Application of software tools for moisture Protection of buildings in different climate zones
Special Example: Control of air humidifier in a cold climate for high comfort and no risk of mould growth in building room

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SUMMARY
The application of software tools for moisture protection of buildings in different climatic zones is demonstrated in this paper. The basics of the programs are presented together with a typical application for a problem specific for the chosen climatic zone. A 1-D calculation has been performed for tropical climate zone with the improvement of a flat roof in Bangkok as an example. For half timbered buildings, which are common in the temperate zone with the 2-D model an infill insulation and its benefits are demonstrated. Finally the combined appliance of the whole building model and the mould risk prognosis model is shown in detail as a special case for the cold climate zone:

In heated buildings of cold climate zones the internal climate with its low relative humidity in wintertime often causes discomfort and health problems for the occupants. In case of using air humidifier the risk of mould growth increases. Instead of an uncontrolled humidifying of the dry air an innovative control system using a thermal bridge, which switches the humidifier off when condensation occurs is presented. To quantify the improvement in the comfort while preventing the risk of mould growth for a typical building comparative calculations of the resulting inner climates and its consequences on comfort have been performed.

KEYWORDS
Hygrothermal building simulation, protection of buildings in different climate zones, mould growth, comfort,

INTRODUCTION
Natural laws are the same anywhere in the world, but building regulations and traditions may vary considerably. Different climatic conditions are frequently the reason for this fact. Whereas fire protection and noise control work independent of climatic conditions to a large extend, experience and specifications concerning thermal insulation and moisture protection usually cannot simply transferred to other countries. The building has to be adapted to the local climatic conditions and users demands but as far as possible avoiding en extensive application of technical equipment like HVAC. The globalisation of the world has inspired many building companies to explore the export chances of their products or services to countries where the climate conditions differ considerably from the domestic situation. Since their experiences and requirements concerning energy savings and moisture protection, which were gained by their local conditions, can not be easily transferred to other climatic situations standard building products and constructions might not lice up to expectations of foreign clients or fail under local exposure conditions. Applying the trial and error method in a foreign country may become very expensive and each failure may results in a long lasting loss of confidence in the company concerned. Regarding the expensive and time-consuming

experimental investigations of the moisture behaviour of building components on a 1:1 scale building up test-sites in every climate region is no option, too. Here the use of software tools may fill the gap. But it is important that the models used are universally valid and imply no restrictions, which are acceptable for the country of origin, but results in arguable outcomes for differing climates. For example standardised calculation procedures like the steady state German "Glaser method" are not suitable for the use in other climate zones and there exists no reasonable way to adapt them.

Nowadays there exist different sophisticated software programs for the transient hygrothermal modelling. This paper intents to illustrate -with the WUFI®-family as an example- the different tools which are appropriate depending on the complexity of questions. For this purpose starting with the one-dimensional program and the two dimensional version the basis of the models are presented together with a typical application for a problem specific for the chosen climatic zone. Finally the whole building model in combination with the mould risk prognosis model is demonstrated. Herewith a typical problem of cold climate zones, the low relative humidity in wintertime, which often causes discomfort and health problems for the occupants, is examined. In this example, which is demonstrated in detail, the effect of a special control of air humidifiers for high comfort but avoiding the risk of mould growth is simulated.

ONE DIMENSIONAL HYGROTHERMAL SIMULATION WITH WUFI®-1D

Moisture transfer processes in porous building materials are due to differences in vapour pressure and water content. A legitimate technique in physics, which is also advantageous for practical purposes, is to indicate the driving forces for transport processes with real potential quantities. Potential quantities are not dependent on the material, they show a steady behaviour and even at the boundary layers of two different materials they do not show any discontinious change. Since the water content does not represent a potential quantity, it is advisable to replace it by the relative humidity, particularly as the moisture storage function also indicates the water content as a function of the relative humidity. By using the vapour pressure and the relative humidity as potential values all the processes of moisture storage and moisture transport should thereby be covered. Since the gradients of both potentials often go in opposite directions within the same building component - the vapour pressure on the inside of a building is generally higher than on the outside due to the higher temperature, whereas the opposite applies for the relative moisture - a generally applicable calculation model has to explicitly take into account both moisture potentials.

In the following, the differential equations for the simultaneous heat and moisture transport in multilayer building components, which form the basis for the data processing program WUFI (Künzel, 1994), are briefly summed up, stating the essential material parameters for one-dimensional conditions. By taking into account the influence moisture has on the heat storage capacity and the heat conduction you obtain the following equation for the heat balance:

$$\left(\rho_M c_M + u\rho_w c_w\right)\frac{\partial\vartheta}{\vartheta t} = \frac{\vartheta}{\vartheta x}\left[\lambda(u)\frac{\partial\vartheta}{\vartheta x}\right] + h_v\,\frac{\partial}{\partial x}\left[\frac{\delta\partial p_D}{\mu\,\partial x}\right] \qquad (1)$$

The storage term appears on the left and the term for the heat conduction and the latent heat transport by vapour diffusion on the right.

The equation for the moisture flow process is:

$$\rho_w \frac{\partial u}{\partial \varphi}\frac{\partial \varphi}{\partial t} = \rho_w \frac{\partial}{\partial x}\left[D_w(u)\frac{\partial u}{\partial \varphi}\frac{\partial \varphi}{\partial x}\right] + \frac{\partial}{\partial x}\left[\frac{\delta}{\mu}\frac{\partial}{\partial x}\right] \quad (2)$$

On the left hand side of the equation moisture storage is expressed in terms of a moisture storage function. The two terms on the right hand side show the liquid transfer as dependent on moisture and vapour transfer as independent of water content. The symbols of both equations mean:

ϑ	[°C]	temperature
u	[-]	moisture content volume by volume
P_D	[Pa]	vapour pressure
φ	[-]	relative humidity
$\lambda(u)$	[W/(mK)]	heat conductivity with dependence on moisture
h_v	[kJ/kg]	enthalpy of evaporation
ρ_M	[kg/m³]	dry bulk density of the building materials
ρ_W	[kg/m³]	density of water
c_M	[kJ/(kgK)]	specific heat capacity of the building material
c_W	[kJ/(KgK)]	specific heat capacity of water
$Dw(u)$	[m²/h]	liquid flow coefficient with dependence on moisture
δ	[kg/(mhPa)]	vapour diffusion coefficient
μ	[-]	vapour diffusion resistance number under dry conditions
t	[h]	time
x	[m]	place co-ordinate

The term $\partial u/\partial \varphi$ represents the derivation of the moisture storage function. The material qualities essential for the calculation are the moisture dependent heat conductivity, the value of resistance of vapour diffusion under dry conditions, the liquid transfer coefficients with dependency on moisture and the moisture storage function. Whereas the first two material qualities are generally known or can be easily found out, the determination of the liquid transfer coefficients and the moisture storage functions of building materials, with capillary action, is more complex. Preliminary reckoning, however, allows an approximate calculation of the liquid transfer coefficient by the water absorption coefficient (A-value), as shown in (Krus, Holm, 1999/1) and by a simple drying experiment. Similar operations can be applied for the moisture storage function, which can be approximated quite accurately, if the sorption moisture at 80 % r.h. (actual moisture content of the building) and the pore size distribution is known (Krus, Holm, 1999/2).

