The Hygrothermal Performance of External Walls with Inside Insulation

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ABSTRACT

On one hand, interior insulation is a risky method. On the other hand, there is no other method to improve the heating energy and comfort situation of existing buildings when their facades are to be preserved. For more than ten years, a team has been dealing with the special questions concerning interior insulation systems in order to develop design and methods of execution for them. As a result, it was found that with new materials and new technologies, inside insulation can be a viable method. However, the hygrothermal situation must be evaluated to avoid damage and to quantify the heat transmission losses.

Using a model developed for the numerical simulation of the coupled heat, air, and moisture transfer, the authors calculated temperature and moisture fields, heat flow densities, and hygroscopic and overhygroscopic moisture contents. Different insulation materials (foams, wools, calcium silicates, wooden materials, and plasters) with various thermophysical properties and details of window area and embedded beam heads have been investigated, including the impact of heating pipes.

In parallel, a comprehensive experimental work was done to validate the computer model and the calculated results. These investigations are shown to be necessary to confirm new ideas and to develop materials with improved properties.

INTRODUCTION

On one hand, conservation of energy sources and environmental protection are promoted. On the other hand, the demands of comfort of the inhabitants are increasing. One consequence is that existing buildings should be insulated in an extensive way. Many investigations have shown that exterior insulation is preferable from the point of view of building physics. Insulating from the interior has some major disadvantages (Hens 1998). Besides the unfavorable course of temperature within the cross section of outside walls and moisture problems, the floor area is decreased and risks concerning airborne sound transmission and fire protection have to be considered.

Nevertheless, inside insulation has advantages too. There is no other method to improve the thermal comfort and to reduce the heating energy consumption of existing buildings if old and historical facades are to be preserved. This conservation of heritage is not only a question of aesthetics; it is a matter of culture and human behavior in general.

We see a logical sequence.

1. The preservation and maintenance of a lot of old buildings is necessary.
2. All buildings are to be preserved only by a lasting use.
3. Today the user and technology demand better comfort with regard to hygienic and climatic conditions.
4. In opposition to this, we have to save heating energy.
5. Thus, there is a necessity to install insulation on the inside, and more and better products and techniques are available. Unfortunately, due to uncertainties and lack of knowledge, administrators and architects often decide not to insulate

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Figure 1 *Building before restoration.*

Figure 2 *The restored building.*

outside walls if facades worth preserving are to be retrofitted.

THERMAL PROTECTION OF FACADES WORTH PRESERVING

Importance of Historical Facades

Tradition is a basic of mankind. Traditional architecture induces an identification with the immediate environment. The individual structures, materials, and colors of facades promote engagement with it (Hauser 1999). Figures 1 and 2 demonstrate an example for an engaged retrofitting of small buildings in the eastern part of Germany with insulation on the inside of the outside walls. All in all, the authors manage five different types of test houses.

Integration of Interior Insulation in the Decision Process

It is known that interior insulation can be a risky method. However, when retrofitting facades worth preserving, the question is not if, but how, the thermal insulation is to be installed from an energy-saving, comfort, and hygienic point of view and, moreover, how it is to be integrated in the decision process of projects (Häupl and Stopp 1999).

Many architects are unsure with regard to thickness of insulation, vapor retarder at the inner surface of outside walls, and concerning the details near the windows or embedded beam heads. In connection with new thermally insulated, sealed glazing units and better airtightness, fungus and mold grow where there are deficiencies in the thermal protection at corners, at lintels or rabbets, and at reveals.

In former times, frame houses were protected by sufficient ventilation between the gaps of their envelope parts. Today, the consumption of water, the higher indoor temperatures, and the reduction of ventilation heat losses lead to a different indoor climate that induces hygrothermal stresses of envelope parts. To avoid damage by the altered climatic boundary conditions, we need information on the structure of the buildings through documents or measurements. The task becomes more and more complicated and comprehensive because the variety of techniques and products increases. Administrators, engineers, and natural scientists are interested in finding sustainable solutions.

A model and a computer code for the numerical simulation of the coupled heat and moisture transfer were developed and validated to evaluate and to judge the hygrothermal performance of envelope parts and in order to reduce the experimental investigations (Grunewald et al. 1996; Häupl et al. 1995). We need ways of thinking and acting as engineers. Politicians and administrators should give only supporting (not determining) activities. The following survey (see Figure 3) demonstrates the contradictory influences on the decision-making process.

INSIDE INSULATION SYSTEMS

General Survey

Figure 4 shows the variety of inside insulation systems from the hygrothermal point of view.

Investigations of Inside Insulation Systems

In East Germany and in the eastern part of Europe, a lot of building ensembles need to be improved with regard to their heat transmission through the envelope parts. In order to fulfill the demands for heat energy reduction and CO_2 production, respectively, the improvement of the facades worth preserving referring to a higher insulation level, must be realized without exception and without damage concerning the hygrothermal performance.

Later in this paper, examples demonstrate the preparation of design by means of numerical simulation and measurements. In test houses and test fields, the different inside insulation systems are investigated under conditions of use. Sensors are installed in a comprehensive way to record the climatic boundary conditions, the temperatures, relative humidities, moisture contents, heat flow densities, and the thermal conductivities of materials (Stopp et al. 2001). The last one was carried out by means of a designed and constructed so-called λ-needle probe (Stopp et al. 1998).

