Analysis of Physical Parameters for External Partition Wall Joints Insulated from The Inside

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Abstract. The article introduces material and technological characteristics in insulation of external partitions from the inside. Selected joints of external partition walls were analyzed: corner joint of external walls and wall-window joint in a frame cross-section. The numerical calculations were performed using TRISCO and WUFI software with various isolation thickness and location. Basic physical parameters were defined: linear heat penetration coefficient Ψ, temperature distribution, temperature factor f_Rsi and real pressure distribution of steam and saturated steam, and humidity increase of external walls and their joints for insulation applied from the inside. Based on calculations and analyses performed design recommendation were formulated resulting from application of insulation from the inside, arising from binding requirements for heat and humidity.

1. Introduction

Thermal insulation of external partitions from the inside has been designed for many years for a group of buildings which because of different reasons cannot or should not be insulated from the outside. They are: historical buildings (buildings registered as monuments of history or under conservator’s supervision), buildings of architectural value (interesting elevation character or original view), restricted property rights (in case when a part of external walls is located exactly on a lot border), temporarily used objects (periodical heating in irregular periods). In papers [1, 2, 9, 13] there was described characteristics of insulation materials used in internal insulation, their disadvantages and experiences in design and installation of insulation from internal side.

The sequence of laying for particular layers does not influence the thermal insulation of the entire partition because it results only from the sum of thermal resistance of material used. But opposite to external insulation it requires more detailed analysis of partitions, first of all because of humidity effects (surface and interlayer condensation). That is why a choice of material for inside insulation requires reliable calculations and analyses of physical parameters for external partitions and their joints.

From 1st January 2017 according to [14] the new limit values of heat penetration coefficient U_cmax for external partitions are binding (for external walls U_cmax= 0,23 W/(m²·K)). In order to fulfill the criterion U_c ≤ U_cmax an appropriate thickness of recommended insulation material should be selected. However, internal insulation is associated with steam penetration into partition structure and its condensation. Low environment temperature results in lowering temperature inside a partition causing condensation in contact surface of construction and insulation layers (Fig. 1).
Insulation layer from internal side of a partition separates a wall construction from internal environment which lowers the heat capacity of the entire building and causes entering of whole construction layer into freezing zone. The basic advantage of internal insulation is lowering the heat amount necessary for heating rooms to desired temperature and shortening the heating time [15].

Internal insulation material group includes: lime silicate, mineral boards, resol boards, climatic boards, perlite boards, and wood wool board. Physical parameter values of external partitions and their joints depend mostly on thermal conductivity coefficient $\lambda$ [W/(m·K)], diffusion resistance coefficient $\mu$ [-], diffusive equivalent thickness of air layer $s_d = \mu·d$ [m] of insulation materials. Detailed characteristics of selected insulation materials is introduced in articles [5, 15].

In case of design concept development for internal insulation protecting condensation it is necessary to take into account microclimate conditions inside rooms. Thus it is reasonable to calculate and analyze humidity increase on internally insulated walls with special attention and accounting for changing exploitation conditions. In order to ensure proper exploitation conditions, insulation with a very high diffusion resistance coefficient $\mu$ [-] or additional vapor-tight insulation from internal side should be used. In this way, steam diffusion from rooms into wall construction will be theoretically eliminated. According to DIN 4108-3 standard [3] it is recommended that diffusive equivalent thickness of air layer $s_d$ of insulation or used vapor-tight insulation not to exceed 1500 m. These types of solutions are recommended in case of wall insulation in wet rooms where continuous increased wet conditions persist (i.e. in-door swimming-pools, laundries). Additionally, it is acceptable according to DIN 4108-3 [3], use of materials presenting diffusion resistance for which diffusion equivalent air layer $s_d$ ranges from 0.5m to 1500m. This wide range of $s_d$ ambiguously affects the evaluation of insulation applied. Material which $s_d$ amounts over 0.5 m is a "diffusively open" material, while material with $s_d$ slightly less than 1500 m is defined in practice as "vapor-tight insulation". In such case it is necessary making humidity simulation of the analyzed partition during a full year of its exploitation. The amount of humidity acceptable for this insulation must be at a level which allows for its evaporation in room direction or do not cause accumulation in consecutive years. It is essential to provide complete tightness against uncontrolled air infiltration [7].