The discretization of the transport equations (1) and (2) is done by a fully implicit finite volume scheme with variable grid spacing. The coupling of the discretized equations is assured by iterative consecutive solution of these equations, using under relaxation factors adapted to the progress of solution. The calculation procedure, including the necessary input and the obtainable results are demonstrated with the aid of Fig. 1.

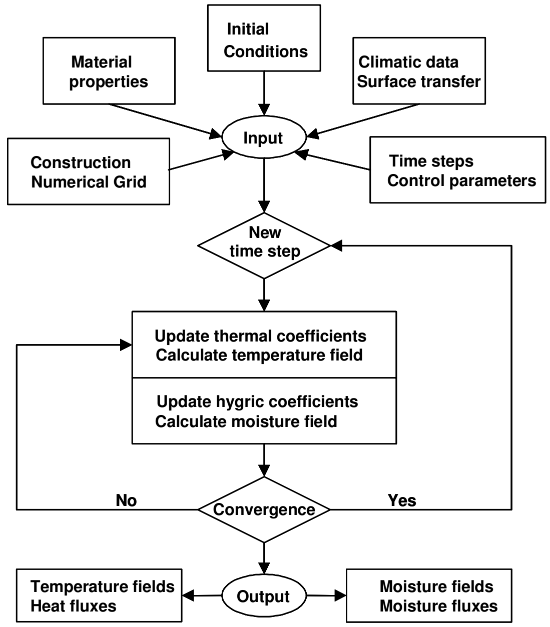

Figure 1.Flow chart of the calculation technique on which WUFI® is based.

It is the choice of the correct boundary and transient conditions, which is at least of equal importance. The calculation model takes into account all the essential climatic parameters, such as air temperature, air moisture, effects caused by the sun or rain. Special attention is paid to the realistic determination of the actual effects on the surfaces of walls caused by driving rain. As the calculations of the energy demand of buildings necessitate a comparability of the calculation results and a standardised point of reference, test reference years have been established which gather the data on an hourly basis for the most important climate parameters for different climatic zones. Like energy calculations, realistic moisture calculations also need climate data obtained on an hourly basis, as it is pointless for some parameters, like the rain, to be registered as a longer-term mean value. The screenshot shown in Fig. 2 demonstrates with North America as an example the great amount of climatic data available for calculations.

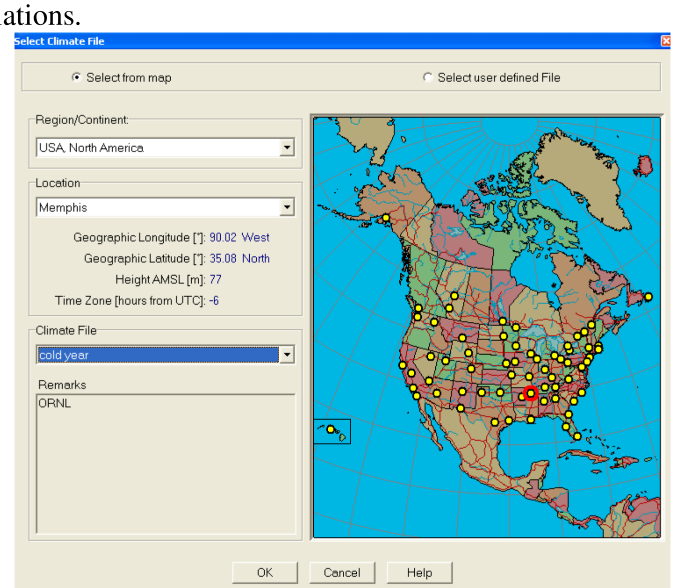

Figure 2. Screenshot of the program WUFI®.

You have different possibility for the choice of the indoor climate. In some cases it is sufficient to ignore short-term fluctuations of the boundary conditions and to consider only their long-term (e.g. yearly) trend. Temperature and relative humidity may then be modelled by simple sine curves with yearly period, or even by constant values. These conditions are usually met by the interior climate: the daily variations of indoor temperature and humidity are strongly damped by the heat and sorption capacities of the furnishings; the remaining fluctuations do not penetrate far into the building components and only have a negligible effect on their hygrothermal behaviour. The default values suggested for indoor correspond to typical situations in residential homes in Germany, as determined by measurements (WTA Guideline 6-2-01/E). To get reasonable indoor climate courses for other climatic regions you have the possibility to derive them from the exterior climate, using different algorithms specified by EN ISO 13788, EN 15026 or ASHRAE Standard 160P. There you have the choice of different moisture loads depending on the use of the building

With the 1-dimensional hygrothermal model you can evaluate the performance of your design under any climate and predict for example:

- drying time of built-in moisture
- condensation problems
- water absorption due to driving rain
- moisture influence on thermal performance
- long term system behaviour or hygrothermal consequences of construction modifications.

APPLICATION OF A 1D-SIMULATION FOR A TROPIC CLIMATE ZONE

Thailand is characterised by a damp hot climate throughout the year. The average temperatures lie well above 25ºC, with maximum temperatures of 40ºC. Because of the nearness to the equator powerful rainshowers occur during the monsoon after previous massive daily exposure to the sun. The relative humidity lies mostly between 80% and, after the monsoon storms, 100%. During the dry season it is a little less.

Figure 3. Photo of typical residential buildings in Bangkok with mould growth on the facades.

This climate requires air-conditioning throughout the year, especially in modern flats and office buildings. It must be noted here that skeleton constructions dominate in Thailand, with external walls of 10 cm of brick or similar materials, without the use of insulation materials. Even in luxurious hotel buildings the windows are single-glazed. As a result, the permanent air-conditioning leads to electric power consumption, which should be reduced because of energetical and financial reasons. This permanent cooling in combination with the bad insulation standard is the reason that in many cases you find a big amount of mould on the facades of residential buildings (see Fig. 3):

The following hygrothermal measures would seem very appropriate to reduce energy consumption: The energy savings by solar protection and the influence of a better interior insulation of the external walls as well as the use of the frequent rain for cooling the roof.

Figure 4 shows the influence of a shading measure and of the use of insulation material on the annual energy flux through the outside walls of such a typical building. The shading of the wall reduces the heat flux from about 320 kWh/m²a to about 240 kWh/m²a, this means a reduction of 25 %. Much more effective is the improvement of the insulation. With 2 cm of standard insulation material (with a heat conductivity of 0.04 W/m²K) the heat loss can be lowered to 125 kWh/m²a and with 5 cm to 60 kWh/m²a. Because of the permanent air-conditioning resulting in a permanent lower inside temperature from the hygric sight of view an internal insulation is optimal. This means that an easy and cheap measure which can be easily performed by the inhabitants can reduce the energy consumption for the heat gains through the wall by 60 to 80 %.

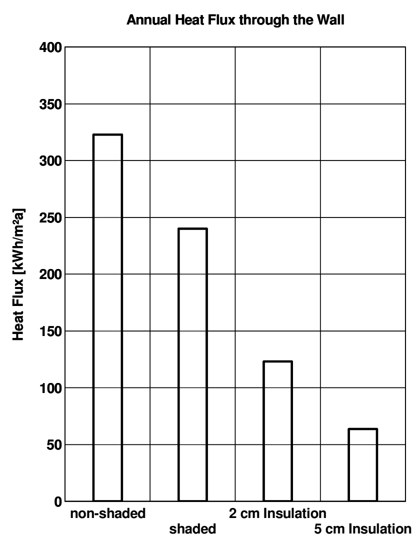

Figure 4. Influence of a shading measure and of the use of insulation material on the annual energy flux through the outside walls of such a typical building of Bangkok.