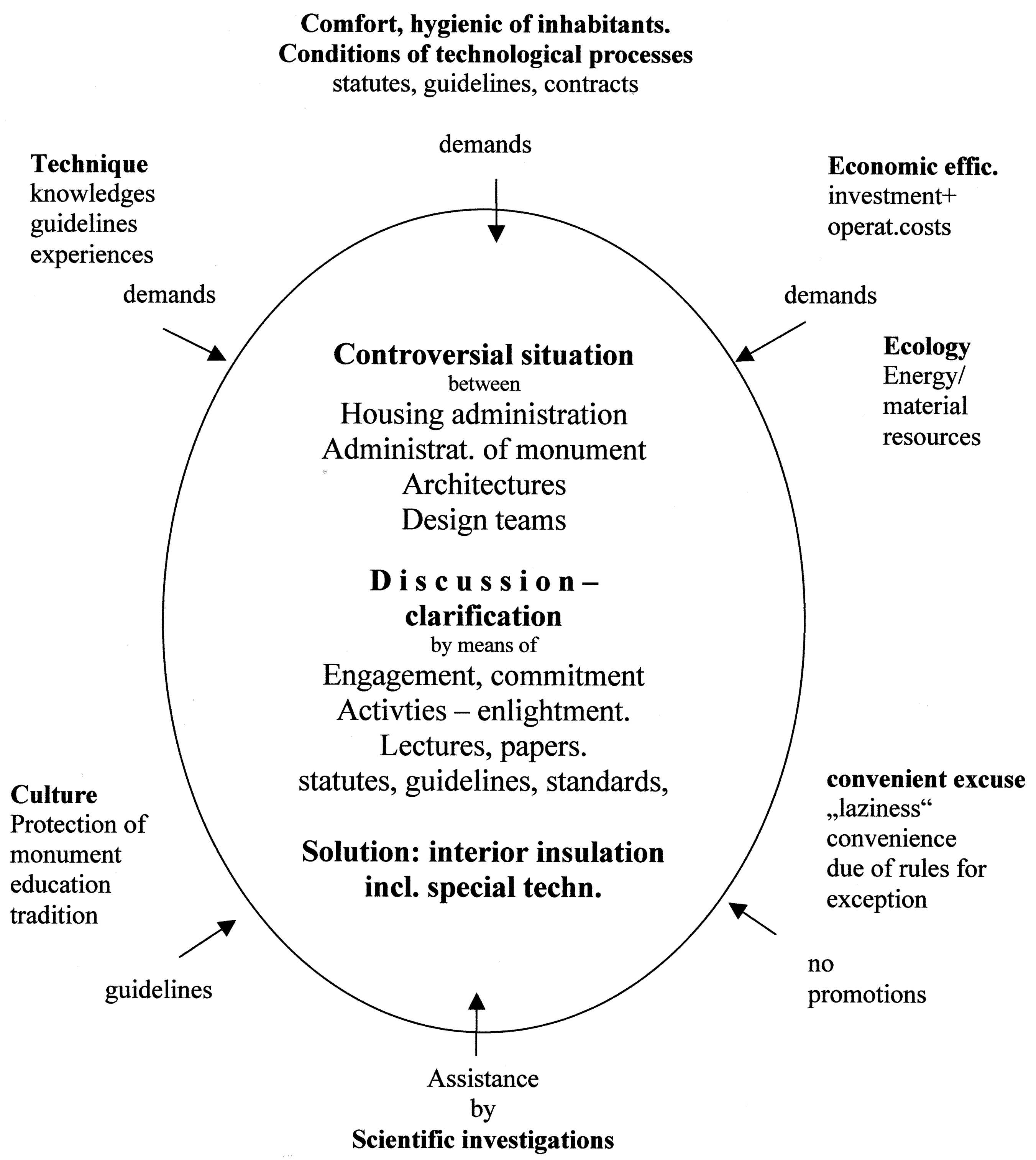

Figure 3 *Influences on the decision-making process for inside insulation systems.*

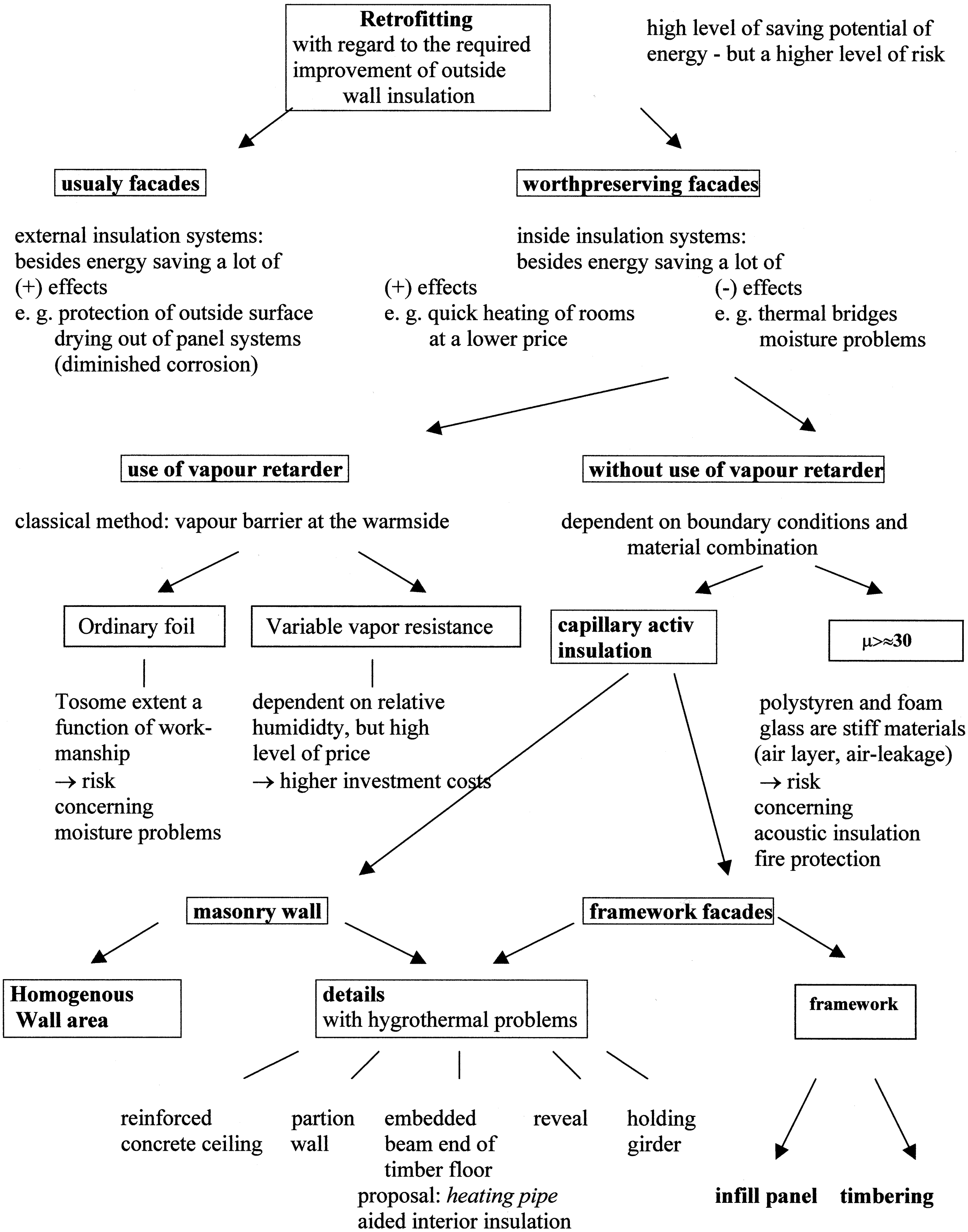

Figure 4 *Several versions of envelope systems with interior insulation.*

Costs

Depending on the materials and the technologies, the costs vary. Figure 5 demonstrates the range of variation of costs, including the labor costs for the five following inside insulation systems:

1. 38 mm expanded polystyrene laminated with 12 mm gypsum board — $U_{wall} = 0.55$ $W/m^2 \cdot K$
2. 55 mm board of calcium silicate (insulation material comprising hydrated calcium silicate normally reinforced by incorporating fibers) — $U_{wall} = 0.64$ $W/m^2 \cdot K$
3. 75 mm wood fiber soft board laminated with 12 mm gypsum board (product manufactured from wood fibers) — $U_{wall} = 0.41$ $W/m^2 \cdot K$
4. 60 mm super-insulating cellular concrete with 12 mm gypsum board (concrete containing a substantial number of small air cells — $U_{wall} = 0.48$ $W/m^2 \cdot K$
5. 50 mm insulating plaster (containing lightweight aggregate) — $U_{wall} = 0.98$ $W/m^2 \cdot K$

These data represent the average of the current German situation in the year 2000, but the relative differences between the systems can be transferred approximately to the Middle European markets. The graph includes the material prices and the expenses for workmen. Figure 5 shows that all five insulation systems could be carried out at a cost of about 44 Euro. The financial assessment of the different inside insulation systems should be discussed in connection with the total costs of a restoration. In the case of the retrofitted building shown in Figures 1 and 2, less than 3% of the total cost of the restoration was invested for thermal improvement of the outside walls by an inside insulation system with expanded polystyrene covered by gypsum board.

Besides cost, other characteristics must be considered too. Polystyrene combined with gypsum board is the cheapest insulation system, but it is a product using oil sources. The acoustic resonance and, in the case of fire at least, poisonous damps are to be considered. Calsium silicate is actually the most expensive material. Maybe this capillary active insulation material could be cheaper in the future if there were more extensive use.

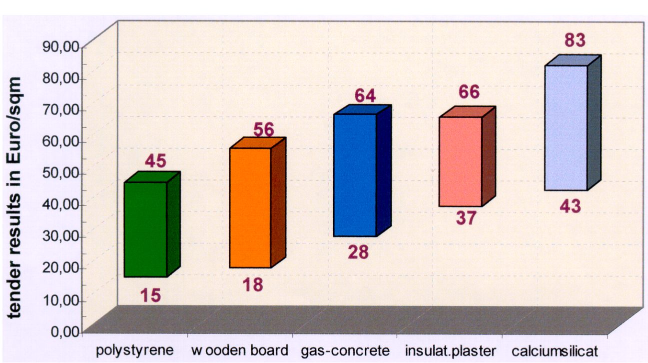

Figure 5 *Costs of inside insulation systems (labor costs included).*

Wooden products represent alternative materials, but in case of moisture, the danger of mold is very strong. The super-insulating gas concrete is a new mineral product. Similar to polystyrene, it must be covered with gypsum board. It is not easy to handle and, due to a vapor-resistance factor of $\mu \approx 3$, water vapor penetrates into the construction. A later section deals with the hygrothermal performance of the materials.

The Effect of Infrared Reflecting Coatings

The temperature profile of an outside wall insulated on the inside can be influenced in a favorable way by low-emission coatings on the facade (Häupl et al. 2000). Due to reduced emission of radiation, the temperature at the exterior surface and, thus, the temperature at the cold side of the thermal insulation, reaches a higher level. This means a decreased relative humidity and a shorter condensation period (Figure 6). Figure 7 shows

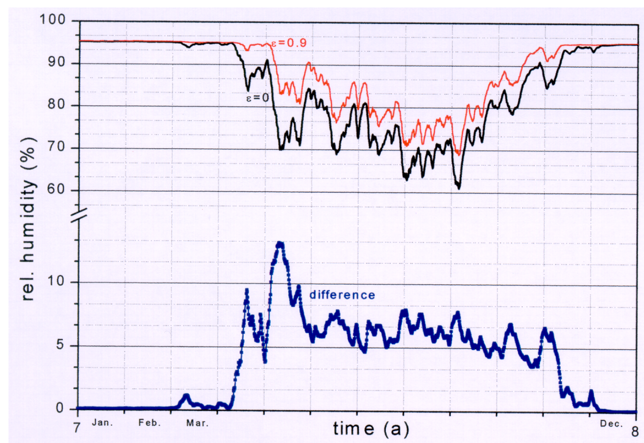

Figure 6 *Course of relative humidity at the cold site of the thermal insulation layer.*

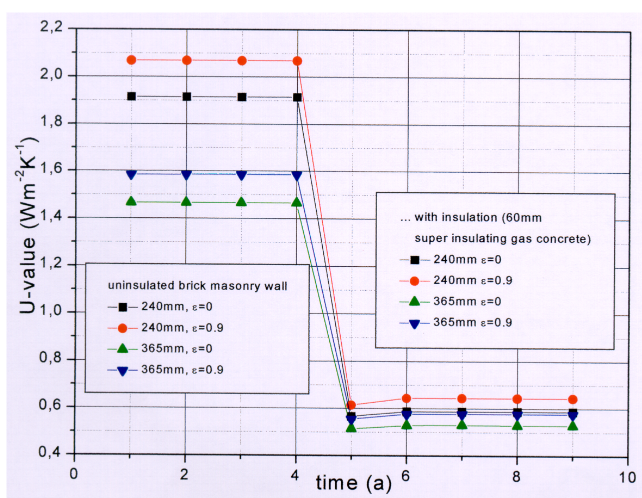

Figure 7 *Comparison of U-factors influenced by infrared reflecting coatings.*

TABLE 1

Air temp.	Relative humidity	Recip. of heat trans. coeff.
i **= 20.0°C**	***i*** **= 50.0%**	***i*** **= 0.13 m²K/W**
e **= –10.0°C**	***e*** **= 80.0%**	***e*** **= 0.04 m²K/W**

material	thickness (mm)	wh (Vol%)	ws (Vol%)	K (m^2/s)	μ	wv Vol%	λ W/mK
Calcium silicate	60	1.0	70.0	2.0E–06	5.0/5.0	0.70	0.060
Brick masonry	380	1.0	30.0	1.0E–07	6.0/6.0	0.65	0.700

Algorithm 1: condensate in the 1st and 2nd layer

t = 60.0 d **Results** **iterat.: 1**

Layer	temp. (°C)	Ps (Pa)	P (Pa)	➤R *Rvorch* (m^2K/W)	*wi* *we* (Vol%)	width *sk* width *sks* (mm)	moisture content (kg/m^2)	
Air indoor	20.0	2337	1168	➤0.130				
	17.7	2021	1168					
Calcium silicate					0.4		h	0.438
				➤1.000		23	o	0.066
[1] 60 mm				0.986	1.4	–	Σ	0.504
	–0.2	600	600					
Brick masonry					1.2		h	2.628
				➤0.507		28	o	0.034
[2] 380 mm				0.505	0.5	–	Σ	2.662
	–9.3	277	208					
Air outdoor	–10.0	260	208	➤0.040				
					Σ hygrosc. moist.		h	3.066
➤ – thermal resistance				➤1.507	Σ ov. hygr. moist.		o	0.100
– existing therm. resistance				1.491	Σ total moisture		Σ	3.166

Total flow density	Moisture content (DIN / GLASER)
Interior: Gi = 1.160E–4 kg/m²h	Condensate: Wt = 1.652 kg/m²
Exterior: Ge = 1.16E–4 kg/m²h	Evaporation: Wv = 2.287 kg/m²
Half time τ = 3 days	U-factor = 0.664 W/m²K

the improvement of the heat transmission coefficient U-factor of an uninsulated and insulated outside wall by low-emission coatings.

