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# Influence of environment factors on humidity conditions of selected external wall solutions in a heated building

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**Abstract.** Contemporary single-family houses in Poland are often built during 3 quarters of a year (spring to autumn) are usually settled in a winter season. It is a special case when exploitation humidity coincides with technological one, causing unfavourable humidity conditions during the first years of exploitation. In consequence, thermal parameters of partitions differ from those assumed in the project. In construction stage the humidity state of a wall stabilizes as a result of water: associated with storage, entered technologically during wall construction and plastering, coming from rainfall. Thermo-insulation materials are built-in at dry state. During erection and exploitation of a building their thermal conductivity is changing depending on humidity conditions. According to building rules, construction humidity should be removed from a partition before the building transfer to usage, because it lowers the thermal partition insulation ability and increases air humidity of building interior. Walls are plastered and insulated in condition of simultaneous presence of atmospheric and technological humidity which cause special humidity condition during first years of exploitation. As a consequence, heating costs are substantially higher. In this article the results of simulation are shown performed with WUFI ®PRO 5 software, which was intended to define the time necessary for reaching the stabilised humidity in selected solutions of two-layer walls applied in a heated building. In the research performed, the partition orientation along geographic directions, short and long wave radiation, and environment humidity (air humidity, driving rain) coincidence with technological humidity in assumed wall solutions were taken into account.

## 1. Introduction

Contemporary single-family housing construction in Poland bases mainly on traditional technologies characterizing with significant humidity introduced into construction interior during construction process. During construction phase the humidity level of walls is defined as a result of:

- water associated with production and storing of materials,
- technological water introduced during wall bricklaying and plastering,
- water from external environment.

According to construction art this humidity should be removed from partitions of a room until the building is received for usage, because it lowers the insulation power of partitions and increases air humidity in the interior of the building. However, in practice there is no time for drying of the building – the full construction cycle is close to 3 quarters of a year (from spring to autumn). During this period the walls are sprayed with rainfall – in Polish climate conditions dry periods are very short and spring as well as summer are characterized with high rainfall level. The analysis of monthly rainfall for Bydgoszcz in selected consecutive years shows that the highest rainfall occurred in July and August of each year Figure 1.

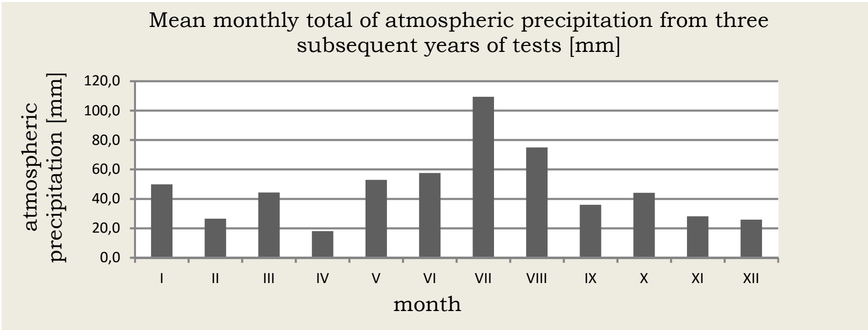


Figure 1. Total monthly rainfall for Bydgoszcz

In state of coincidence of atmospheric and technological humidity walls are insulated and plastered. Settlement usually happens in winter season. It must be remembered that in such case exploitation humidity coincide with technological one causing specific humidity conditions over initial years of usage. Insulating materials are built in as dry. During erection and exploitation of a building their thermal conductivity changes according to humidity state (Figure 2).

