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A Detailed Investigation of Humidity Effects on the Buildings: A Case Study

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Abstract

In this paper, a residential non-insulated building located in Switzerland-Zurich is investigated. The reason of choosing this building was mold growth in summer-time. The initial humidity measurements and infrared thermography showed that moisture was high in this building and it could be the reason of the mold formation. It was observed that mold had grown more in the places that were the structural intersections, since thermal bridge can occur in these locations. Hence, the building was insulated by using HP-K Pro insulation material. This material had lower operating cost in comparison with other insulation materials, and it was more effective. For more investigations and validations, this building was also evaluated by COMSOL software. By comparing the results for insulated and non-insulated buildings, it was observed that the HP-K Pro insulation material was effective, and it could decrease the moisture by half. Moreover, liquid or capillary flow did not occur across the insulated walls. The temperature of the walls was increased so that lower energy was required for heating. The calculations showed that insulation could reduce the risk of mold formation significantly. The results are confirmed by the experimental observations for mold growth in cold weather. In conclusion, HP-K pro could provide healthy and improved indoor air quality, and decreased the energy consumption by 20%.

Keywords: zero-energy, moisture, heat transfer, mold, climate change, co2 emission, insulation, health

1 Introduction

In modern world, excessive energy consumption has caused many environmental issues, such as greenhouse gas (GHG) emissions and global warming. It has been reported that about 40% of the energy consumption and 30% of CO2 emissions are related to building sector [1]. Therefore, the EU (European Union) has established policies to achieve 50% of reduction in total energy usage by 2050. According to the new building policies, energy-efficient buildings must be constructed in a way that they can cover their own demands in each season.

Most of the existing buildings are not properly insulated and they are influenced by the presence of thermal bridges, which can lead to indoor air problems like moisture problems and mold growth. Molds are kind of fungi and they can grow fast in suitable moisture and temperature conditions [2,3,4,5]. In Finland, most of the air problems in buildings are corresponded to moisture and structural mold damage, which can endanger the health of the users [6,7]. In a study [8], 25 Finnish public buildings were chosen to carry out moisture performance assessments on them, since all of the users of these buildings had health symptoms. For this purpose, the structures of these buildings were assumed as 6 groups: roofing decks, external walls, intermediate floors, partition walls, walls in soil contact, and base floors. The results showed that base floors were the structures that had damaged the most (57%). The distribution of damage for each structure was very different between the buildings. It was concluded that the extensive mold and moisture damage distributed between several structures can be the reason of the indoor air problems.

In addition to the above-mentioned moisture problems, moisture can increase the energy-consumption and heating cost, since more energy is needed to warm up the moist air. In order to stop the harmful effects of moisture, it is important to recognize and fix the sources of the moisture problems. For this purpose, a residential masonry building in Switzerland [9, 10] is studied as a real case-study in current paper. This building was not insulated, and it was exposed to indoor mold. In order to prevent moisture penetration, a new insulation material, “HP-K Pro”, was injected into parts of the walls that had moisture problems. Then, the coupled heat and moisture transfer equation is calculated numerically. At the end, the results of the numerical and experimental studies are compared to validate the experimental investigations.

2 Methods

In this section, a residential building in Switzerland (Figure 1) is studied to detect its moisture problems, since it was exposed to mold growth. This building is masonry, and non-insulated. The first signs of mold were detected in summer in the intersection of the inner wall and horizontal slab (Figure 2). In order to detect and characterize the structural damages, an outer heating source was utilized to create different temperatures between the damaged and non-damaged areas. Then, infrared thermography procedures were used to detect the heat transfer of different areas (Figure 3).

As shown in Figure 4, for initial evaluation, the relative humidity was measured by using Hygrometer device.

After identifying the moisture problem, it can be fixed with suitable insulation system which is selected according to the careful analysis. In this study, high purity paraffin oil, HP-K Pro, is used as a new material for insulation. It was injected into the distinguished problem areas of the walls through 14-mm diameter holes at every 25 cm (Figure 5) to stop the moisture penetration horizontally and vertically.

Figure 1: The case study building located in Switzerland, Zurich [9,10].

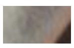

Figure 2: Mold growth in a residential masonry building located in Switzerland.