The typical flat roof of modern buildings in Thailand is made of concrete with a vapour barrier below the insulation and a membrane above which drains off the rain water (see Fig 5 left side above). If you put a covering on top of this roof, which allows retaining a part of the rain (see Fig 5 left side below) while drying the latent heat can be used for energy savings. Assuming a typical daily rain the heat flux is remarkably reduced from 127 kWh/m²a to 81 kWh/m²a as can be seen clearly from Fig. 5 right side. This means a decrease of more than 35 %. A positive side effect is the relieve of the canalisation. These results may explain, why you find thatched roofs on many traditional buildings in Thailand.

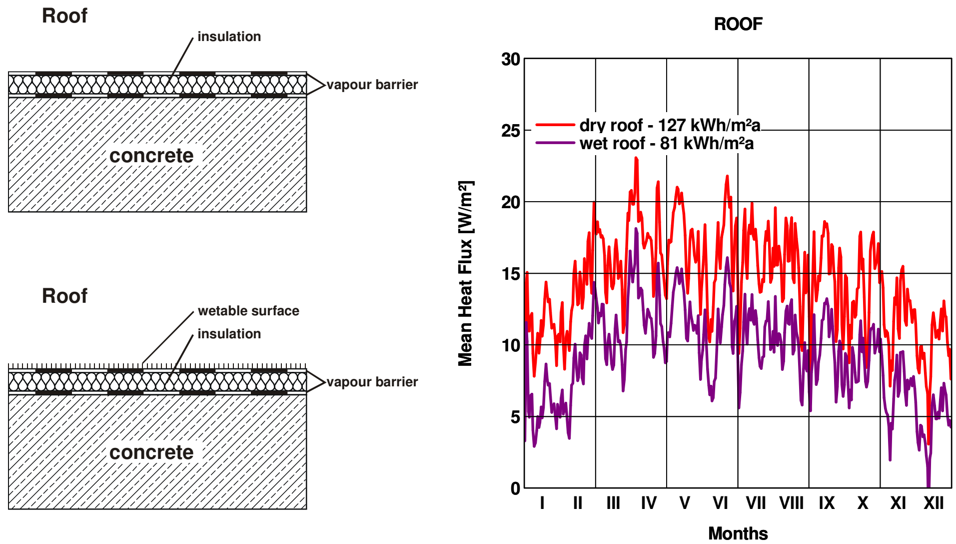

Figure 5 Typical flat roof of modern buildings in Thailand and upgraded with a moisture retaining surface layer (left side above and below) and the resulting mean heat fluxes through the roof.

TWO DIMENSIONAL HYGROTHERMAL SIMULATION WITH WUFI®-2D

Some constructions cannot be modelled accurately by one dimensional simulation. In these cases two dimensional calculations with WUFI®-2D should be performed. There is no fundamental difference between a one dimensional and a two dimensional calculation. Creating a two dimensional model, however, is considerably more complex and the calculation time is much longer. Therefore the use of the WUFI®-2D needs much more experience checking the plausibility and interpreting the results.

Some two dimensional effects like heat and moisture exchange in ventilated cavities and rain water penetration are also implemented in a simplified way. Typical application areas are

- moisture conditions at structural and geometrical thermal bridges
- timber framed constructions with multiple insulation layers
- building components with anisotropic materials.

APPLICATION OF 2D-SIMULATION FOR A TEMPERATE CLIMATE ZONE

Because half-timbered buildings are very sensitive to moisture loads they are only common in temperate climate zones. Since many timber-framed houses are listed as ancient monuments, a practicable compromise between thermal rehabilitation and preservation of the historic appearance and fabric must be found. Mostly the thermal protection can only be achieved by applying thermal insulation to the interior side of the exterior wall. But since interior insulation lowers the temperature between insulation layer and filling material and thus raises the humidity level, such measures are not without risk. The choice of a suitable type of insulation and an appropriate type of assembly must be made with proper consideration of the hygrothermal conditions at the timber-framed façade. It has been investigated to which extend the moisture problems created by an interior insulation can be mitigated by applying a moisture-adaptive vapour retarder or by using a capillary active insulation material (Sedlbauer, Krus, 2009).

Another novel approach which will be shown here consists in using the insulation as part of the infill. A newly designed infill assembly with mineral wool as insulation material is presented whose performance has been demonstrated by outdoor exposure tests (Details in (Krus, Sedlbauer, Fitz, 2009)). One of the most important problems with half timbered buildings is that the big difference in the hygrothermal characteristics of the wooden beams and the material of the infill causes small gaps between them. The warm and humid air passing through this gap from inside to outside moistens the sensitive wood due to condensation. Although the measurements with as special equipment developed for this purpose showed the tightness of this design in the long run the formation of a gap cannot be excluded. To investigate the effect of such a gap a special version of WUFI®-2D is used in which the convection of air through a straight gap is implemented in a simplified way. Fig. 6 shows the implemented construction with the air gap above the timber frame.

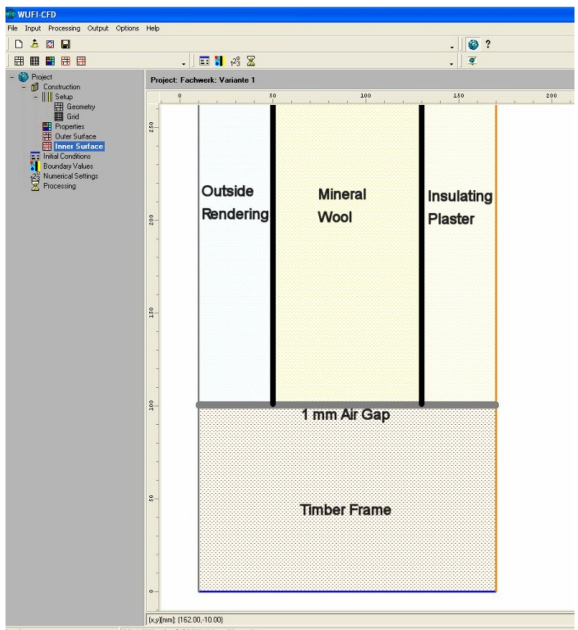

Figure 5 Implemented half timbered frame construction with infill insulation and an air gap above the timber frame.

In Fig. 6 the calculated temperature and moisture distributions within the half timbered frame construction at the point of maximal water content in March are illustrated. Noticeable is the temperature near the gap. The passing warm air from inside is warming up the materials alongside. The left side of Fig. 6 shows an accumulation of humidity at position 4 in the outside rendering. The reason for this effect is the low diffusion resistance of the insulation material made of mineral wool. The moisture of the humid air stream diffuses to the cold inside surface of the rendering where the temperature lies below the dew point temperature.

