulting practice, and the rest of this paper is devoted to showing an example of such application of the model by one of the companies that originally tested the model.

The example is an old building for a museum located in Stockholm, Sweden. The purpose of the investigation was to see if the requirements of the indoor climate's temperature and relative humidity could be fulfilled using passive climatisation with different compositions of the surrounding walls and floor of a particular room being studied. The requirement was that the temperature should be between 10 and 18°C and the humidity between 40 and 60% RH. The only climatisation was by heating to ensure that the room temperature did not drop below 10°C (16°C in May/Oct., and 18°C in June-Sept).

The room is located on the third floor immediately under the attic. The outer walls consist of 500 mm of brick, and the existing windows will be blinded by filling with

400 mm brick. The floor consists of 50 mm beech wood. The ceiling is made of paint ($Z = 0.5$ GPa·m^2·s/kg), 15 mm cement mortar, 500 mm beech, and 200 mm mineral wool.

For running the model, the climate in the attic was prescribed by an assumed seasonal sine variation over the year: Maximum 27°C in July, and minimum 15°C in January, overlayed by a daily sine variation of 15°C. The attic humidity was varied in a similar way with yearly maximum 12 g/kg in July, minimum 2 g/kg in January, and daily variation 2 g/kg.

The climate in the room below and in neighbouring rooms to the one being investigated was assumed as follows: Yearly maximum temperature was 24°C in July, minimum 19°C in January, and daily variation 2°C. The annual maximum humidity was 11g/kg in July, 2g/kg in January, and daily variation was 1 g/kg.

The outer walls were exposed to the outdoor climate (weather file) of Stockholm.

The infiltration was set to 0.1h^{-1} most of year, but reduced to 0.075 May through August.

The room investigated was zone 2 (Z-2) of room 338 in the floor plan figure 2. The room was 17 m by 10 m. The model takes into account the buffering of moisture in the building constructions of the museum, but furnishing in the room was not considered.

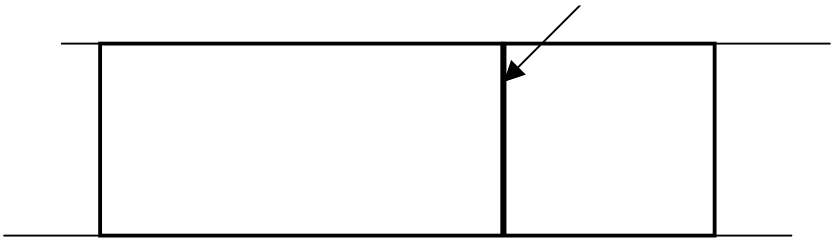

Figure 2 Floor plan of the museum showing the zone (Z-2 of room 338) that must be passively conditioned within the bounds T: 10-18 °C and RH: 40-60 %.

The first run of the model for the temperature and humidity gave the predictions shown in Figure 3. The results are also shown in the curves Figure 4 as cumulative frequencies of the results over one year. Obviously, the room conditions did not meet the requirements as the relative humidity was below 40% in about 5000 hours of the year.

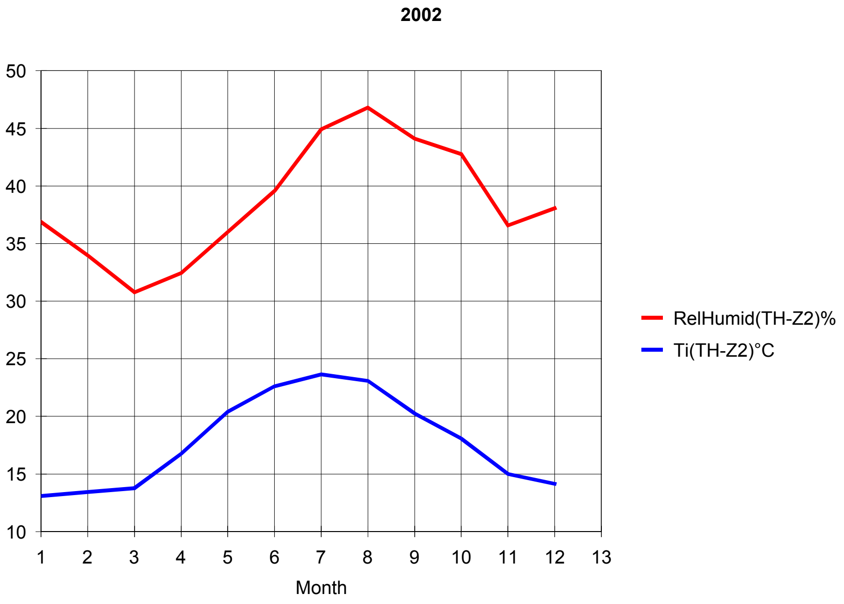

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Figure 3 First calculation of relative humidity (upper curve) and temperature (lower curve) of the room under investigation.