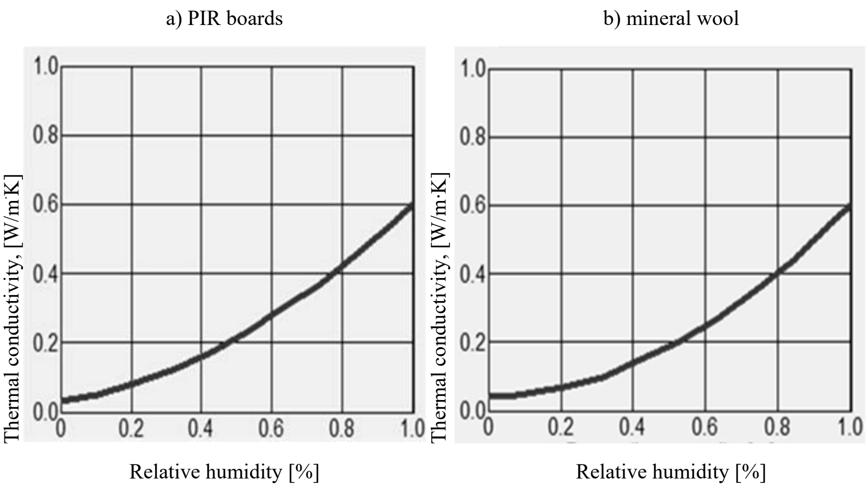


Figure 2. Thermal conductivity thermo-insulation materials depending on humidity level according to WUFI®PRO 5

The aim of this work is a simulation analysis by WUFI PRO 5 program to evaluate necessary period to reach stabilized humidity in selected solutions of two-layer walls in a heated building. In the tests the influence of partition direction according to geographic directions, short and long wave radiation, and environment al and technological humidity interaction were taken into account.

## 2. Research subject and methods

The thermal-humidity analysis of walls was performed using WUFI® PRO 5 program. The base for calculation are two partial differential equations describing heat and humidity transport in building materials [1]:

a) Equation describing the heat transfer

$$\frac{\partial H}{\partial \vartheta}\frac{\partial \vartheta}{\partial t} = \frac{\partial}{\partial x}(\lambda \frac{\partial \vartheta}{\partial x}) + h_v \frac{\partial}{\partial x}(\frac{\partial}{\mu}\frac{\partial p}{\partial x}) \quad (1)$$

where:
H – enthalpy of moist building material [J/m$^3$],
ϑ – temperature [$^o$C],
λ – thermal conductivity of humid material [W/(m·K)],
hw – evaporation enthalpy of water [J/kg],
δ – water vapour diffusion coefficient in air [kg/(m·s·Pa)],
μ – vapour diffusion resistance factor of dry material,
p – watervapor partial pressure [Pa]

b) Equation describing the humidity transfer

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

where:
ρw – density of water [kg/m$^3$],
u – water content [m$^3$/m$^3$],
φ – relative humidity,
DW – liquid transport coefficient [m$^2$/s].

In the wall it was modelled overlapping of environmental (air humidity, driving rain) and technological humidity. Rain absorption rate was assumed according to designed partition tilt and type amounting to 0.7. The yearly rainfall for this weather data was 493.1mm, and maximum hourly rainfall - 7 mm/h, rainfall time - 760 h [2].
The partitions under tests were charged with external climate characteristic for a Typical Meteorological Year for Warsaw. The calculations were done for wall fragments located on east, north, west, and south elevations. In all analyzed models absorption of short-wave 0,4 and long-wave radiations 0,9 were taken into account. In the tests two classes of room internal humidity were assumed [3]:
- class 3 (relating to aware usage of rooms with necessity of intensive ventilation and heating),
- class 4 (relating to usage of rooms with insufficient ventilation).

Two solutions of external two-layer walls were analyzed (Fig. 2):
- ceramic airbrick 25cm, mineral wool 18cm,
- ceramic airbrick 25cm, PIR board 12cm.

Properties of component materials of the analyzed partitions are listed in Table 1.

**Table 1.** Thermal and humidity properties of component materials of external walls.

| Item | Material | Volume density | Porosity | Specific heat | Thermal conductivity |
|---|---|---|---|---|---|
| - | - | [kg/m$^3$] | [m$^3$/m$^3$] | [J/kg·K] | [W/m·K] |
| 1 | Mineral plaster | 1900 | 0.24 | 850 | 0.8 |
| 2 | PIR board 12cm | 40 | 0.95 | 1400 | 0.029 |
| 3 | Mineral wool 18cm | 120 | 0.95 | 850 | 0.04 |
| 4 | Ceramic airbrick 25cm | 800 | 0.6 | 850 | 0.18 |
| 5 | Internal cement-lime plaster 1.5cm | 1900 | 0.24 | 850 | 0.67 |

The analyzed solutions fulfil requirements for thermal protection of heated buildings in Poland projected for 2021. The limit value of heat permeation value U is less than 0.20 W/(m$^2$·K). The simulation will include consecutive 6 years of exploitation.