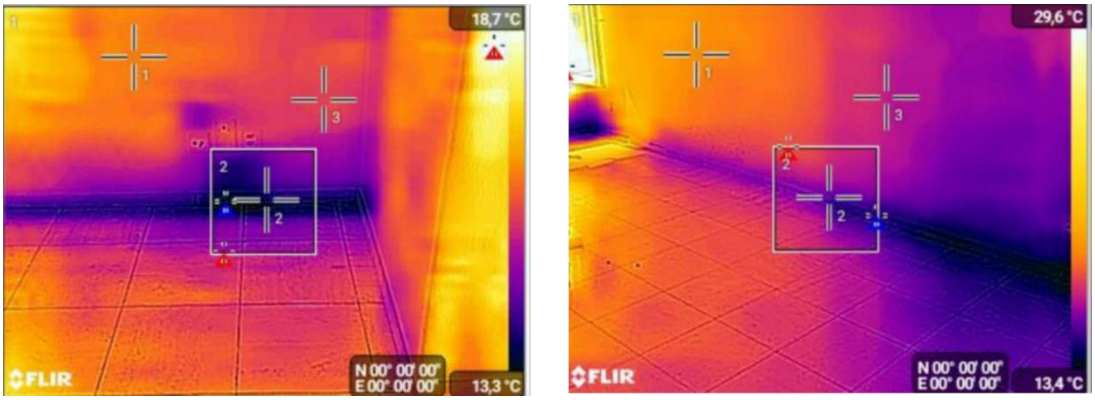

Figure 3: Infrared thermography

Figure 4: Hygrometer device

Figure 5: HP-K Pro injection into the walls

To validate the experimental studies, COMSOL software was used to estimate the correlation between heat and moisture transfer of the walls with exterior temperature. COMSOL software is based on finite element methods, and it solves the Heat and moisture equations simultaneously [11,12]. It was essential to study the building's moisture performance for the cold weather too. However, it would be high-priced and time-consuming to do experimental tests. Hence, two numerical models were also evaluated using COMSOL software for cold weather. One of these models (Study-A) was insulated, and another was non-insulated (Study-B). For all the models, thickness of the masonry walls was 0.2 meter, and time step was assumed as 1 day. Structural intersections are the most critical places for mold growth, since thermal bridge can occur in these locations. The mold growth and condensation risk can be calculated by using temperature factor, equation (1) [13]. This factor must be more than 0.7. Otherwise, it shows that the risk of mold formation is high.

$$f_{Rsi} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e} \quad (1)$$

In this equation, $\theta_{si}[°C]$ is inside surface temperature, θ_e $[°C]$ is outside air temperature, and θ_i $[°C]$ is indoor air temperature.

3 Results

Thermal conduction can cause water to evaporate and condense. Latent heat can result in changes in the moisture content by phase change. Figure 6 shows the results of COMSOL analysis for the non-insulated wall of the case study in Switzerland in summertime. It can be seen that water vapor flows inside the porous material because of capillary pressure gradient and gas pressure gradient. As mentioned in previous section, this model was studied experimentally too. Hence, it was validated with experimental thermal imaging and moisture measurements.

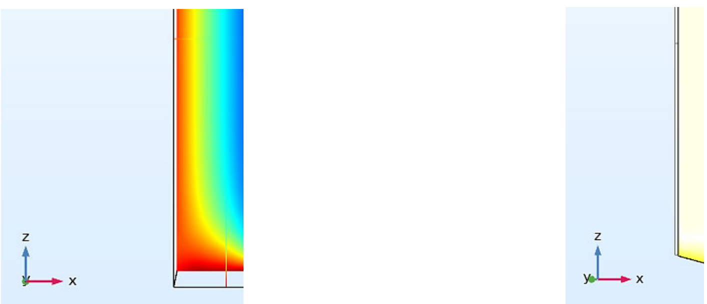

Figure 6: The coupled heat and moisture transfer of the case study
(Summer time- without moisture insulation)

Figure 7: The coupled heat and moisture transfer of the case study
(Winter- without moisture insulation)