INSIDE INSULATIONS OF NONSTRUCTURAL OUTSIDE WALLS

Influence of Material Properties and Climatic Boundary Conditions

The use of a vapor retarder at the warm side of an inside insulation system is the usual practice. The vapor resistance prevents the diffusion of water vapor to the cold side of the insulation layer. On the other hand, such a vapor retarder reduces the drying out of built-in moisture or penetrating moisture from the outside and calls for workmanship. Moreover, the total costs increase. Therefore, a capillary-active inside insulation system, by means of calcium silicate without a vapor retarder, is an alternative solution (Häupl et al. 1999).

By means of an analytical approximation and the computer program COND (Häupl et al. 1989), it is possible to calculate the moisture distribution within the structures. Table 1 lists the layers of an outside wall from indoors to outdoors. The values of physical quantities demonstrate the thermal and hygric properties of wall structures (w_h = maximum hygroscopic moisture content, w_s = saturation moisture, K = parameter of the capillary water transfer function [Grunewald 1997; Häupl et al. 1999]). The table also includes the temperatures, vapor pressure values, moisture of material by volume w_i, w_e at the interface planes, and the moisture content (h = hygroscopic, o = over-hygroscopic, Σ = total moisture content). In this example, the climatic boundary conditions of the German standard DIN 4108/3 are used (e.g., outdoor temperature –10ºC for 60 days).

In spite of a missing vapor retarder, the over-hygroscopic moisture content (condensate) under the condition of a strong winter period is only 0.1 kg/m^2. The distribution of the moisture (over-hygroscopic: dense hatching; hygroscopic: wide hatching) is represented in Figure 8. Without the effect of the capillary water activities (so-called Glaser scheme), the condensation is more than 1.5 kg/m^2 because the distribution of the over-hygroscopic moisture and, connected with it, the decrease of the interior vapor pressure gradient are not considered.

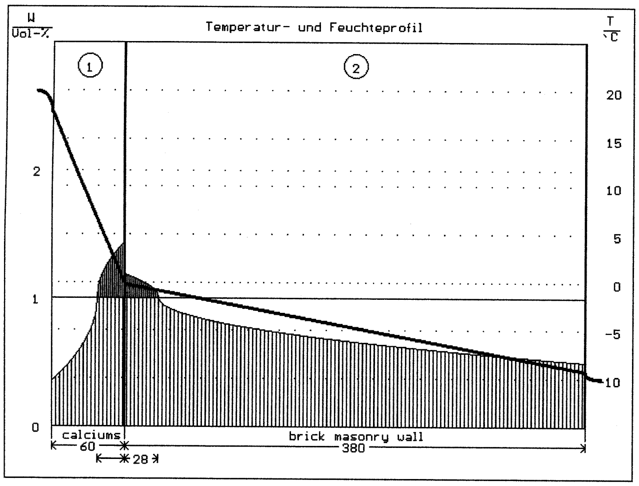

Figure 8 *Moisture distribution calculated by method COND: calcium silicate inside insulation.*

In the same way, other materials are investigated. In the case of expanded polystyrene with a vapor resistance factor μ=40 and parameter K=10^{-13}m^2/s, the result of over-hygroscopic moisture is 0.15 kg/m^2. Admittedly due to the stiffness of material, the sound insulation can be reduced.

The aerated cell-concrete (μ = 3, K = 5.10^{-8}m^2/s) results in more than 1.2 kg/m^2 condensate under this strong outdoor climate. However, under the moderate climatic boundary conditions of the TRY Essen, representing the lowlands of Middle Europe, the last one results in an acceptable over-hygroscopic moisture content. By means of the computer code DIM 3.1 (Grunewald 1997), Figure 9 demonstrates the numerical simulation of the moisture field. Due to the drying out during summertime, a quasi-stationary state is reached and the over-hygroscopic moisture content in the winter period is limited to 0.050 kg/m^2.

In Figure 10, the influence of the capillary properties on hygrothermal performance is shown again (a_o = maximum capillary conductivity [Häupl et al. 1999]). For an inside insulating plaster under the climatic conditions of TRY Essen, owing to an increase of the capillary conductivity, the total condensate and the condensate of the insulation layer, respectively, would decrease from 0.150 kg/m^2 to 0.040 kg/m^2 and from 0.080 kg/m^2 to about zero.

Another important material property with regard to the hygrothermal performance of inside insulation systems is the hygroscopicity. Figure 11 shows the moisture field of a brick masonry wall insulated on its inside by means of laminated wooden board with the gypsum board having a maximum

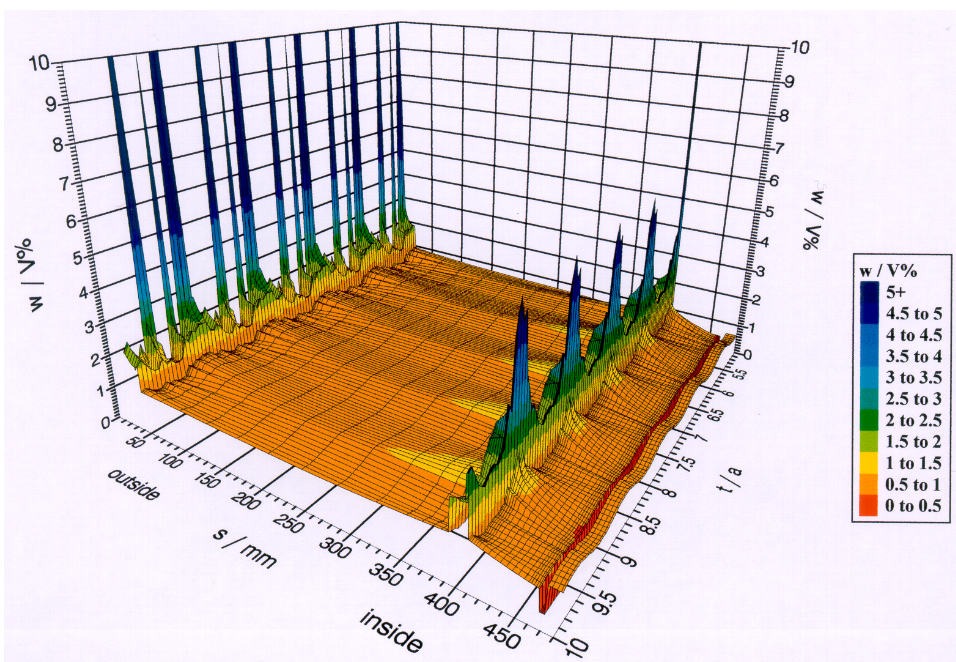

Figure 9 *Inside insulation: aerated cell-concrete; numerical simulated moisture distribution.*

