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Pathological manifestations associated with hygrothermal stresses: A brief theoretical approach

Cesar Fabiano Fioriti *, Bárbara Vargas Rodrigues Botelho and Geovanna Morales Faldão

School of Technology and Sciences, Department of Planning, Urbanism and Environment, São Paulo State University (Unesp), Presidente Prudente, Brazil.

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Abstract

This paper presents a brief theoretical approach regarding the pathological manifestations affecting buildings due to hygrothermal stresses. The methodology – exploratory – involved consulting scientific articles published in journals through internet search platforms, associated with the theme of hygrothermal stresses in the civil construction sector. Based on the analyzed content, we found that water is an agent that contributes to the degradation process of buildings, as it is directly or indirectly responsible for the emergence of various types of pathological manifestations, usually linked to design and execution process flaws, as well as materials with inadequate behavior under the conditions of use. Therefore, it should be noted that repair techniques for the identified damage must be carried out immediately in order to minimize both financial costs and discomfort to building users.

Keywords: Moisture; Degradation; Anomalies; Theoretical survey

1. Introduction

Rising damp, or capillarity, or capillary action, can be defined as the phenomenon of attraction and repulsion caused by the contact that occurs between liquids and a solid body. It is manifested by the tendency of liquids (usually water) to rise through capillary tubes. According to [1], rising damp occurs when the porous material comes into permanent contact with water in the liquid state. This occurrence provides particular wetting properties for the solid grains, as it ensures the formation of the so-called curved interfaces between the water and the air that is retained in the pores.

Therefore, rising damp, when studied in construction materials such as cement composites, ceramics, wood, stone, and plastics, becomes a relevant point for understanding their performance, as well as for assessing the durability process of these materials.

As reported by [2-3], the construction materials normally used in Brazil are hygroscopic; that is, their internal structure has pores that absorb moisture from the air. Thus, determining the origin of moisture in buildings can be considered a complex task, as it involves many aspects (transport mechanisms). Figure 1 presents two examples of pathological manifestations triggered by water-related problems in buildings.

* Corresponding author: Cesar Fabiano Fioriti

Source: Authors.

Figure 1 Examples of buildings with damage caused by hygrothermal stresses

In parallel, the thermal performance of buildings in Brazil has been gaining prominence each year, while the so-called performance standard [4] (which has six parts), among the topics covered, includes requirements involving humidity in building systems, in addition to outlining design recommendations. And as discussed in [5], the aforementioned standard [4] does not make any mention of the transport and diffusion of water vapor in building elements, focusing only on aspects related to water in the liquid state.

Therefore, this paper presents a brief theoretical approach to the pathological manifestations affecting buildings resulting from hygrothermal stresses.

2. Methodology

This paper – a brief theoretical approach – was developed using a simple exploratory methodology, focusing on the hygrothermal stresses experienced by buildings in use. The theoretical framework was obtained through a search on the internet, specifically the platforms 'Web of Science' and 'Google Scholar', and specifically scientific articles published in open-access journals related to hygrothermal stresses in the construction industry. Three keywords were used on these search platforms: (i) humidity, (ii) hygrothermal stresses, and (iii) buildings. The selection of scientific articles was based on an analysis of their abstracts, objectives, and conclusions, as well as their classification within the Qualis/Capes A category. The sample of 20 scientific articles (six of which were systematic reviews) constitutes the brief theoretical approach presented in this text.

3. Results and discussion

Considering relevant scientific articles related to the topic of hygrothermal stresses in buildings, Table 1 presents a summary of the papers used in the theoretical approach.

Table 1 Summary of papers involving hygrothermal stresses in buildings

Study	Objectives	Key Considerations
[6]	Correlation of tables and matrices related to different types of stains, as well as their probable causes, diagnoses, and repair techniques (focused on cleaning plastered facades) – proposed methodology	In some cases, cleaning techniques may be inadequate for two reasons: they fail to remove the stains, or they may damage the substrate. The test areas highlighted the evaluation of cleaning methods and their effects on the substrate
[7]	Influence of different cardinal directions considering humidity, temperature, and rainfall on building facades in Santa Maria (Brazil), using solid bricks or blocks, both coated with cement mortar	The substrate of the cement mortar wall, whether brick or block, did not interfere with the impact of temperature and rainfall humidity. However, the results showed differences depending on the cardinal orientation that was considered
[8]	Analysis of the effect of humidity on facades based on statistics from 6	Moisture as a defect caused by other agents. Moisture was responsible for the emergence of anomalies such as biological colonization and