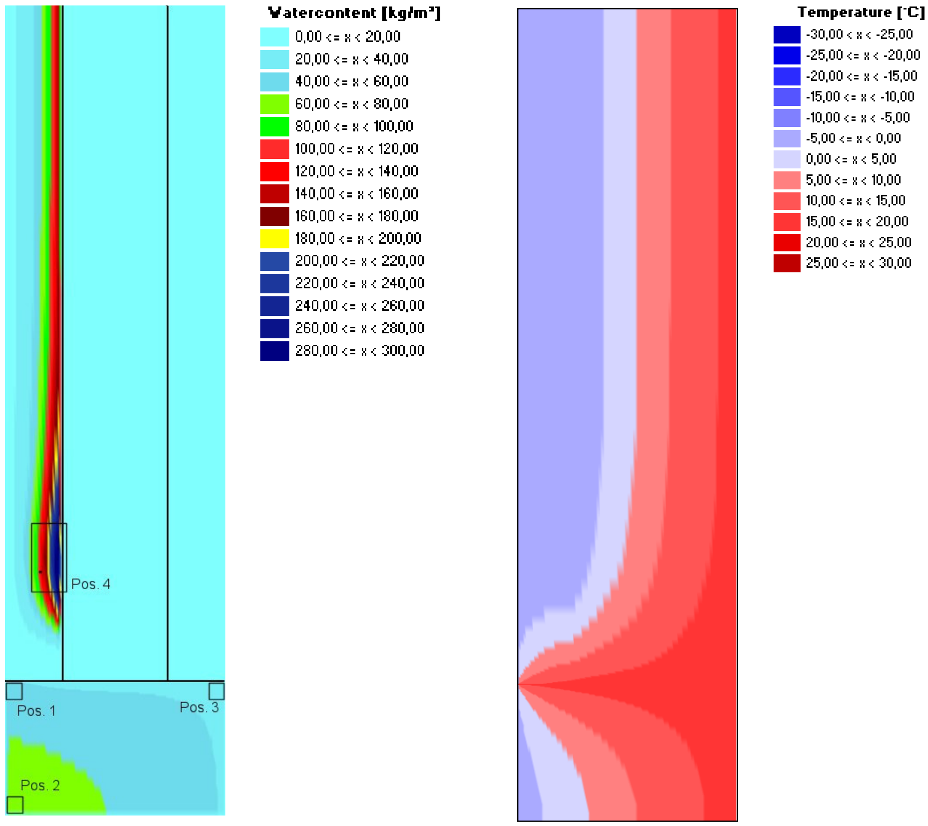

Figure 6: Calculated temperature (right) and moisture (left) distributions within the half timbered frame construction at the point of maximal water content in March.

For the four positions marked in Fig. 6 the courses of temperature (red line) and moisture content (blue line) are displayed in Fig. 7**.** In all the positions within the wood (Pos. 1 to Pos. 3) the water content lies always below the critical 20 Mass-% respectively 80 kg/m³ (green line). For mineral building material a simple criterion for the prevention of frost damages is that the moisture content doesn't exceed a saturation degree of 90 % which means 450 kg/m³ for the rendering used (green line in Fig. 7 bottom left side). The maximum water content in March is far below this value.

The calculations on this novel approach with an infill insulation show an unexpected positive effect for timber construction. Due to the diffusion openness of the insulation material the moisture in or near the gap will be transported to the cold rendering by vapour diffusion. There the capillarity of the rendering disperses the moisture and enhances its drying. With this effect the infill insulation gives an additive protection against wood destroying microorganisms.

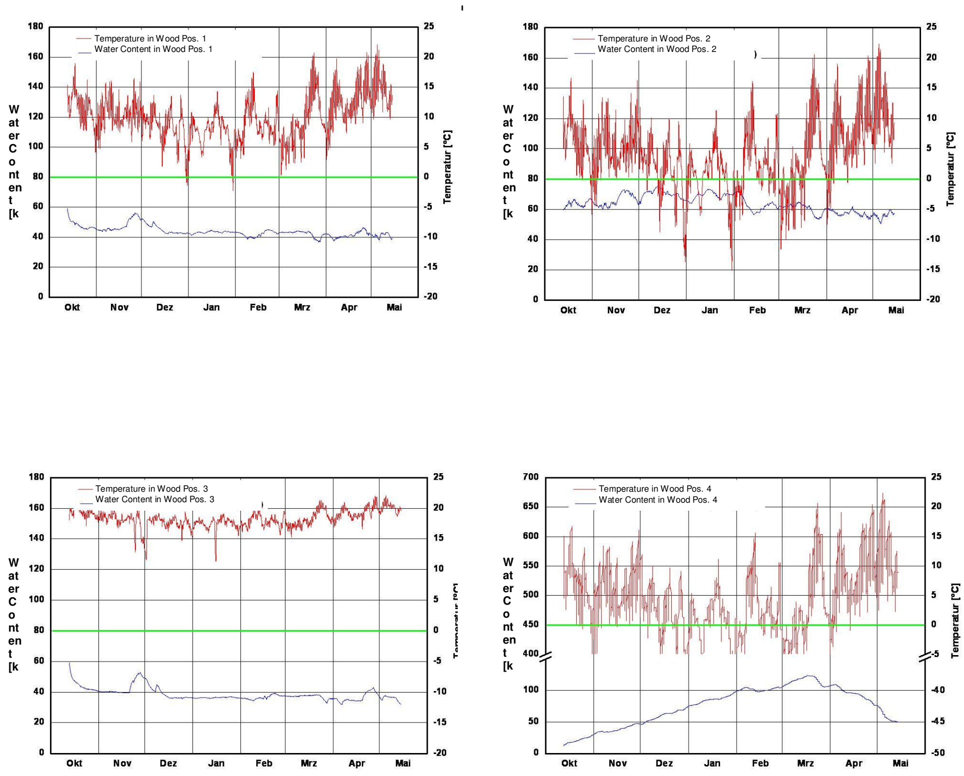

Figure 7: Courses of temperature (red line) and moisture content (blue line) for the four positions marked in **Fig. 6** and critical water contents (green line) of the materials.

WHOLE BUILDING MODEL WUFI®-PLUS

The heat and moisture behaviour of the building envelope is an important aspect of the overall performance of a building. Today the hygrothermal transport phenomena through a building enclosure exposed to natural climate conditions are well understood and a number of models and computer codes have been developed and validated worldwide [Trechsel et al. 2001]. The same holds for thermal whole building simulations where a wide range of validated computer codes exists, e.g. ESP-r, TRNSYS, DOE-2 and EnergyPlus. However, very few models consider all hygrothermal interactions between the indoor air and the building envelope in detail.

There are a number of validated models for thermal building simulations as well as hygrothermal envelope calculations used in building practice today. However, working combinations of these models are not yet available for the practitioner. In principle, this combination is achieved by coupling existing models of both types. Figure 8 shows the concept of such a combination where balance equations for the interior space and the different envelope parts have to be solved simultaneously. Recently the first real hygrothermal simulation models have been developed (Karagiozis et al. 2001, Rode et al. 2001)but so far only limited validation cases have been reported. The model employed in this paper is called WUFI®PLUS ([Holm et al, 2003) and is based on the hygrothermal envelope calculation model WUFI® (Künzel, 1994).