2. Calculations of physical parameters for external partitions and joints insulated from the inside

A building is a system of construction partitions and joints of individual physical character and it is influenced by external and internal environment. In many cases an analysis of partitions and joints in construction, material, and technological aspects does not cause reservations at a design stage. However, knowledge of their physical parameters associated with heat and humidity transfer lets avoid numerous corrosion and physical defects. It particularly refers to partitions insulated from the inside.

At the first stage of calculations (in order to find the correct solution of material set which fulfills binding thermal and humidity requirements, detailed calculations (in a few variants) of physical parameters for external partitions and their joints were made i.e.:
- heat flux $\Phi$ [W],
- heat penetration coefficient for full partition $U$ ($U_{1D}$) [W/(m²·K)],
- heat coupling linear coefficient $L^{2D}$ [W/(m·K)],
- heat linear penetration coefficient (defining additional heat losses resulting from linear thermal bridges) \( \Psi \) [W/(m·K)],
- thermal factor for full partition \( f_{Rsi(1D)} \) [-],
- minimum temperature on inside partition surface at thermal bridge \( t_{min} \) [ºC],
- temperature factor defined on minimum temperature on internal partition surface at a thermal bridge location \( f_{Rsi(2D)} \) [-].

The following assumptions were taken for calculation:
- joint modeling was done according to guidelines set by PN-EN ISO 10211:2008 standard [10],
- heat transfer resistances \( (R_{ai}, R_{se}) \) were assumed according PN-EN ISO 6946:2008 standard [11] during heat flux calculations and according PN-EN ISO 13788:2003 standard [12] in calculation of temperature distributions and thermal factor \( f_{Rsi(2D)} \),
- internal air temperature \( t_i = 20 \) ºC (sitting room), external air temperature \( t_e = -20 \) ºC (zone III),
- heat conduction coefficient of construction materials \( \lambda \) [W/(m·K)] was assumed based on the table from [8],
- selected construction joints: external walls corner joint (warming up of two branches – case A) – Fig. 2, external walls corner joint (warming up of one branch – case B) – Fig. 3, external wall contact with a window in frame section (3 cases of window location in a wall - cases C, D, E) – Fig. 4,
- external two-layer wall: full brick 38 cm thick \(-\lambda=0,77 \) W/(m·K), resol board 8cm thick (variant I) and 16 cm (variant II) \(-\lambda=0,022 \) W/(m·K), gypsum plaster 1 cm thick \(-\lambda=0,40 \) W/(m·K),
- window frames \( U_w=0,762 \) [W/(m²·K)].

Detailed calculation procedures for external partitions and their joints parameters are described in [8]. Results of physical parameter calculation are listed in Tables 1 and 2.

**Figure 2.** Analyzed corner of exterior walls insulated from the inside (two branches) – case A

**Figure 3.** Analyzed corner of exterior walls insulated from the inside (one branch) – case B
**Table 1.** Physical parameters for the analyzed corners of external walls insulated from the inside

| Calculation variant | U [W/(m²·K)] | \(f_{Rsi(1D)}\) [-] | \(\Phi\) [W] | \(L^{2D}\) [W/(m·K)] | \(\Psi_i\) [W/(m·K)] | t_{min.} [°C] | \(f_{Rsi(2D)}\) [-] |
|---------------------|--------------|----------------|-------------|----------------|----------------|-------------|----------------|
| IA                  | 0.231        | 0.970          | 19.29       | 0.482          | 0.020          | 15.81       | 0.895          |
| IIA                 | 0.126        | 0.984          | 10.66       | 0.267          | 0.015          | 17.24       | 0.931          |
| IB                  | 0.231/1.452  | 0.970/0.806    | 76.23       | 1.906          | 0.204          | 1.81        | 0.545          |
| IIB                 | 0.126/1.452  | 0.984/0.806    | 71.94       | 1.799          | 0.202          | 2.26        | 0.557          |

Figure 4. Analyzed material systems for external wall-window joint in frame cross-section