## 3. Results and discussions

In the work there were analyzed 16 variants of external two-layer walls, functioning in two humidity classes of room internal humidity. The partitions were oriented along the north, south, east and west directions. The results obtained from the simulation are listed in Table 2 and 3 and in Figure 3 and 4. For all variants constant humidity of external mineral plaster was assumed as 45kg/m$^3$.

**Table 2.**Total humidity content in external two-layer wall insulated with PIRboard during 6 years of exploitation.

| Wall part orientation | Class 3 of internal humidity | | | | Class 4 of internal humidity | | | |
|---|---|---|---|---|---|---|---|---|
| | Humidity content [kg/m$^3$] | | | | Humidity content [kg/m$^3$] | | | |
| | start | end | min. | max | start | end | min. | max |
| North | 4.59 | 2.72 | 2.27 | 4.60 | 4.59 | 3.08 | 2.73 | 4.65 |
| South | 1.99 | 1.90 | 1.62 | 1.99 | 2.33 | 2.29 | 1.08 | 2.33 |
| East | 2.46 | 1.97 | 1.65 | 2.46 | 2.52 | 2.04 | 1.72 | 2.54 |
| West | 2.57 | 1.98 | 1.63 | 2.59 | 2.56 | 2.05 | 1.71 | 2.69 |

**Table 3.** Total humidity content in external two-layer wall insulated with mineral wool during 6 years of exploitation.

| Wall part orientation | Class 3 of internal humidity | | | | Class 4 of internal humidity | | | |
|---|---|---|---|---|---|---|---|---|
| | Humidity content [kg/m$^3$] | | | | Humidity content [kg/m$^3$] | | | |
| | start | end | min. | max | start | end | min. | max |
| North | 4.70 | 2.68 | 1.88 | 4.74 | 4.70 | 2.82 | 2.13 | 4.79 |
| South | 2.48 | 1.81 | 1.49 | 2.61 | 2.47 | 1.97 | 1.67 | 2.68 |
| East | 2.54 | 1.97 | 1.62 | 2.57 | 2.59 | 2.04 | 1.69 | 2.59 |
| West | 2.58 | 1.98 | 1.62 | 2.75 | 2.61 | 2.05 | 1.67 | 2.78 |

While comparing the results in Table 2,3 it can be noticed that differences between room internal humidity classes 3 and 4 are rather small. The type of material used also did not influence the total value of humidity content in the partition.The most unfavorable was the north orientation of the partition both for mineral wool insulation, as well as with PIR boards. Similar tendencies persist in the west orientation.The results were significantly influenced by limited sunlight from northern and western directions. Additionally it is associated with dominant west circulation in Poland which results in driving rain. The humidity results obtained in the partitions under tests did not exceed acceptable values [4].
The analysis of Figure 3 and 4 proves that both the type of insulating material, assumed room internal humidity class and influence of environment factors significantly affect the time to achieve the stabilized humidity levelling partitions. It is noticed that both for 3 and 4 class the drying period for walls insulated with PIR boards is on average one year longer. Humidity of a wall insulated with mineral wool stabilizes after about 2 years independently of internal humidity conditions. Thermal insulation with PIR boards is characterized with tendency of rising humidity in the initial two years and then it goes down. The humidity of mineral wool reaches its maximum value within the first year of exploitation and then it decreases to stabilized humidity. During the first period

with extended humidity of built-in materials their thermal conductivity is also higher, which undoubtedly influences increase of real heat permeation coefficient U assumed in the project.