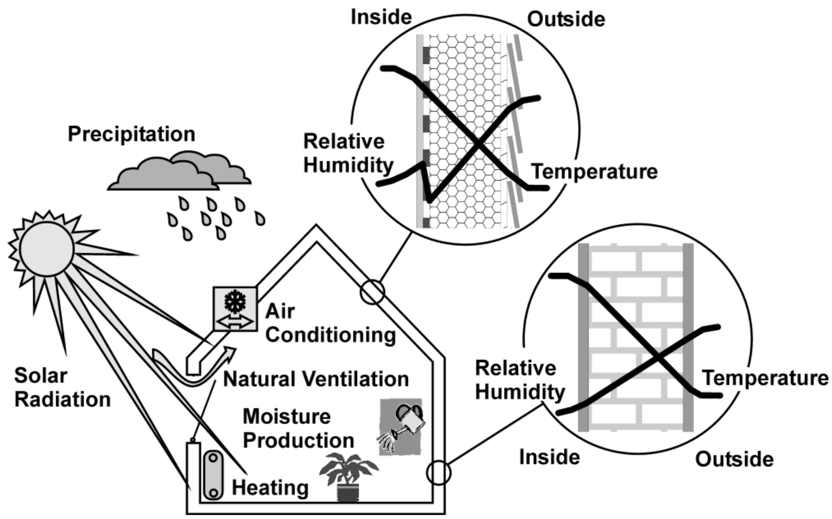

Figure 8: Coupling concept for the simultaneous treatment of the hygrothermal effects of interior heat and moisture loads, exterior climate and transient behaviour of envelope components.

The model for the hygrothermal envelope calculation taking into account vapour diffusion, liquid flow and thermal transport in porous is based on the same equations 1 and 2 as WUFI®-1D.

The indoor air temperature θ_i is linked to the heat fluxes into the room. This means that not only the heat flux through the envelope (transmission and solar input) is important. In addition, internal thermal loads and the air exchange due to natural convection or HVAC systems must be taken into account. The energy balance can be described with the following equation.

$$\rho \cdot c \cdot V \cdot \frac{d\theta_i}{dt} = \sum_j A_j \alpha_j (\theta_j - \theta_i) + \dot{Q}_{Sol} + \dot{Q}_{il} + n \cdot V \cdot \rho \cdot c \cdot (\theta_a - \theta_i) + \dot{Q}_{vent} \quad (3)$$

where:

ρ = density of the air, [kg/m³]
α_j = heat transfer coefficients [W/m^{2}K]
θ_a = exterior air temperature, [K]
θ_j = surface temperature, [K]
θ_I = indoor air temperature, [K]
t = time, [s]
A_j = surface area, [m²]
c = heat capacity of the air [J/kgK]
n = air change per hour, [h^{-1}]
Q_{sol} = solar input leading directly to an increase of the air temperature or furniture, [W]
Q_{il} = internal gains such as people, lights and equipment, [W]
$Q_{vent.}$ = heat fluxes gained or lost due to ventilation, [W]
V = volume, [m³]

The humidity condition in the room are a consequence of the moisture fluxes over the interior surfaces, the user dependent moisture production rate and the gains or loses due to air infiltration, natural or mechanical ventilation as well as sources or sinks due to HVAC systems.

$$V \cdot \frac{dc_i}{dt} = \sum_j A_j \dot{g}_{w\,j} \quad + \quad n \cdot V(c_a - c_i) + \dot{W}_{IMP} + \dot{W}_{Vent} + \dot{W}_{HVAC} \tag{4}$$

where:

c_a = absolute moisture ratio of the exterior air, kg/m3

c_i = absolute moisture ratio of the interior air , kg/m3

$\dot{g}_{w\,j}$ = moisture flux from the interior surface into the room, kg/(sm²)]

W_{MP} = moisture production, kg/h

W_{vent} = moisture gains or loses due to ventilation, kg/h

W_{HVAC} = moisture gains or loses due to the HVAC system, kg/h.

A number of quite different questions, which have gained importance lately, may be answered with this model

- How much ventilation and additional heating or cooling energy is required to ensure hygienic indoor conditions when a building contains construction moisture or has been flooded?
- What happens to the building envelope when the indoor environment of a historic building is severely changed e.g. by turning it into a laundry or restaurant?
- How do different envelope components react to fluctuating indoor air conditions of buildings with temporary occupation?
- What humidity control strategies should be employed to preclude mould formation on the external and internal surfaces of the building envelope?
- Can vapour absorbing finish materials help to save energy and improve human comfort conditions?

BIOHYGROTHERMAL MODEL WUFI®-BIO

The growth conditions for mould may be described in so-called isopleth diagrams (Ayerst, 1969). These diagrams describe the germination times or growth rates. Beyond the lowest line every mould activity ceases, under these unfavorable temperature and humidity conditions spore germination or growth can be ruled out. The isopleths are determined under steady state conditions, i.e. constant temperature and relative humidity. The three factors required for growth – nutrients, temperature and humidity – must exist simultaneously for a certain period of time; this is the reason why time is one of the most important influence factors. It is assumed that germinable spores are present in most cases. This means that mould growth will occur when hygrothermal growth conditions are fulfilled.

Significant differences exist among the various fungus species. Therefore, when developing common Isopleth systems all fungi were regarded that can be detected in buildings. Quantitative statements on the growth prerequisites temperature and humidity will be set up for these more than 150 species that fulfil both features, as far as they are given in literature. Within the Isopleth model the prerequisites for the growth of mould fungi in dependence of temperature and relative humidity are stated for the above mentioned hazardous classes at first for the optimal culture medium. The Isopleth systems are based on measured biological data and also consider the growth prerequisites of all fungi of one hazardous class. The resulting lowest boundary lines of possible fungus activity are called LIM (Lowest Isopleth for Mould).

In order to regard the influence of the substrate on the formation of mould fungus, that is the building materials or possible soiling, Isopleth systems for 4 categories of substrates were suggested that could be derived from experimental examinations:

Substrate category 0: Optimal culture medium;
Substrate category I: Biologically recyclable building materials like wall paper, plaster cardboard, building materials made of biologically degradable raw materials, material for permanent elastic joints;
Substrate category II: Biologically adverse recyclable building materials such as renderings, mineral building material, certain wood as well as insulation material not covered by I;
Substrate category III: Building materials that are neither degradable nor contain nutrients.

For the substrate category III no Isopleth system is given since it can be assumed that formation of mould fungi is not possible without soiling. In case of considerable soiling, substrate category I always has to be assumed (Figure 9). Persistent building materials with high open porosity mostly belong to substrate category II. The basic principle of the new method and of defining the building material categories is to assume a worst case scenario, therefore always being on the safe side in respect of preventing the formation of mould fungi.

