Thermal Design Code for Civil Building (GB 50176-93). The boundary conditions and the initial values of each layer were assigned according to the measured values.

The simulation results of the three-year period (Figure 6) shows that the inside of each wall will achieve a moisture balance with the external environment after three years, and will have low overall moisture content. The nine-year period simulation confirmed that the moisture content will remain stable after three years. In fact, the buildings with Type RPPPs and Type GHBIM had been in service for almost 8 years. The unstable moisture content was caused by the structural defects. These results highlight the importance of the construction quality, especially that of the waterproof structure on the outside of the walls.

When the moisture was stable, Type GHBIM had the highest moisture content, while Type RWB had the lowest moisture content. Thus, the GHBIM, as a thermal insulation material, achieved a poor effect when applied on the exterior wall. By contrast, the rock wool can realize excellent thermal insulation effect and durability in the same application scenario.

The simulated results reflected basically the same trend as those of the ten-day experiment, but differed greatly from the latter in numerical values. The difference came from the different settings of the initial humidity. In the software simulation, the initial humidity was configured as the comprehensive humidity of the exterior wall; in the actual measurement, the initial humidity was configured as the local humidity.

4.2 Comparison with analytical values

Dr. Liu Xiangwei constructed a heat-air-humidity coupling transfer model for the envelope structures in China's hot summer and cold winter region [11], and applied the model to examine the effects of the moisture transfer in building walls on the thermal properties and energy consumption of the buildings in this region. In this paper, preliminary calculations were conducted by Liu's model. The results turned out as in line with our conclusions in previous sections.

5. CONCLUSIONS

1. The moisture content was measured by the capacitive reactance of high-frequency electromagnetic wave sensors. The experimental results prove the convenience and feasibility of this method, and that moisture content can be obtained accurately through instrument calibration.

2. Through infrared scanning, measured moisture content and simulation calculations, it is concluded that the GHBIM has a high moisture content, which will cause deterioration of the wall surface. The deteriorated surface will absorb even more moisture, forming a vicious cycle. The rock wool enjoys a better thermal insulation effect on exterior walls than the GHBIM.

3. No internal condensation was observed in the walls, revealing that the moisture absorption and dampness are attributable to the external water seepage. Under the seepage, the thermal insulation effects of the three ETICS were declined to different degrees.

4. The three ETICS will reach moisture equilibrium after three years of service, as long as the moisture absorption and dampness penetration are avoided.

5. Despite certain deviation, the analytical data reflects consistent trends, and the final results are reliable. Of course, further verification is needed for the modelling and analytical calculations.

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REFERENCES

[1] Ham Y, Mani M. (2013). Calculating the cost of heating and cooling loss for building diagnostics using EPAR - energy performance augmented reality- models. Computing in Civil Engineering 242-249. https://doi.org/10.1061/9780784413029.031

[2] Fazio P, Athienitis K, Marsh C, Rao JW. (1997). Environmental chamber for investigation of building envelope performance. J. Archit. Eng. 3(2): 97-102. https://doi.org/10.1061/(ASCE)1076-0431(1997)3:2(97)

[3] Feng R, Li JP, Li XZ. (2016). Performance study of external wall insulation and a hybrid energy supply system for a rural residential building. Journal of Energy Engineering 142(4). https://doi.org/10.1061/(ASCE)EY.1943-7897.0000366

[4] Barreira E, Freitas VPD. (2007). Evaluation of building materials using infrared thermography. Construction and Building Materials 21: 218-224. https://doi.org/10.1016/j.conbuildmat.2005.06.049

[5] Blaise KK, Magloire KEP, Prosper G. (2018). Thermal performance evaluation of an indirect solar dryer. Instrumentation, Mesure, Métrologie 17(1): 131-151 http://dx.doi.org/10.3166/I2M.17.131-151

[6] Zheng KK, Cho YK, Wang C, Li HR. (2016). Noninvasive residential building envelope R-value measurement method based on inter facial thermal resistance. J. Archit. Eng. 22(4): A4015002. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000182.

[7] Barreira1 E, Vasco P, Freitas D. (2016). Evaluation of surface humidification of exterior insulation and finish systems. J. Perform. Constr. Facil. 30(2): 04015026. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000777

[8] Amir A, Strand RK, Hammann RE, Bhandari MS. (2018). Determination and assessment of optimum internal thermal insulation for masonry walls in historic multifamily buildings. J. Archit. Eng. 24(3): 04018016. https://doi.org/10.1061/(ASCE)AE.1943- 5568.0000320

[9] Liu YF. (2016). Research on the effect of moisture transfer on heat transfer coefficient of building enclosure. Master Dissertation 2016, Xi'an University of Architectural Science and Technology 19-47.

[10] Wang ZH. (2006). Basic research of confirm moisture stability and the infrared method for thermal performance qualitative detection of thermal irregularities in building envelops. Master Dissertation 2006, Harbin University of Technology 25-48.

[11] Liu XW. (2009). Investigation of the coupled heat, air and moisture transport in building walls in hot summer and cold winter zone. Doctoral Dissertation 2009, Hunan University, China 55-89.