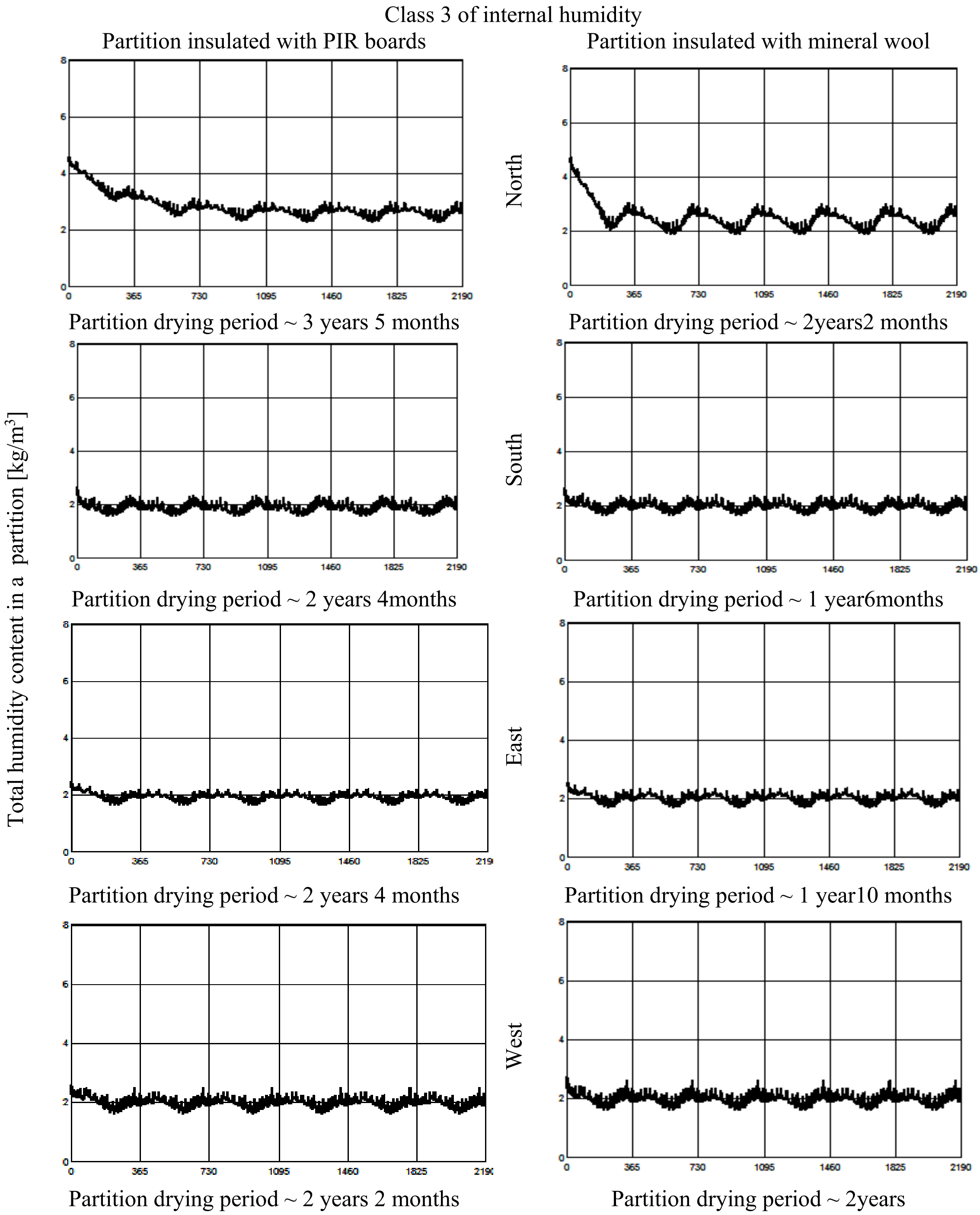


Figure 3. Drying period of a two-layer external partition of room internal humidity class 3.