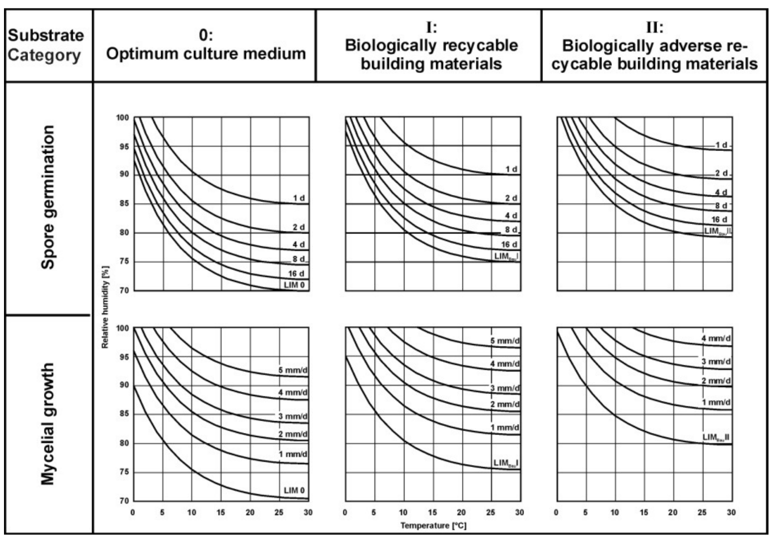

Figure 9: Isopleth systems for 3 categories of substrates, in order to regard the influence of the substrate on the formation of mould fungus (Sedlbauer, 2001).

For transient boundary conditions of temperature and relative humidity, either spore germination time or the mycel growth can be determined with the help of these Isopleth systems. The assessment of spore germination on the basis of the Isopleth model has the disadvantage that an interim drying out of the fungi spores cannot be taken into account in case of occurring transient micro-climatic boundary conditions. Therefore in these cases, this process will more often predict the germination of spores than the following Biohygrothermal model.

The decisive condition for the germination of the spores is the ambient humidity which determines the moisture content within a spore. The objective of the so called “Biohygrothermal Model“ (Sedlbauer, 2001) is to predict this moisture balance as affected by realistic transient boundary conditions as found in buildings, in order to permit predictions of growth probabilities. Of course, the moisture content of a spore is also determined by biological processes, but the current knowledge is far from sufficient to allow modelling of these. It is safe to assume that only above a certain minimum moisture content the spore begins to germinate and no biological metabolic processes occur before that. Until then, the spore may be considered as an abiotic material whose properties are subject to purely physical principles (see Figure 10). The Biohygrothermal Model only describes the development of the spore up to this point. Due to the small size of the spore an isothermal model is sufficient, so that liquid transport processes (such as capillary suction) can be lumped together with diffusion transport. Under these assumptions only the moisture storage function of the spore and the moisture-dependent vapour diffusion resistance of the spore wall are needed as material parameters (Krus, 1996). According to the assumptions noted earlier the germination is principally affected by thermal and hygric conditions only. Therefore it should be independent of the substrate. But normally the starting point of germination is defined by the first visible growth and not by the start of metabolism. The apparent start of germination depends on the quality of the substrate according to these considerations. This influence of the substrate is taken into account by using the LIMs in order to calculate the so called critical water content.

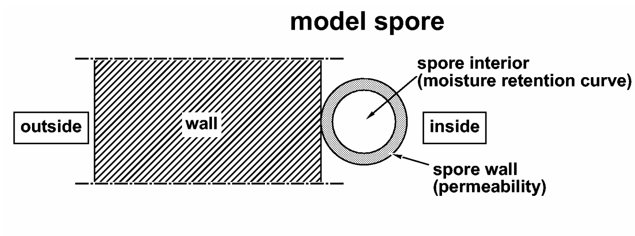

Figure 10: Schematic diagram of the Biohygrothermal Model (Sedlbauer, 2001).

COMBINED APPLICATION OF THE WHOLE BUILDING MODEL AND THE BIOHYGROTHERMAL MODEL FOR A COLD CLIMATE ZONE

The low relative humidity of the indoor air in building constructions located in cold climate zones often causes discomfort and health problems for their occupants. A solution to enhance the relative humidity in such zones, is to install a humidifier, which produces a constant amount of water per day. Unfortunately, this increases also the risk of mould growth, which results from the conditions on the inner wall surfaces of the building envelope. Therefore, such a constant and uncontrolled humidifying is not a good solution to manage this problem. Herewith, an alternative solution is proposed by controlling the humidifier with an artificial thermal bridge, which is dimensioned in a way that condensation occurs on its surface, when the risk of mould growth is given in critical areas of the building construction.

In the following, three cases are analyzed:

- In the first case, a room of a building construction located in a cold climate zone is considered without any humidifier. This case should reflect the problems (discomfort) caused by the low relative humidity of the indoor air.

- In the second case, a constant humidifier is integrated in the building room. This case should show the consequences of a humidifier, which permanently works without taking into account the resulting conditions on inner wall surfaces.

- In the third case, the thermal bridge with the dew sensor is integrated in the building room to control the humidifier. This case should demonstrate that the integration of such a system could deal with the problems cause by an uncontrolled humidifying of the indoor air.

For the simulation of the three cases, the building model of the new Modelica-Library is used.

Artificial thermal bridge with a dew point switch

The idea of the development (Krus et. al., 2005), described in the following and derived from new knowledge about mould growth, is to install artificial thermal bridges at selected points of the external wall. By means of novel programmes e.g. WUFI (Künzel, 1994), the hygrothermal room model (Holm et. al., 2002) and the bio-hygrothermal method to assess the risk of mould growth (Sedlbauer, 2001), which were developed by the IBP, this "thermal bridge" may be thermally designed in a way that condensation is developed, if the surface humidity has reached a value in the problematic areas of the internal surfaces of external walls (e.g. corners) to expect mould growth. Figure 11**Figure** (left) shows the draft of a simple structure of such an artificial "thermal bridge".

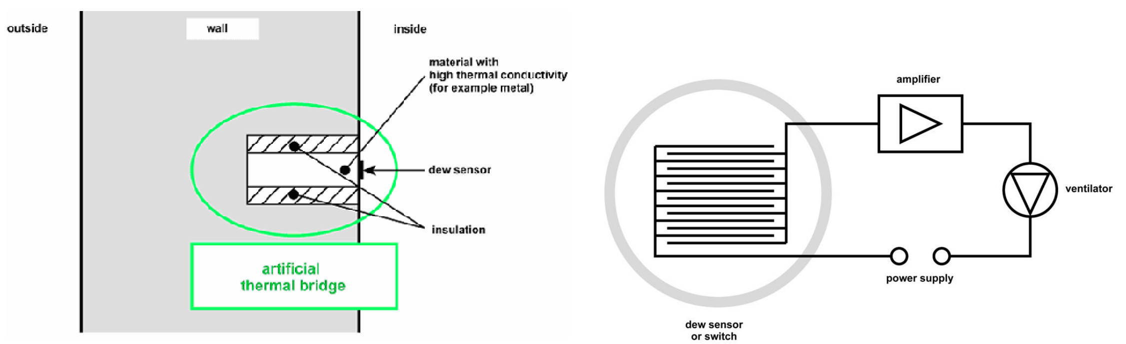

Figure 11. Schematic design of an artificial "thermal bridge" with dewing sensor (left) and of a dewing sensor for the regulation of ventilation (right).

If there are simple switching dewing sensors on the internal surface of such an artificial "thermal bridge" (structure e.g. as in Figure 11 (right), but also simple resistive sensors or others), then a humidifier, which produces a constant amount of water per day, can be automatically switched off, when condensation occurs on the surface of the thermal bridge. This ensures that unnecessary and partly false humidifying is thus prevented. The special advantage of the application of such a dew point switch is that it is working without any measurement equipment. The dew point switch is cost-efficient and almost maintenance-free, regular calibration measures are unnecessary.