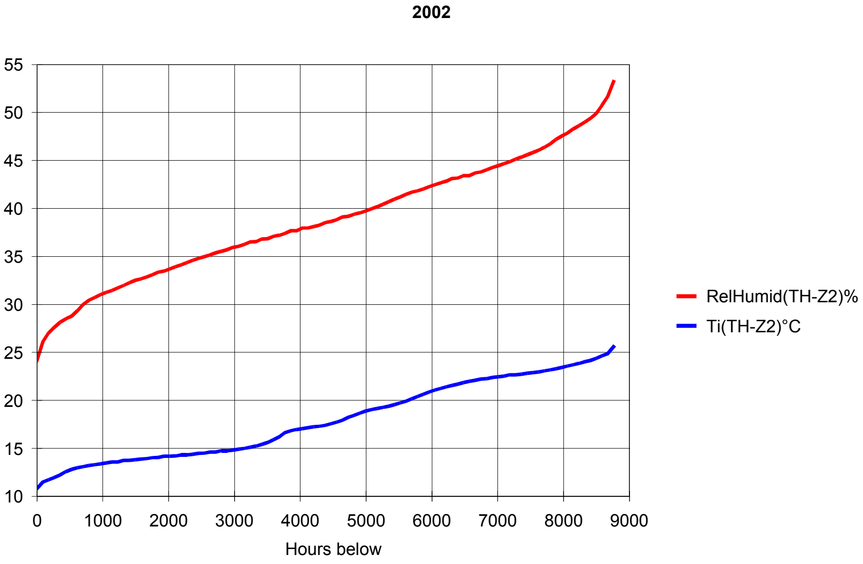

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Figure 4 Cumulative frequencies of the relative humidity and temperature from the first calculation of conditions in the critical zone.

It was decided then to investigate the effect of adding insulation to the floor under the room. The floor was changed to: 50 mm beech, 200 mm mineral wool, 15 mm cement mortar, and paint. This had the effect in winter to keep the room more cool, and thus to increase the relative humidity. The result is shown in Figure 5. The new cumulative frequency curve is shown in Figure 6.

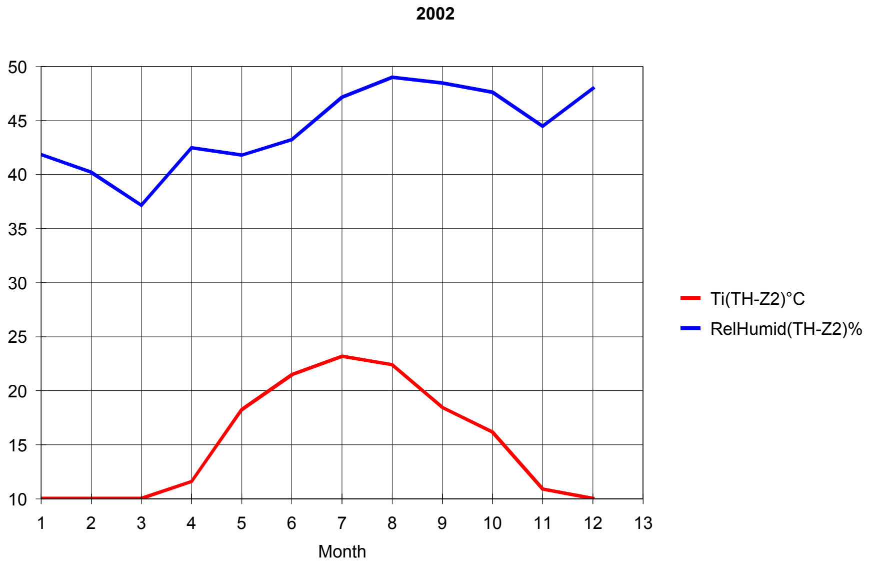

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Figure 5 Second calculation of relative humidity (upper curve) and temperature (lower curve) of the room after the floor was insulated with 200 mm of insulation.

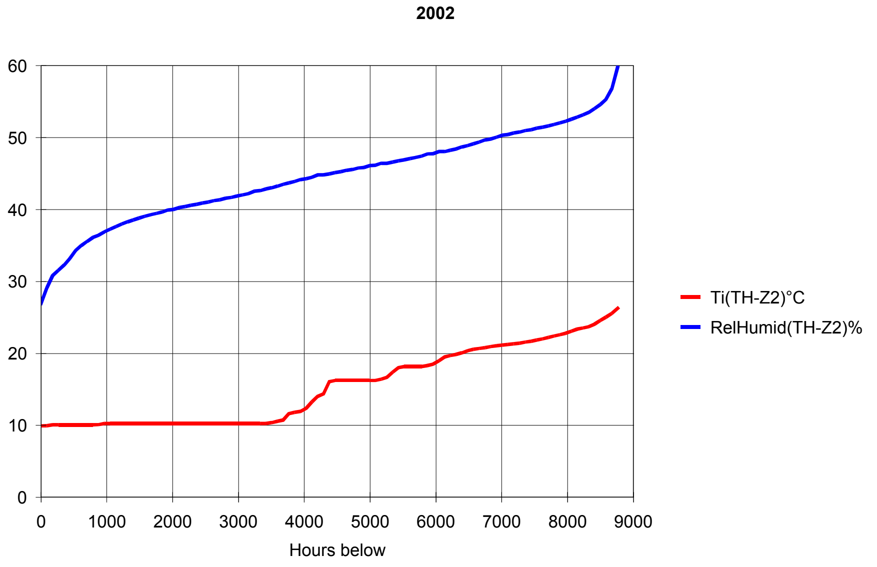

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Figure 6 Cumulative frequencies of the relative humidity and temperature after insulation was added to the floor.