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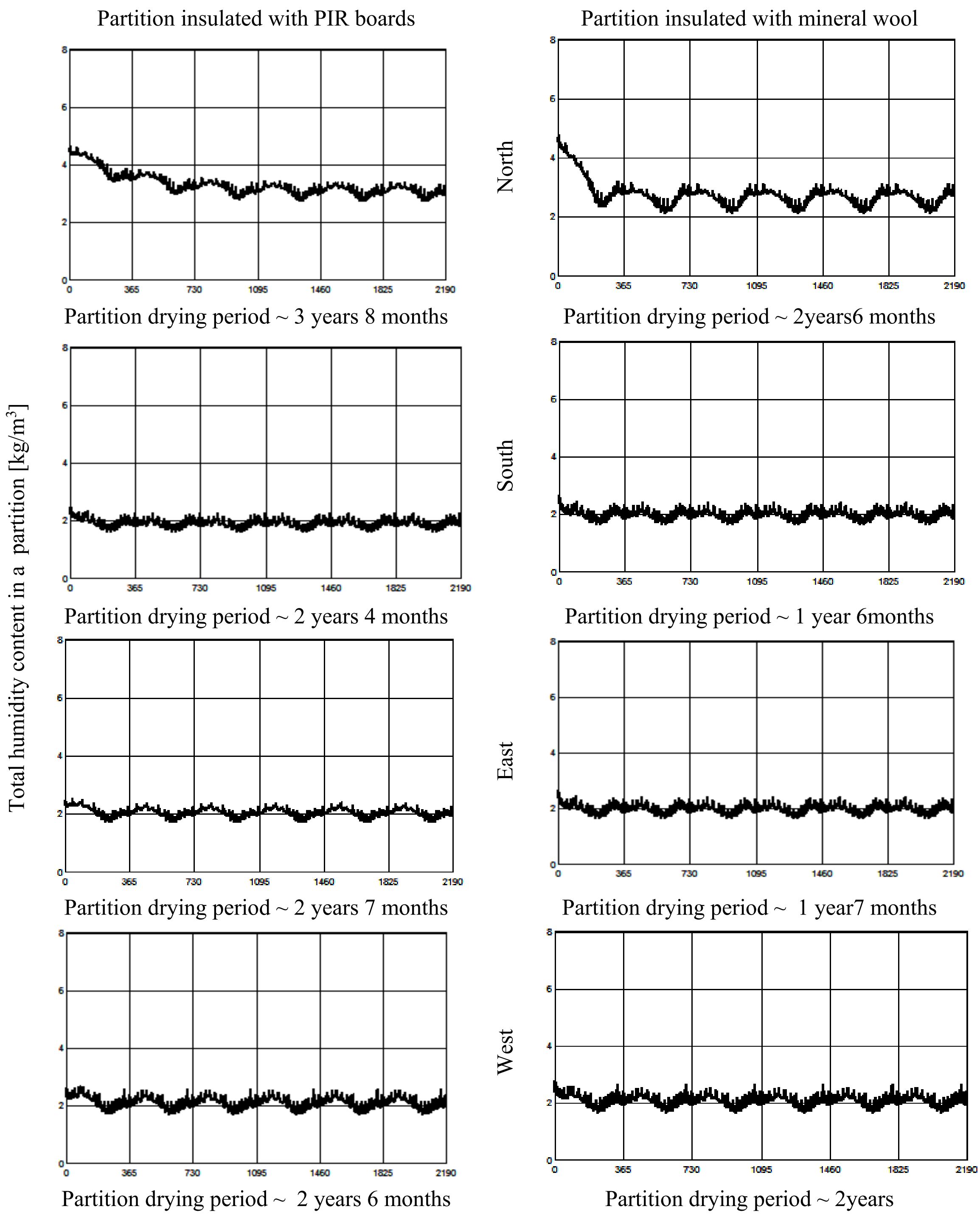


Figure 4. Drying period of a two-layer external partition of room internal humidity class 4.

## 4. Conclusions

As the above analysis implies the shortened period of building in Poland (overlaid environmental and technological humidity) in significant way affects the time necessary to reach the stabilized humidity level in a partition. Both the material used, as well as internal and environmental conditions can extend this process. Mineral wool is characterized with diffusion resistance factor$\mu$=1, while PIR boards with $\mu$=50. Thus mineral wool does not block humidity flow in

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outsider direction while PIR boards create a barrier for its free movement, and drying occurs in direction to the inside of a building [5]. The obtained results in significant way influence the heat demand especially in the heating period. This situation results in increasing of real exploitation costs with estimated 40% during the first year of exploitation with a PIR board insulated wall and about 25% with mineral wool insulated walls. These results are confirmed by real exploitation costs for single-family housing buildings in Poland [6].

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