Modelica - *BuildingsPhysicsLibrary*

Because the thermal bridge with a dew point switch wasn't already implemented in WUFI®-Plus the building room model of the Modelica-*BuildingsPhysicsLibrary* is used to perform the simulations of an old construction located in Greenland. This library includes many models as for instance a hygrothermal wall model, an air volume model, a zone model, a window model and an environment model. Due to the object-oriented modeling approach, some models of this library can be configured to a complex hygrothermal room model and quick and easy adaptations to new problems are possible but in principle it is comparable to the commercial WUFI®-Plus.

Simulation set-up

For the investigation of the risk of mould growth, one room of an old building construction is considered. This room has a ground area of 20 m^2, an air volume of 50 m^3 and a window facing south. The ground plan of the construction is shown in Figure 12 The U-values of the walls, corner and window used for the simulations are presented in Table 1. Due to the lack of information about building elements of building constructions of Greenland, modified material data of wood constructions located in Sweden (Sjödalshus, 2008) were used. To simulate the corner in the whole building model, a one-dimensional wall with modified and adapted material data of the outside wall was integrated in the building room, to represent the two-dimensional thermal bridge effects due to corner as proposed in (Reichelt, 2004). Through this approach it was possible to calculate the temperature and moisture conditions on the surface of the corner.

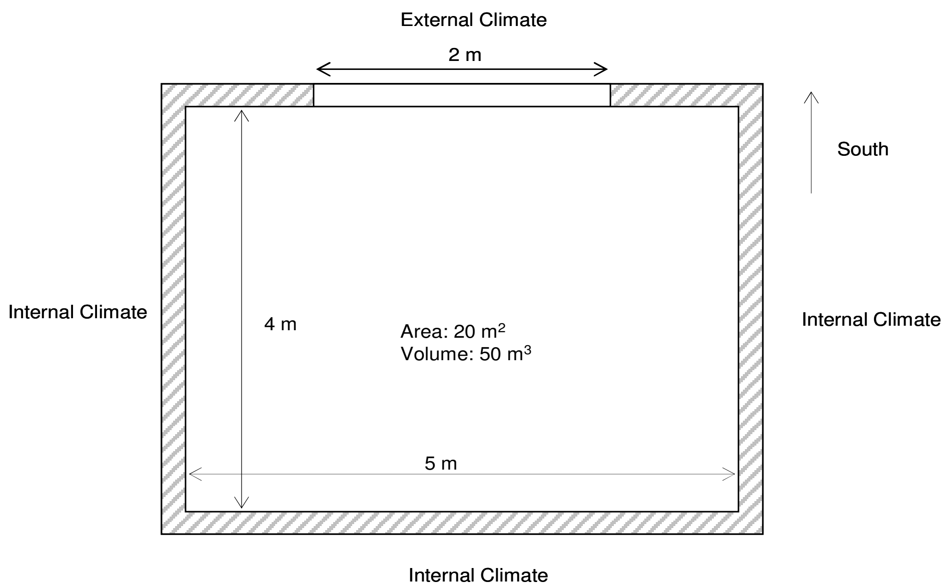

Figure 12. Ground plan of the building room.

Table 1. U-value of the old construction

Construction	**U-value**
Outside wall	0.5 W/m^2K
Outside corner	0.9 W/m^2K
Inside wall	0.4 W/m^2K
Floor	0.6 W/m^2K
Roof	0.6 W/m^2K
Window	2.0 W/m^2K

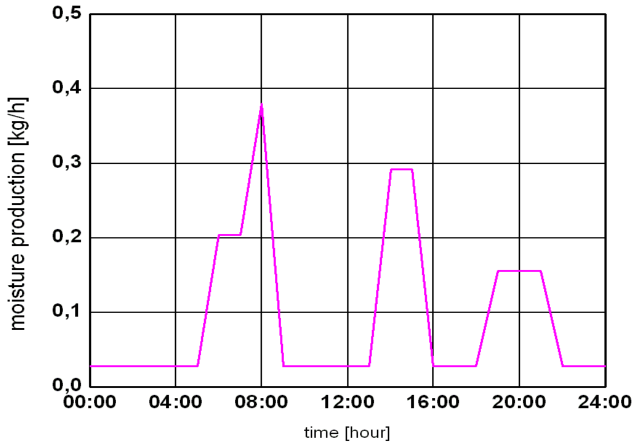

Figure 13. Diurnal moisture production pattern in the building room.

For the calculations, a natural air change rate of 0.7 h^{-1} is assumed. The temperature in the room is controlled to 20°C. A moisture production of 2.0 kg per day, which is derived from (Hartmann et. al., 2001) and which simulates the activities of the occupants for a three persons household and adapted to the implemented room size, is set in the building model. Figure 13 shows the diurnal moisture pattern in the building room.

With the Modelica building room model, the relative humidity of the air and the relative humidity on the surface of the corner are calculated for the three different cases. The simulations are carried out with the climate data of the Sisimut locality. The data are generated with the program METEONORM 6.0 (METEOTEST, 2007). Figure 14Figure shows the curves of the outdoor temperature and relative humidity used for the simulations.

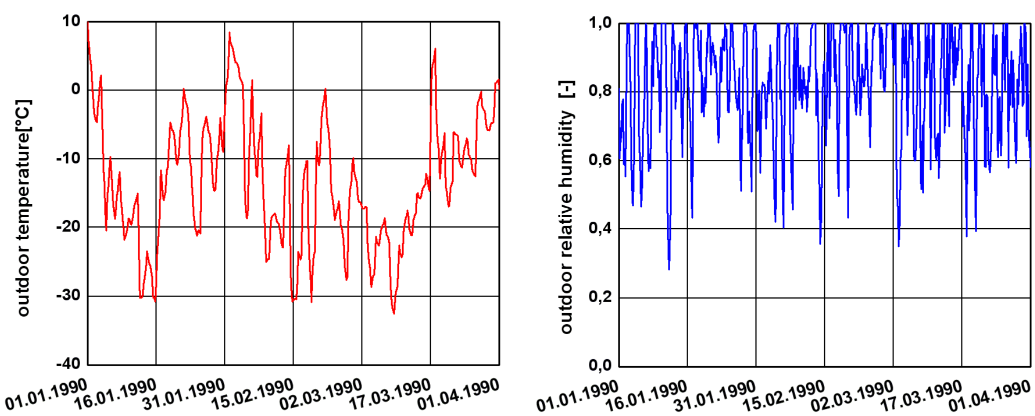

Figure 14. Outdoor temperature (left) and outdoor relative humidity (right).

Simulation results

Figure 15 (left) shows for the first case the curve of the relative humidity of the air. Due to the high air change rate of 0.7 h-1 and the cold and dry outdoor climate of Greenland, the relative humidity of the air is very low. This leads to a high discomfort in the room. The positive consequence of the low relative humidity is that there is no risk of mould growth in the corner as seen in Figure 15 (right). In the first four months of the year, the surface relative humidity is always under the critical relative humidity necessary for mould growth of substrate category 1.