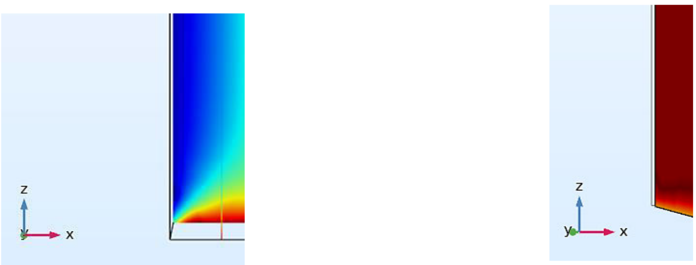

Figure 8: The coupled heat and moisture transfer of the case.
(Winter- with moisture insulation)

Figures 7 and 8 show the results of COMSOL analysis for the non-insulated and insulated walls in winter. By comparing these figures, it can be concluded that HP-K Pro-Paraffin has reduced the amount of moisture by half, and no liquid or capillary flow can occur across this moisture-barrier insulation.

The suitable temperature and moisture conditions for mold growth are presented in figure 9, which is deviated from DIN 4701 [14]. According to this code, moisture insulation can prevent the formation of mold by not allowing the suitable temperature and moisture to be supplied.

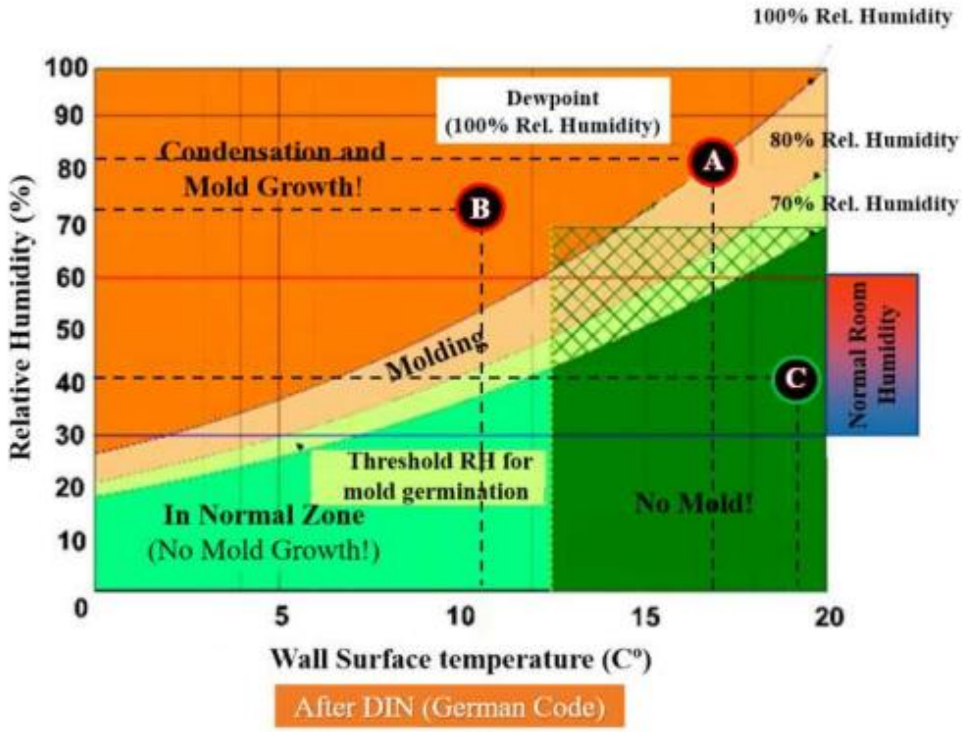

Figure 9: mold growth possibility [14]
(A) Summer-Without Moisture Insulation (Molding Problem)
(B) Winter-Without Moisture Insulation (Molding Problem)
(C) Winter-With Moisture Insulation (No mold)

The risk of mold growth before and after moisture insulation was calculated by using Eq.1 [14] as follows:

- Winter-Without moisture insulation

$$f_{Rsi} = \frac{\theta_{si}-\theta_e}{\theta_i-\theta_e} = \frac{11℃ - 10℃}{22℃ - 10℃} = 0.083 < 0.7 \quad \text{(Mold growth risk is high)}$$

- Winter-With moisture insulation

$$f_{Rsi} = \frac{\theta_{si}-\theta_e}{\theta_i-\theta_e} = \frac{19℃ - 10℃}{22℃ - 10℃} = 0.75 < 0.7 \quad \text{(No Mold)}$$

These results indicate that no mold can form after insulation and they are in agreement with DIN 4701 and the detected mold formation in winter in experimental studies. Four months after moisture insulation, in winter, the building's humidity was measured again. The measurements showed that the humidity had decreased (38%) significantly, and the temperature of the walls' surface had increased. However, on some days that the humidity was higher, the amount of indoor water vapor was different. Figure 10 shows the mean percent of relative humidity of the exterior walls for different dates.

