

SIMULATION OF WHOLE-BUILDING HYGROTHERMAL CONDITIONS

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Summary

The existing computer tool *BSim2000* for dynamic thermal simulation of buildings has been extended with new capabilities for transient simulation of the indoor humidity taking into account the moisture storage capacity of the building components and furnishing, and the supply of humidity from indoor activities. The moisture conditions in the full depth of envelope components are calculated in the same simulation.

The advantage is that simulation of both boundary conditions for the envelope and the materials' capacity of buffering indoor humidity can be performed in the same calculation.

This paper presents the principles for the model, validation and some experience of using the model in practice.

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 to 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 neglected 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. In a literature review by Wang (2000) and Rode et al (2001) references to some at-

tempts of modelling the indoor or whole-building moisture conditions are given.

Moisture conditions cannot be predicted without knowing the thermal conditions. It is thus obvious to develop a model for prediction of whole building moisture conditions as an extension to existing models for detailed, thermal analysis of buildings. Such models already predict the thermal condition of the indoor environment and all the surrounding 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., 2000).

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. An experiment using a full-scale test cell to investigate the moisture buffering effect of building materials is described in this paper. The results are used both to characterise the buffering capacity of different materials and to verify predictions of a numerical model for whole building hygrothermal analysis. The term "moisture buffering effect" will be used to indicate the ability of building materials to decrease humidity variations in indoor spaces.

Building Simulation 2000

BSim2000 is a computational design tool for analysis of indoor climate, energy consumption and daylight performance of buildings. It 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 all the design tools, and a common database with typical building materials, constructions, windows and doors. Figure 1 illustrates the user interface of *BSim2000*.

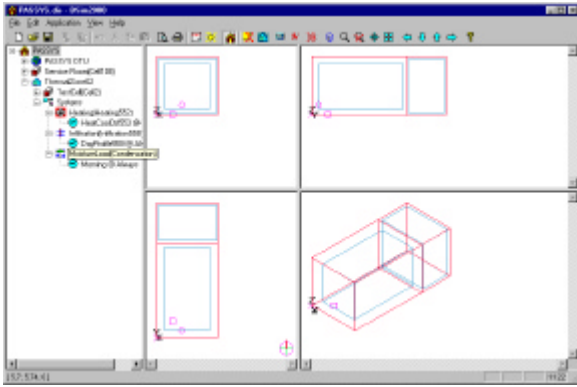


Figure 1. Graphical user interface of the BSim2000 program showing the model of the test cell from which experimental data will be used to compare against model predictions.

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,
- Moisture balance,
- Thermal indoor environment,
- Heat and air exchange between zones,
- Shading conditions,
- Variable infiltration and venting,
- Several different ventilation systems simultaneously,
- Surface and node temperatures and condensation risks,
- Air exchange in connection with infiltration and opening of windows,
- 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. 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 taking into account the buffer capacity of the zone air.

The new moisture model makes simultaneous calculations of transient moisture conditions in all 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, and how much is removed. 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 humidity transfer between the surfaces of constructions and the zone air is governed by the convective mass transfer coefficient, which is calculated from the Lewis relation and the

convective heat transfer coefficient of each particular surface. In *BSim2000*, depending on a user selection, the interior heat transfer coefficient can either be constant or it is determined from empirical equations for natural surface convection from the ASHRAE Handbook of Fundamentals (ASHRAE, 2001), and equations for heat exchange by radiation in convex rooms. In case constant heat transfer coefficients are used, a default value of $2.0 \cdot 10^{-8} \text{ kg}/(\text{m}^2 \cdot \text{s} \cdot \text{Pa})$ is used for the moisture transfer coefficient at indoor surfaces.

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

Validation

An existing test cell originally developed for validation of thermal simulation tools in a major European project has been remodelled to incorporate the measurement of indoor humidity conditions under transient exposure. It is possible to control the release or extraction of humidity from the cell's indoor space and measure the response in relative humidity of the air and the moisture content in adjacent building materials. A sequence of experiments has been conducted using different interior materials to provide a suite of source data for the effect of moisture absorption and release. The results are used both to characterise the buffering capacity of different materials and to verify predictions of the numerical model.

The new moisture model in *BSim2000* was used to simulate the indoor humidity during the tests. The program was run for the actual test conditions regarding moisture supply rates and surface areas of different materials, and the needed sorption curves and vapour permeability's had been measured in the laboratory for the actual materials. The measured and predicted absolute indoor humidity is shown in Figure 2.

Except for the room with chipboard, the predictions are quite similar to the measured values. Especially in the case of plasterboard, cellular concrete and wood panels, the deviations between measurement and simulation of the absolute humidity are very small. However, for the room furnished with chipboard, there is a substantial deviation in the range from 1.0 g/kg to 1.5 g/kg between measurements and predictions. It may be suspected that the hygrother

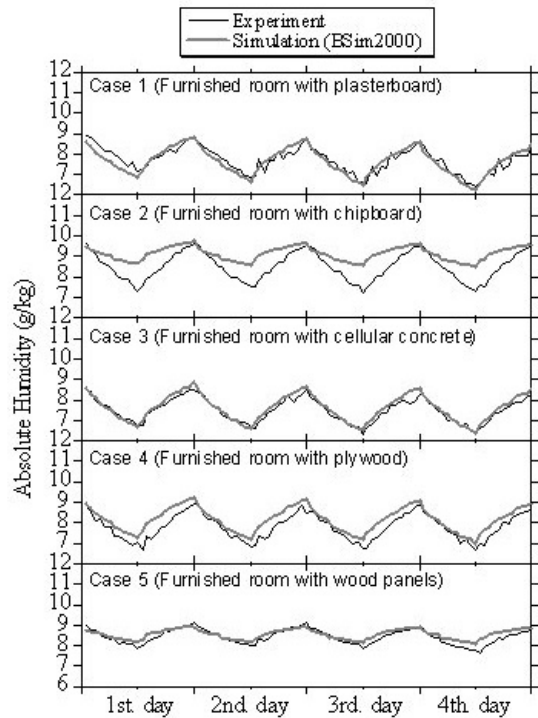


Figure 2. Measured and predicted absolute humidity in the furnished room.

mal property of the surface of this material is somewhat different from those of the interior part of the material. Although the chipboard has the appearance of a homogeneous material, the surface of the chipboard is rather dense, while the interior of the material is more porous.

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.

In one project a study of the relative humidity of the indoor air in an office building was performed, taking into account the ability of the building materials to buffer the humidity. The aim was to estimate the risk of condensation on a chilled ceiling, and in general to estimate the indoor air quality.

In another project the moisture conditions of a planned museum store was analysed. The most important parameter of the indoor climate for storing objects is the relative humidity. The moisture model has been used to analyse the moisture conditions of the air in the rooms when

changing building materials and control of the heating systems.

The third project dealt with investigation of moisture problems in the exterior walls of an ice rink. This special form of indoor climate normally demands a certain configuration of layers in the exterior envelope to avoid moisture problems. The project has dealt with analysing the problem after problems have occurred and different ways to resolve it.

The consulting firm's 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.

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. 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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