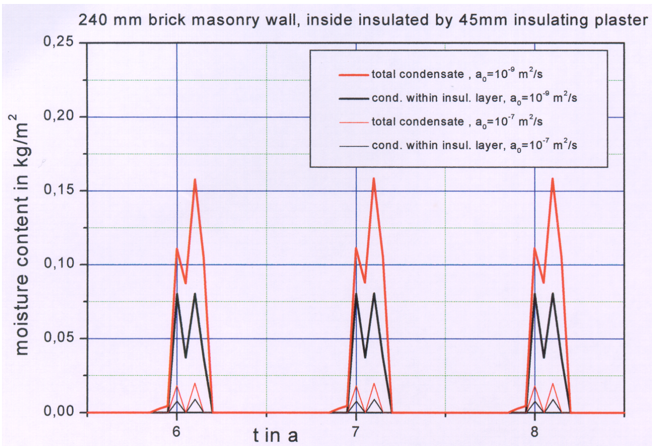

Figure 10 *Influence of capillary conductivity of the insulating plaster on the total condensate and the condensate within the plaster.*

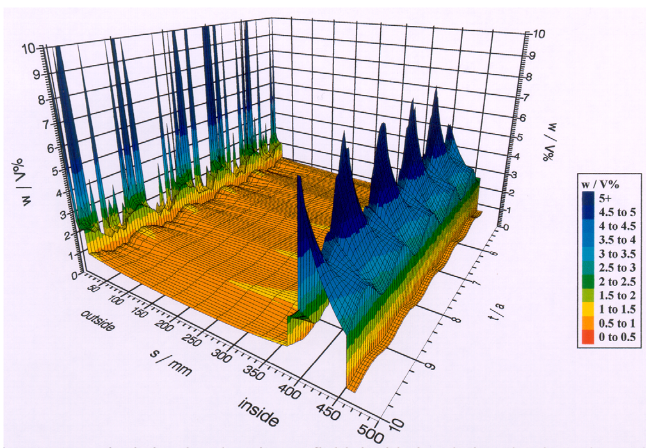

Figure 11 *Numerical simulated moisture field, inside insulation: laminated wooden board.*

hygroscopic moisture of 8 V%. The moisture values do not reach this limit, and condensation does not take place in the case of TRY Essen. But due to the larger hygroscopic moisture content, the U-factor increases from 0.56 $W/m^2 \cdot K$ to 0.63 $W/m^2 \cdot K$ ($\cong$+10%) as the hygroscopicity of the wooden board rises from 5 V% to 8 V%.

Comparison Between Measured and Calculated Results

The measurement equipment in the test house has worked only one winter period. For the structure illustrated in Table 1 and Figure 8, moisture and temperature values have been measured for four years.

Figure 12 shows the street front of the building. The exterior wall of the main front is a two-layer, one-skin brickwork covered with sandstone or clinker. The thickness of the wall toward the street reduces with each story (720 to 400 mm). The main clinker "Gründerzeit" facade, with its rich sandstone decorations, is the signature of the building and is, as such, under the protection of historic preservation. The ground level is dominated by the sandstone rustics. The window framing and breasts of that level lie 120 mm behind the facade. The upper finish of the wall is realized by a sandstone cornice. Beside the facade, the appearance of the building is also determined by the mansard roof, with its vertical dormer windows together with the slate roofing.

Figure 12 *Street front of the building after the reconstruction.*

The modernization includes the thermal retrofitting of the building. The exterior wall to the street—in the ground level brick with sandstone, upper stories brick with clinker—was insulated from the inside with 30-mm-strong fiber-dotted capillary-active calcium silicate boards. The main emphasis of the scientific investigation of the project lies here. Since October 1996, the house has been occupied again. Parallel to the listed work, the building climate measuring technology, with about 60 measurement probes, was installed in 1996.

For the period from December 5, 1996, to August 2, 2000, all exterior and interior climatic measurements (hourly values of air temperature, relative humidity, shortwave radiation, precipitation, wind speed, and wind direction), as well as the thermal and hygric measurements in the main front exterior wall (30 mm calcium silicate insulation, 10 mm or 3 mm adhesive layer, 15 mm interior plaster, 430 mm brickwork, 150 mm sandstone for the ground level, and 90 mm clinker for the upper levels, respectively), have been analyzed (Figure 13). The measuring period includes four winters and summers. Moreover, the hygrothermal behavior of both wall sections has been simulated by means of the physical model and the software DIM using the measured climatic boundary conditions as input of the calculations. The measured and calculated values correspond very well. Figures 14 through 17 show some results for the exterior wall, street side, and first floor.

In the temperature curve at the cold side of the insulation layer (Figure 14), measured and calculated data correspond especially well. The temperature lies without exception above

0°C. The heat flow densities vary between 25 W/m^2 in the winter and –2 W/m^2 in the summer (Figure 15). From that, and with the exterior air temperatures, effective heat transfer values of U = 0.61 W/m^{2}K in the first level result for the heating periods. The U-factor contains the energy gains from the shortwave radiation, but also the losses by the moisture content, the moisture movement, and the phase change in the structure. In the opinion of the authors, this represents an optimum value for building structures with interior insulation.

As Figure 16 shows, the measured and the calculated moisture data agree quite well for the critical section behind the insulation layer. Here, too, it becomes obvious that only in the first winter, the area of over-hygroscopic moisture was reached with φ > 90%.

In Figure 17, the moisture field within the first level for the first time period (December 1996 to August 1998) is demonstrated (inside left hand, outside right hand). The moisture content is always below 3 Vol%. Only in the cold winter of 1996/97, some condensate forms at the cold side of the interior insulation and penetrates capillary in the calcium silicate layer and in the old interior plaster. The peaks at the outside (right hand) result from specific rain events. However, the driving rain stress at the east side is extremely low. The computer code DIM enables the judgement of the hygrothermal behavior of newly built and renovated buildings.

Of course, the different kinds of inside insulation materials have positive and negative properties. The authors prefer calcium silicate because this material can distribute the liquid moisture content in the structures, and, therefore, it accelerates the drying out process. Moreover, it is resistant against mold forming and absolutely nontoxic. Unfortunately, calcium silicate is quite expensive.