**Table 2.** Physical parameters of external wall-window joint insulated from the inside

| Calculation variant | \(U_{es}/U_n\) [W/(m²·K)] | \(f_{Rsi(1D)}\) [-] | \(\Phi\) [W] | \(L^{2D}\) [W/(m·K)] | \(\Psi_{es}\) [W/(m·K)] | \(\Psi_{es}\) [W/(m·K)] | t_{min.} [°C] | \(f_{Rsi(2D)}\) [-] |
|---------------------|-----------------------------|----------------|-------------|----------------|----------------|----------------|-------------|----------------|
| IC                  | 0.231/0.762                 | 0.970          | 35.89       | 0.897          | 0.210          | -0.002        | 0.208       | 3.48           | 0.587          |
| IIC                 | 0.126/0.762                 | 0.984          | 33.71       | 0.843          | 0.230          | -0.002        | 0.228       | 3.16           | 0.579          |
| ID                  | 0.231/0.762                 | 0.970          | 31.86       | 0.797          | 0.137          | -0.016        | 0.121       | 7.63           | 0.691          |
| IID                 | 0.126/0.762                 | 0.984          | 29.40       | 0.735          | 0.148          | -0.012        | 0.136       | 7.44           | 0.686          |
| IE                  | 0.231/0.762                 | 0.970          | 28.30       | 0.708          | 0.047          | -0.006        | 0.041       | 11.58          | 0.790          |
| IIE                 | 0.126/0.762                 | 0.984          | 25.47       | 0.637          | 0.058          | -0.010        | 0.048       | 11.17          | 0.779          |

**Ψ₁** - heat linear penetration coefficient [W/(m·K)]

**Ψ_{es}** - heat linear penetration coefficient (outer wall) [W/(m·K)]

**Ψ₀** - heat linear penetration coefficient (window) [W/(m·K)]

In the second calculation stage the parameters were defined as for presence of interlayer condensation in a partition insulated from the inside. Estimate methods based on the Glaser method and described in PN-EN ISO 13788:2003 standard [12] cause a lot of doubts as for quality of calculation results and their interpretation way (Fig. 5). Simulation methods are based on advanced computer software for thermal and humidity phenomena simulation with changing parameters of internal and external air.
Three basic cases of partitions insulated from the inside were selected:
- brick wall 38 cm thick insulated internally with mineral wool 10 cm thick with vapor-tight insulation (Figure 6),
- brick wall 38 cm thick insulated internally with mineral wool 10 cm with vapor-tight insulation of $s_d=1500$ (Figure 7),
- brick wall 38 cm thick insulated internally with Multipor board (Figure 8).

In Figures 6, 7, 8 the real pressure distribution for steam and saturated steam, and humidity increase is showed. Exemplary calculations for January with WUFI-PRO 5.0 program totally confirm literature recommendation for most cases of internal insulation applications.

| EVALUATION METHODS FOR INTERLAYER CONDENSATION |
|-----------------------------------------------|
| **Advantages:**                               |
| - simple methodology                          |
| - calculations can be done on your own         |
| - small requirements for input data (inside and outside air parameters, and material properties) |
| **Advantages:**                               |
| - non-stationary analysis                     |
| - one hour time step (calculated)             |
| - incorporation of additional factors (rainfall, sun radiation, wind, geographic directions) |
| - precise projection of material properties    |
| - analysis possible for period over ten years  |

| **Disadvantages:**                            |
| - only estimation of a partition behavior     |
| - analysis concerns a short period of usage   |
| - analysis does not include a lot of physical phenomena occurring in the partition |
| - humidity classification based on data from Western Europe |
| **Disadvantages:**                            |
| - complicated calculation process            |
| - requires necessary input data              |
| - lack of experienced designers              |
| - databases of climates and materials for countries where they were prepared |

| **Results:**                                  |
| - partition quality evaluation                |
| - monthly humidity distribution during 1 year |
| **Results:**                                  |
| - partition humidity distribution in long calculation period |
| - condensation steam amount inside partition in one calculation year |
| - risk of mildew development on internal surface |
| - ventilation system performance evaluation (as for steam condensation) |

Figure 5. Methods of interlayer condensation evaluation – own work based on [4]

Figure 6. Brick wall insulated internally: a) real pressure distribution of steam and saturated steam in a partition, b) humidity increase [4]
3. Analysis of physical parameters for external partitions and their joints insulated from the inside

Additional heat loss values resulting from a thermal bridge (external wall corner insulated from the inside) depend on type and thickness of insulating material. Attention must be paid that insulation from the inside for one single branch of a corner causes significantly higher additional heat losses ($\Phi$, $L_{2D}$, $\Psi_i$) and lowering the temperature on the inside surface of a partition ($t_{min}$, $f_{R((2D))}$) – Tables 1 and 2. Such a solution causes risk for condensation on the inside surface of a partition (development of mildew and fungi), interlayer condensation and increased energy amount necessary for heating up rooms to desired temperature.