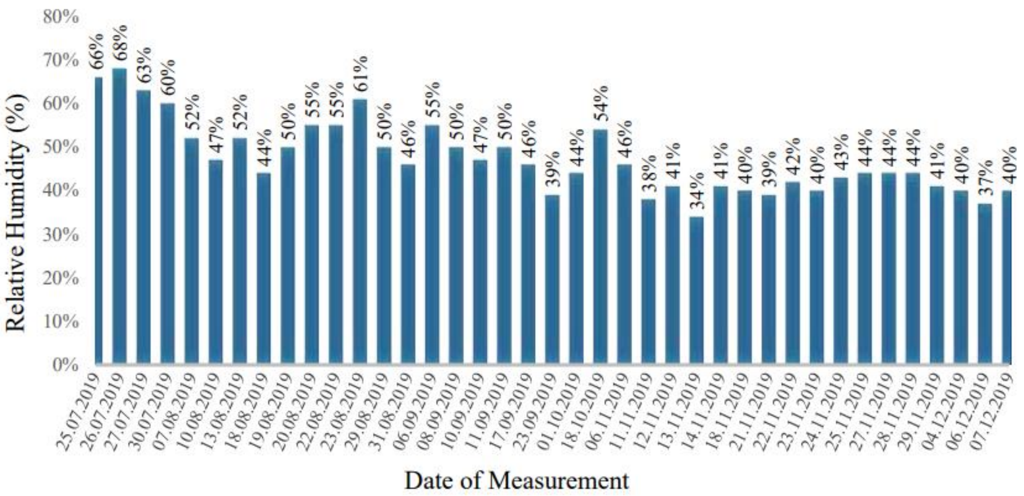

Figure 10: Relative humidity for different dates of the year after moisture-insulation

4 Conclusions and Contributions

It is important to insulate buildings against moisture to enhance comfort and decrease energy consumption. Providing enough warm air for increasing the wet walls' temperature is hard, and it requires more energy and higher heating costs. Careful analysis must be conducted to select a suitable and reasonable insulation systems. For this purpose, initials costs and available budget should be estimated. By considering these factors as well as climate and personal preferences, the most effective insulation system can be selected. Therefore, an effectively- insulated building is both energy-efficient and cost-efficient. In addition, moisture-barrier insulation can improve the users' health condition, since it has been proven that moisture and mold growth can endanger the people's health. According to these reasons, it is very important to construct a well-sealed and moisture-insulated buildings.

In this paper, a residential non-insulated building located in Switzerland-Zurich is investigated. The reason of choosing this building was mold growth in summer-time. The initial humidity measurements and infrared thermography showed that moisture was high in this building and it could be the reason of the mold formation. It was observed that mold had grown more in the places that were the structural intersections, since thermal bridge can occur in these locations. Hence, the building was insulated by using HP-K Pro insulation material. This material had lower operating cost in comparison with other insulation materials, and it was more effective. For more investigations and validations, this building was also evaluated by COMSOL software. By comparing the results for insulated and non-insulated buildings, it was observed that the HP-K Pro insulation material was effective, and it could decrease the moisture by half. Moreover, liquid or capillary flow did not occur across the insulated walls. The temperature of the walls was increased so that lower energy was required for heating. The calculations showed that insulation could reduce the risk of mold formation significantly. The results are confirmed by the experimental observations for mold growth in cold weather. In conclusion, HP-K pro could provide healthy and improved indoor air quality, and decreased the energy consumption by 20%.

There are many old buildings in Switzerland that are constructed according to Swiss code [13], and they have significant thermal bridges. As mentioned before, thermal bridges are the reason of mold formation. Therefore, these buildings should be renovated to remove thermal bridges. The proposed method can be used as an alternative method [15-17] for the required renovations.

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