Figure 7 and 8 illustrate the monthly development of indoor relative humidity and temperature for February and July.

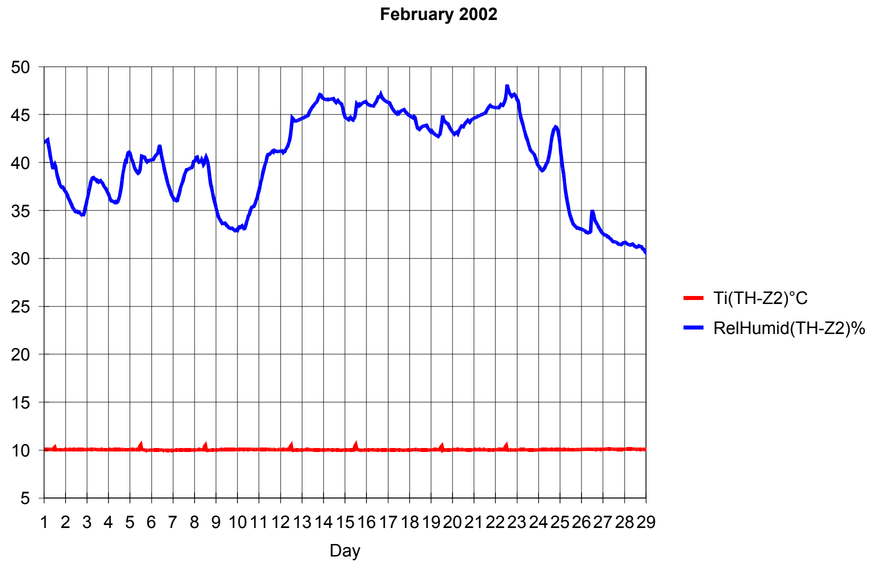

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Figure 7 Development of relative humidity and temperature in the room under investigation for July after adding insulation to the floor.

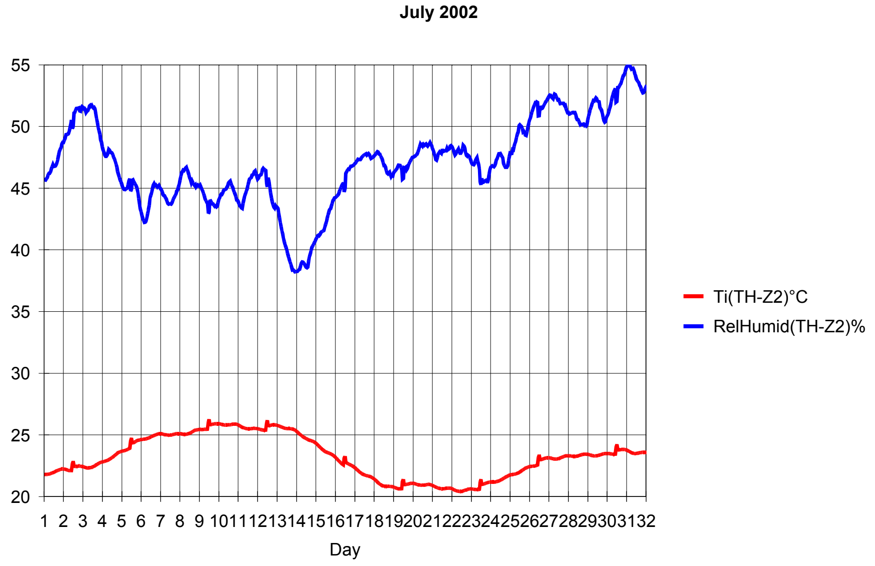

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Figure 8 Development of relative humidity and temperature in the room under investigation for July after adding insulation to the floor.

As can be seen from Figure 6, there are still some 2000 hours, where the relative humidity falls below 40% RH, and thus some further improvement of the passive climatisation is needed. The design project continues, but the purpose here was mainly to present a fresh snapshot of how the new model could be used to provide accurate predictions of the combined heat and moisture conditions in a specific building.

Conclusion

An existing computer tool *BSim2000* for dynamic thermal simulation of buildings has been extended with a transient model for moisture release and uptake in building materials. With the new model it is possible to make more accurate predictions of indoor humidity variations. Simultaneously, complete transient calculations are carried out of the moisture conditions within all the envelope constructions of the building. Since the moisture conditions in building constructions depend very much on the indoor humidity and since the building constructions also influence the indoor humidity, it is anticipated that the new development will result in improved simulations of moisture conditions both for the indoor air and for the building constructions.

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