Fulfillment the criterion for risk of surface condensation avoidance (mildew and fungi development): $f_{R((2D))} \geq f_{R((kryt.))}$, requires to define the value of $f_{R((2D))}$ based on minimum temperature on the partition surface at the thermal bridge (2D) $t_{min}$ [$^\circ$C] and $f_{R((kryt.))}$ value which takes into account internal and external air temperatures (air humidity and temperature). According to PN-EN ISO 13788:2003 standard [12] heat factor $f_{R((kryt.))}$ is calculated or assumed depending on a ventilation type used in a building (gravitational ventilation – dominant in housing buildings or mechanical ventilation being often a component of air conditioning systems allowing in almost discretionary way shaping interior microclimate properties). Table 3 lists calculation results of limit value for temperature factor $f_{R((kryt.))}$ defined by various methods.

Figure 7. Brick wall insulated internally with vapor-tight insulation of $s_d=1500$ m: a) real pressure distribution of steam and saturated steam in a partition, b) humidity increase [4]

Figure 8. Brick wall insulated internally with Multipor board: a) real pressure distribution of steam and saturated steam in a partition, b) humidity increase [4]
Using the Glaser method it is possible to define the risk of interlayer condensation. In all discussed cases condensation will occur (graph lines intersect) which means that amount of condensate in partitions will increase (Fig. 6, 7, 8). Such a situation often takes place in subsequent winter months. Systems with vapor-tight insulation from the inside work best in buildings with high humidity. Because the systems with vapor-tight insulation prevent steam diffusion, buildings with such insulation must have efficient ventilation installation.

The factor which can significantly interfere the results in the assumed calculation method is a humidity condition of a partition before insulation. So it should be defined precisely before the calculation starts. The second factor influencing correctness of the result is assumed (expected) way of room usage by the user. This factor should be treated as a basic determinant of partition humidity during exploitation.

Table 3. Critical value of temperature factor $f_{Rsi(kryt.)}$ for three methods of room ventilation, [6]

| Method | Month | $\theta_e$ [ºC] | $\phi_e$ [%] | $\rho_e$ [Pa] | $\Delta p$ [Pa] | $\phi_i$ [%] | $\theta_i$ [ºC] | $\theta_{kr}$ [ºC] | $f_{Rsi}$ [-] |
|--------|-------|-----------------|---------------|----------------|----------------|--------------|----------------|----------------|--------------|
| A I    | -3.0  | 55              | 20            | 14.1           | 0.743          |              |                |                |              |
| A II   | -1.6  | 55              | 20            | 14.1           | 0.726          |              |                |                |              |
| B XII  | -0.5  | 89              | 522           | 810            | 16             | 14.6         | 0.886          |                |              |
| B I    | -3.0  | 87              | 414           | 810            | 16             | 13.3         | 0.858          |                |              |
| B II   | -1.6  | 85              | 454           | 810            | 16             | 13.8         | 0.875          |                |              |
| C I    | -4.8  | 50              | 24            | 16.4           | 0.736          |              |                |                | 0.72*)       |

- method: A (constant inside humidity – air conditioning), B (inside humidity changing in function of room humidity class – gravitational ventilation), C (internal room temperature $t_i$ ≥20ºC and humidity $\phi_i$=50% defined according [14] – gravitational ventilation)
- building location (methods A and B – Kraków, method C – Bialystok)
- room humidity class 4 (method B) *) limit value defined according to regulation [14]

4. Summary and conclusions

Internal insulation is a commonly used action in thermal modernization of existing buildings in order to achieve binding and changing requirements about heat and humidity. Material solutions for building's partition insulation from the internal side depend on the following factors: room exploitation, type of wall construction material, insulation material used, and mounting technology for additional insulation. It is not allowed to design such insulation based on approximate calculation, e.g. concerning only a flat partition, setting a heat permeation factor $U$ ($U_{ID}$) and temperature factor $f_{Rsi(ID)}$ – Tables 1 and 2. It is reasonable to do calculations of physical parameters for external partitions joints ($\Psi$ [W/(m·K)], $t_{min}$[ºC]), $f_{Rsi(2D)}$ [-]) – Tables 1 and 2 and computer simulation concerning a partition humidity condition analysis during a set exploitation period – Figures 6, 7, 8.

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