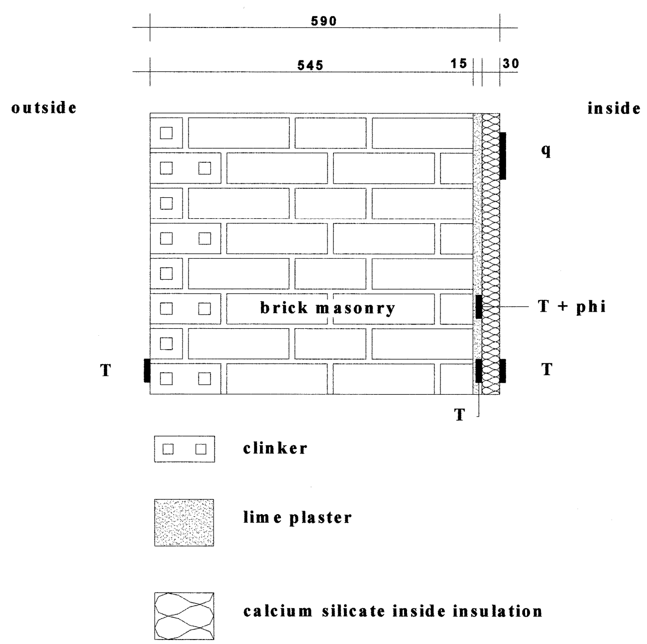

Figure 13 *Outside wall in the first floor with arrangement of the measurement sensors.*

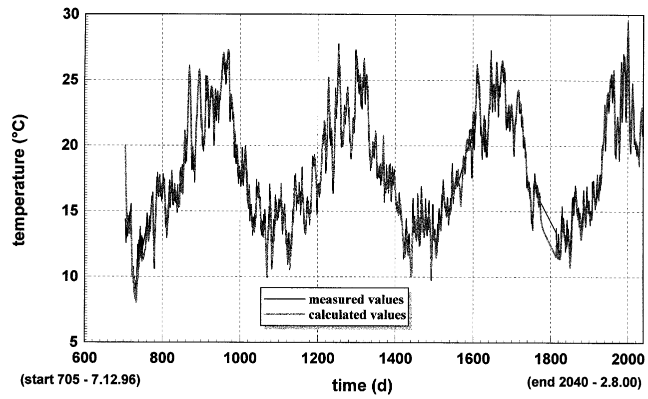

Figure 14 *Comparison of measured and calculated temperature between the inside insulation and the old inside plaster, first floor, December 7, 1996, to August 2, 2000.*

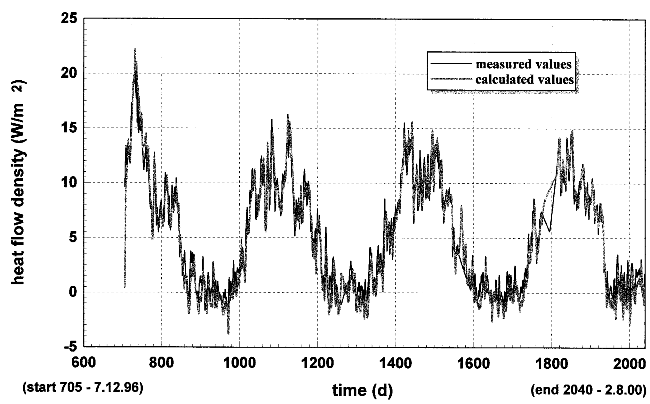

Figure 15 *Comparison of measured and calculated heat flow density from inside into the construction, first floor, December 7, 1996, to August 2, 2000.*

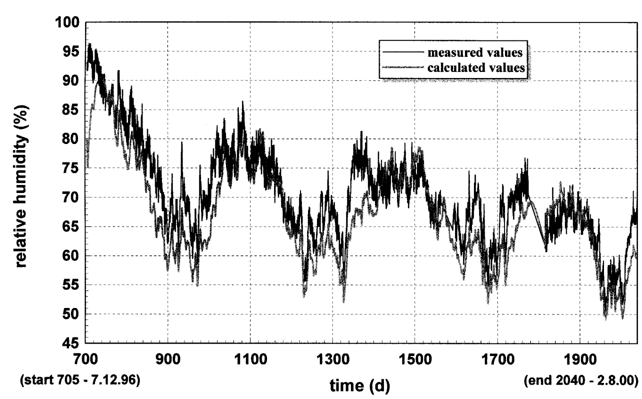

Figure 16 *Comparison of measured and calculated relative humidity between the inside insulation and the old inside plaster, first floor, December 7, 1996, to August 2, 2000.*

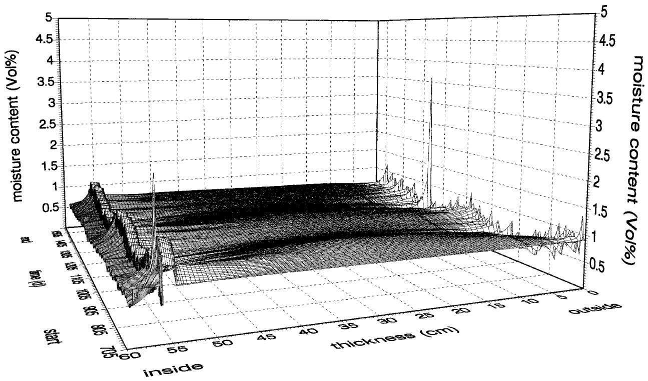

Figure 17 *Moisture distribution in the construction, December 7, 1996, to August 14, 1998, first floor. Construction: (inside) 30 mm calcium silicate—3 mm adhesive—15 mm plaster—455 mm brick—90 mm clinker (outside).*

However, mineral foam (insulating cellular concrete) is relatively cheap. It also has a good vapor diffusivity, but the capillary activity is not as effective. Moreover, mineral foam interior insulation has to be covered with gypsum board because the stability of this material is small.

Wood-fiber insulation material is hygroscopic and, therefore, it is able to store a lot of moisture without condensation phenomena. It is suitable for wooden frame structures, but the danger of mold formation is quite high.

PS foam is well known, cheap, and not difficult to manufacture. However, in the case of moistening, the structure cannot dry out and sensitive materials can be destroyed. PS foam has a very small water vapor and liquid water diffusivity.

Finally, heat insulation plaster enables one to completely cover the inner surface (and problematic areas such as the window jamb, too). From that, a perfect airtightness follows. The authors try to improve the capillary activity and the stability of this plaster in order to expand the application in the practice.