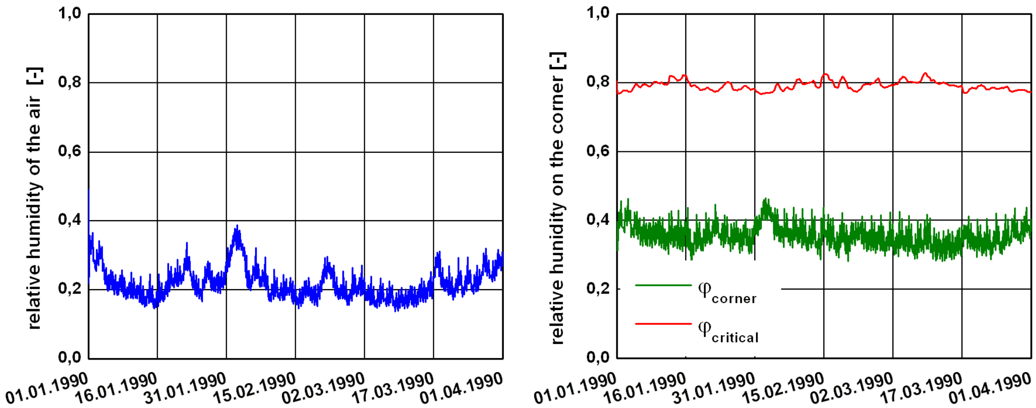

Figure 15. Relative humidity of the air (left), relative humidity on the surface of the corner (right) – First case (no humidification).

In the second case, the integration of a humidifier, which produces a constant amount of 4.0 kg vapour per day, leads to a higher relative humidity of the air. Due to that, the relative humidity on the surface of the corner also increases (Figure 16). Due to the cold surface temperature (Figure 17) of the corner, there are periods, where the conditions of mould growth are given as seen in Figure 16 (right). The use of a constant humidifier leads to conditions for mould growth in the corner of the building room.

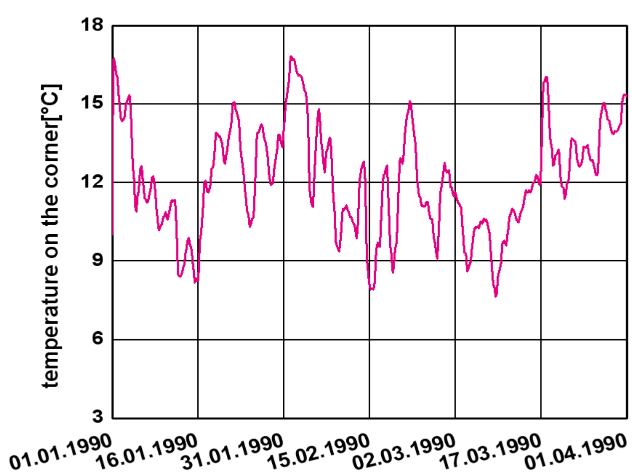

Figure 16. Temperature on the surface of the corner – Second case (constant humidification).

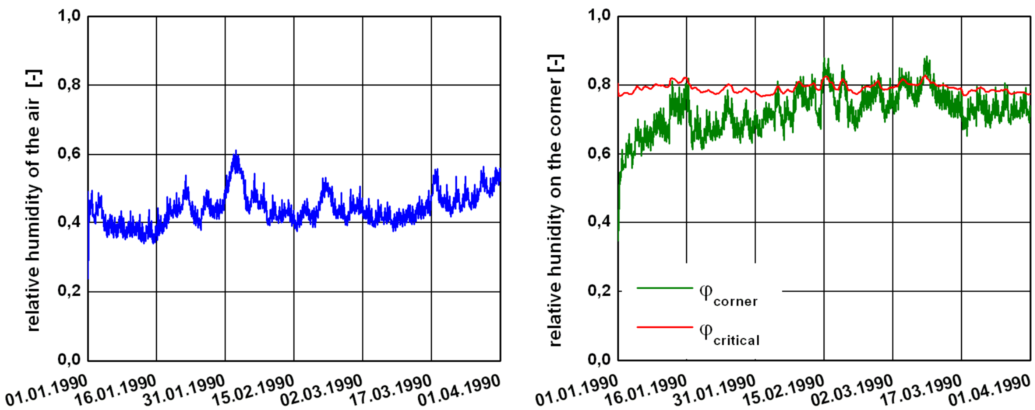

Figure 17. Relative humidity of the air (left), relative humidity on the surface of the corner (right) – Second case (constant humidification).

In the last case, the humidifier is controlled with an artificial thermal bridge in such a way, that it switches the humidifier off, when the conditions of mould growth are given in the corner (Figure 18). With this approach, it is possible to ensure that the relative humidity of the corner permanently stays under the critical relative humidity necessary for mould growth as shown in Figure 18 (right).

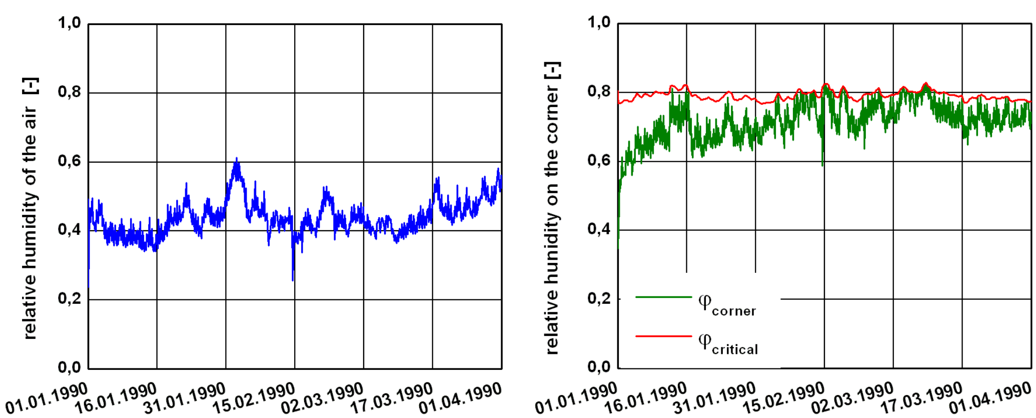

Figure 18. Relative humidity of the air (left), relative humidity on the surface of the corner (right) – Third case (controlled humidification).

CONCLUSIONS

The paper illustrates that the application of software tools for moisture protection of buildings in different climatic zones is a fast and cheap method, which can deliver reliable results when performed with appropriate software tools. For a tropical climate zone for example the calculations show how with easy and cheap measures a lot of energy can be saved. For the temperate zone the behaviour of a half timbered building with an infill insulation is examined. The simulation gives results which are surprising and wouldn't have been got otherwise.

With the combined appliance of the whole building model and the mould risk prognosis model a better solution against the typical problem of dry indoor air in buildings of the cold climate zone is investigated. It is shown by simulation that the installation of a humidifier, which permanently produces a constant amount of water per day, may be a risky solution to enhance the relative humidity of the indoor air in building constructions located in cold climates zones. This solution leads to comfortable indoor conditions but also to temporarily favourable conditions for mould growth on inner wall surfaces of problematic zones of the building constructions like corners. An alternative solution is to install an artificial thermal bridge with a dew sensor, which switches the humidifier off, when condensation occurs on its surfaces. Therewith, it is possible to enhance the relative humidity of the air and to avoid discomfort and health problems in the building room while preventing risk of mould growth in critical areas of the rooms.

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