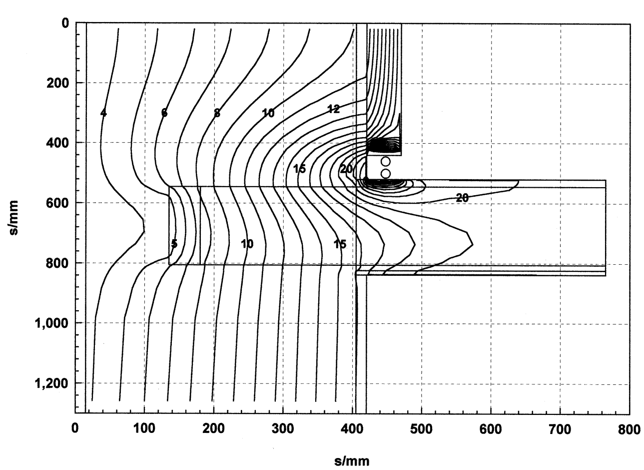

Figure 18 *Isotherms (TRY Essen, January 29), heating operating.*

All materials have to avoid or to reduce the interstitial condensation process in order to guarantee the thermal resistance and the durability of building envelope.

THERMAL BRIDGES OF EXTERNAL WALLS INSIDE INSULATED

Moisture of Wooden Beam Heads

A deficiency of thermal inside insulation is beam heads. Wooden beams are especially dangerous if condensation of water vapor takes place. The idea is to avoid the formation of condensate by a heating channel in the insulation layer at the bottom (Gnoth 1998). A numerical simulation of the coupled heat and moisture transport at this area demonstrates the effect of this measure. Figure 18 represents the isotherms in the case of operating heating. The increase of temperature is about 2º at the beam head during the winter under climatic conditions of TRY Essen in comparison with a completely covered outside wall by the insulation layer of 50 mm calcium silicate, if the air temperature within the channel is 35°C.

In order to be sure, measurements must be carried out. Figure 19 represents installed sensors at the top of inside insulated beam heads.

Figure 20 shows the course of measured wooden moisture depending on time. The light blue colored line represents the result of the original wall structure (brick masonry wall, thickness 0.36 m) without interior thermal insulation and without impact of an additional heating pipe. The moisture values fluctuate by the influence of the outdoor and indoor climates. The red-colored line describes the additionally heated beam area 1 by an operating heating pipe. In spite of an interior thermal insulation, only a small “heating channel” is blocked out near the floor—the moisture of wood runs at a reduced level. Opposite to this, the wooden moisture at the beam end, measured during the same time under the condition of a completely

Figure 19 *Installed sensors at a wooden beam.*

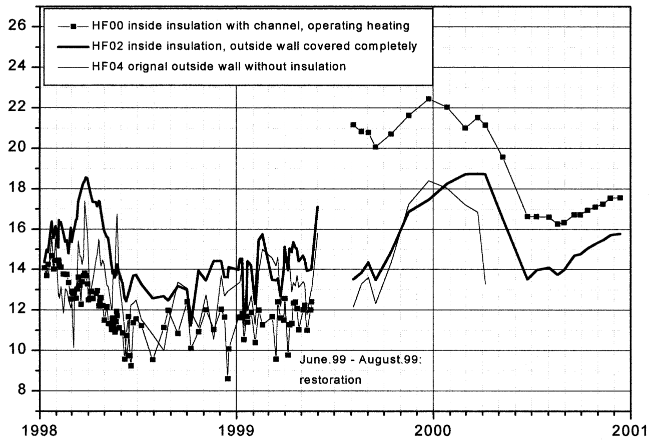

Figure 20 *Course of wooden moisture and temperature at the beam heads.*

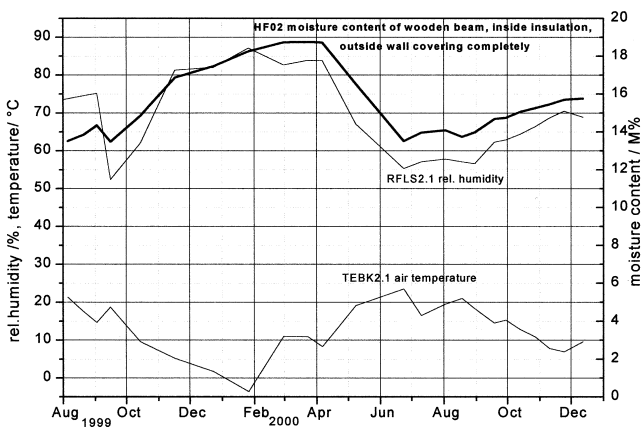

Figure 21 *Relative humidity, air temperature of the air gap around the wooden beam head.*

inside insulation (dark blue, no heating channel), reaches the highest level.

The interruption of the measured values is caused by the total retrofitting of the building from summer 1999 to April 2000. Probably during this time, water due to rain or workmanship came to head area 1. After the building work, both beam heads are subjected to the same indoor and outdoor boundary climatic conditions. Therefore, the measured values of wooden moisture should be at the same level after a sufficient long time.

Figure 21 demonstrates the course of air temperature and relative humidity of the air gap at the top of the beam within the brick masonry wall and the dependence of the wooden moisture on it.

The measurements are still going on. Within the context of a second project of a retrofitted historical building, four wooden beams of two rooms with different inside insulation systems are prepared for concluding investigations. In addition, the influence of penetrating airflow into the air gap around the beam head shall be investigated.

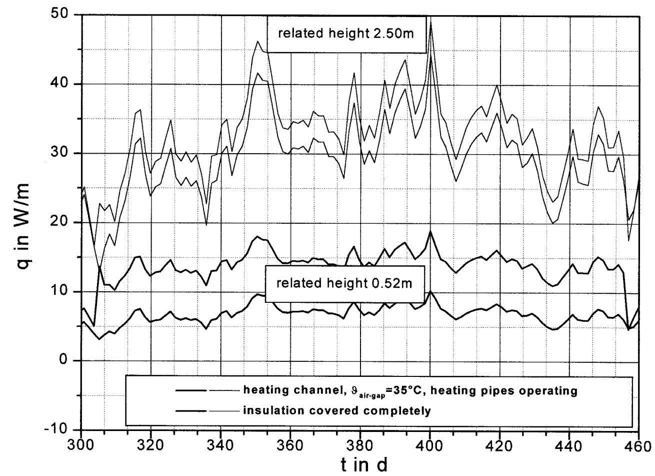

Figure 22 *Heat flow per 1 m width of the wall.*
Var. 1: height of the wall area h = 2.50 m, thin lines.
Var. 2: height of the wall area h = 0.52 m, thick lines

Additional Heat Losses by "Heating Channel"

The blocked out material of the inside insulation at the bottom of the insulating board for the heating pipe causes an increased thermal bridge (Gnoth et al. 2000). The effect depends on the dimensions of the channel and the wall construction. The calculations by means of a two-dimensional simulation represented in Figure 22 are carried out with a height of the heating channel of 80 mm and a thickness of the thermal inside insulation calcium silicate of 50 mm. For this reason, the results show the additional heat losses in case of an infinitely wide wooden beam. Therefore, the embedded infinite ceiling of a wooden "beam head" is replaced by brick masonry material in order to receive the most heat losses by the thermal bridge. The red-colored lines describe the heat flow per width of 1 m in the case of a heating channel with operating heating pipes; the blue one shows the effect of a completely covered inside insulation. In variation 1, the heat flows add up to the total height of the room of 2.5 m; in the second one, the height is only 0.52 m (impact of the thermal bridge). Depending on the related height, the differences are approximately 10% to 50% during the heating period.

Window Area

This area is a very sensitive zone in old buildings and newly built ones too. Due to the improved air-tightness of the new windows, the relative humidity of the rooms increases, and, due to the reduced U-factors of the glass, the condensation takes place at the lintel and jambs of the windows. The situation intensifies by the handling of users to reduce the energy consumption and in the case of newly erected buildings owing to the modern methods.

The use of so-called capillary-active inside insulation with calcium silicate is not recommended if the cold side of the insulation layer is not adjacent to humidity-resistant materials (e.g., the reinforcement or the steel joist of the girder and the wooden blind casing) (Fechner et al. 1999). Sometimes the use of extruded polystyrene is a solution in such a case, but workmanship and enough width of the blind casing are necessary.

An alternative can be an insulating plaster. In all cases, the individual situation is to be considered and a calculation should be carried out. Figures 23 through 25 demonstrate the coupled heat and mass transfer in connection with different plasters at the jamb of a timber window. The climatic boundary conditions are chosen according to the German standard 4108. This means outdoor –10°C/ 80% relative humidity and indoor 20°C/ 50%.

The outside wall is a brick masonry wall, 390 mm thick. The initial situation shall be the usual lime-cement plaster with a thickness of 20 mm. In Figure 23, the 12°C isotherm runs through the edging of plaster/blind casing. The dew point is reached with an air temperature of 20ºC and a relative humidity of 60%.

Due to an insulating plaster of 40 mm, the temperature at the same position decreases to a value of approximately 9°C (Figure 24). This means energy saving and no condensation at the whole interior surface of the jamb except at the edging of jamb/blind casing. In the last area, the situation gets worse with regard to the hygrothermal situation. Figure 25 represents the moisture distribution in the case of 40 mm insulating plaster added as an inside insulation to the jamb area consisting of a homogenous brick masonry (λ = 0.18 W/m.K).

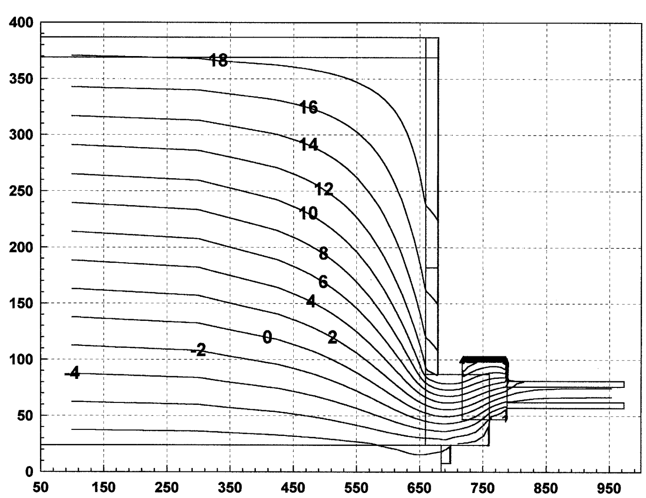

Figure 23 *Isotherms, brick masonry wall, 20 mm lime-cement plaster on the jamb of window.*

CONCLUSION

Because of the positive effects on human behavior, there is a necessity to preserve historical buildings and, above all things, their original facades for the lasting use of such buildings. On the other hand, there are demands for changed room climatic conditions and for energy saving, so we need inside insulation systems. By means of numerical simulation and experimental work, we are able to quantify the hygrothermal performance of external walls insulated on the inside. This means practical work to reduce mistakes in design and workmanship. Moreover, there is knowledge of improved materials (e.g., calcium silicate, insulating plaster, and wooden boards with wanted hygrothermal properties with regard to capillary water transfer function, moisture-dependent water vapor permeability, hygroscopicity) and technologies (e.g., capillary active inside insulation, embedded wooden beam heads aided

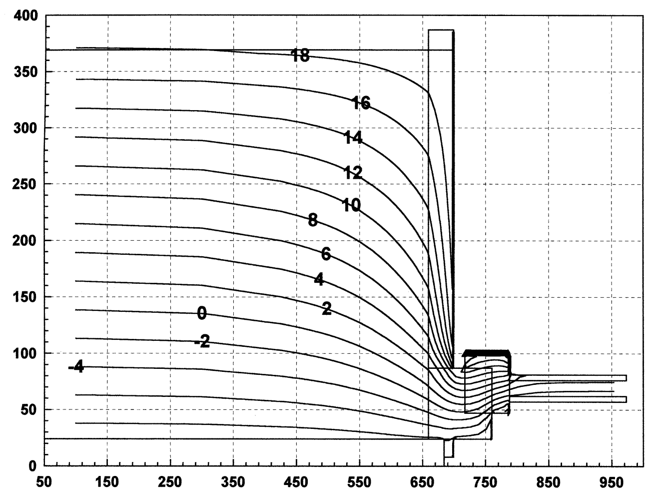

Figure 24 *Isotherms, brick masonry wall, 40 mm insulating plaster at the jamb of window.*

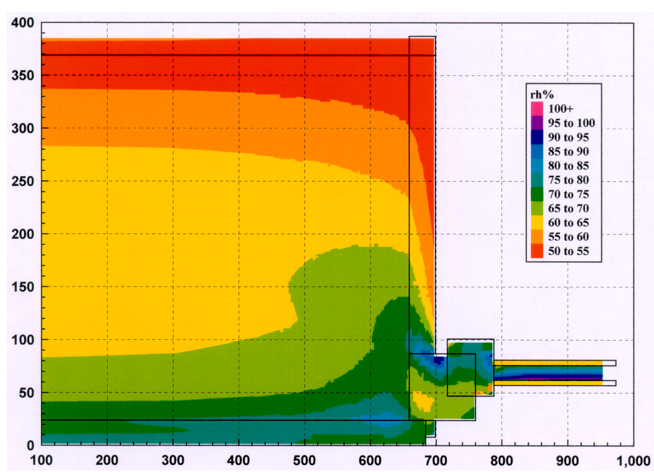

Figure 25 *Isohygrics of the humidity, brick masonry wall, 40 mm insulating plaster at the jamb of window.*

by heating pipes). The validated computer code DIM enables the judgement of the hygrothermic behavior of newly erected and renovated buildings. The expensive measurement program can be reduced.

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