	facade coating inspection systems, but focused on various coatings	efflorescence. Incorrect project detailing was identified as the main cause of moisture-related problems
[9]	Identification of pathological manifestations arising from humidity, as well as their causes, in buildings belonging to the Sultanah Bahiyah Hospital (Malaysia)	Despite being only 10 years old, the hospital presents many anomalies related to humidity (walls, slabs, floors, and roofs) stemming from construction defects (generating functional performance problems). Suggest: analyzing the coordination of work between designers as a way to guarantee the quality of construction
[10]	Assessment of moisture damage patterns and prevention of their occurrence in Swedish buildings, integrating and/or correlating records of anomaly research identified in the region, allowing for damage mapping and prediction	The analysis highlighted several causes, such as microorganism growth, high humidity, and condensation. Lack of preventive maintenance was the main factor in the appearance of the damage. Problems in construction, as well as inadequate insulation, resulted in problems related to thermal comfort. In buildings constructed before 1970, anomalies are mostly related to inadequate maintenance, insufficient insulation, and leaks in water pipes. While execution problems, design flaws, inadequate waterproofing, and exposure during rain and snow are responsible for the pathological manifestations in recent buildings. School buildings showed a higher probability of detecting damage caused by humidity, with 13-52% for microorganism growth, 11-42% for deformation and odors, and 15-30% for leaks in water pipes
[11]	In situ assessment of moisture present on building facades using non-destructive testing (NDT): infrared thermography and measurement of electrical resistance, as well as measurement of air temperature and relative humidity	The two techniques (NDT) provided moisture mapping of the facades. It was possible to obtain, quickly, qualitatively acurat, timely, and at low-cost results that highlight the moisture content of the facades, being considered an important alternative in the analysis and evaluation of historical buildings aimed at their preservation
[12]	Case study involving the need to repair anomalies caused by moisture in floors slabs, and walls (sample universe of 168 public buildings in Finland)	The greatest need for repairs is found in wooden ground floors, followed by floors supported on the ground, and exterior walls and walls in contact with the ground. The need for repairs exists in 56-85% of the buildings. The study revealed that the buildings are considered to have multiple problems, with damage occurring in all types of elements (floors, slabs, and walls) regardless of the age of construction
[13]	A case study involving the use of infrared thermography to evaluate the hygrothermal behavior of building facades, with a view to determining their maintenance and repair techniques	The moisture content on the facades was assessed and quantified, and a priority matrix was applied, enabling the development of conservation strategies for the studied heritage. The technique employed, considered simple, contributed to prioritizing necessary interventions based on the causes of the observed damage
[14]	Presentation of individual moisture values measured in various locations of historical buildings in Slovakia, soluble salt content and degree of wetting, as well as presentation of repair techniques in the rehabilitation of buildings in the face of the effects of moisture	The use of destructive methods to create additional insulation is not considered suitable for use in historic buildings, according to the Venice Charter. However, sometimes this solution is necessary to save these buildings, and it cannot be taken literally, requiring the protection of the original material in historic buildings, as effective solutions for moisture-related problems would not be possible. Results from wetting measurements after applying these methods have shown that invasive techniques are necessary in specific cases
[15]	Case study concerning a residential building without thermal insulation located in Zurich (Switzerland). This case study was chosen due to the high rate of mold growth during summer	Humidity measurements and infrared thermography showed that humidity was high in this building, which could be the cause of mold formation. It was observed that mold grew more at structural intersections, as thermal bridges can occur in these locations. Calculations showed that insulation can reduce the risk of mold

		formation. The results are confirmed by experimental observations on mold growth in cold climates
[16]	This section addresses procedures related to the diagnosis and presentation of drying methods for building walls, as well as an applied renovation method (based on moisture damage identified in a historical building)	The choice of method for protecting and drying masonry is considered important when it comes to the preservation and maintenance of historical buildings. However, for historical buildings, natural or ventilated/heated drying is usually the most suitable. In addition to waterproofing treatments for masonry, i.e., the application of secondary waterproofing, a proper renovation concept also includes choosing the most appropriate drying method
[17]	Case study concerning moisture-related anomalies in a residential building. The internal temperature and humidity conditions of apartments with moisture damage were monitored. The temperatures of the internal and external surfaces of the facades were measured. An infrared thermographic survey was conducted, allowing the detection of irregularities and the assessment of moisture damage	Measurements showed that the apartments were outside the standard operating ranges for heating and ventilation. A risk of surface condensation was detected in some apartments, and a risk of interstitial condensation in one of them. The damage could likely have been avoided if both the design and construction process had been properly executed. The thermal performance of the double-walled construction was homogeneous, and no significant problems were found, as confirmed by infrared thermography. The study confirmed that in double walls, the unventilated air cavity exacerbates the humidity problem due to its low vapor permeability. The recommended solution would be to apply thermal insulation using an ETICS system
[18]	Determination of changes in the moisture behavior of the external walls of buildings in the Baltic region, renovated with ETICS systems, identification of condensation accumulation under certain environmental conditions, and assessment of the risk of moisture condensation to the durability of the external cladding	In the Baltic region, during the use of the heating system, there is a possibility of condensation at the junction of the masonry blocks and the thin layers of plaster in unrenovated walls. After renovation with ETICS systems based on mineral wool, there is a possibility of condensation at the junction of the insulation and the thin layer of plaster. The greater durability of external walls insulated with mineral wool and coated with painted fine plaster depends on the water vapor permeability of the outer layers and the combination of these values in the different layers, allowing for less internal and external moisture accumulation in the wall structure
[19]	Statistical treatment performed using SPSS (Statistical Package for the Social Sciences), presenting the pathological manifestations (and their respective probable causes) of the constructive elements of the exterior envelope in 15 buildings in Leiria (Portugal), built between 1970 and 1995	Most of the buildings analyzed were multi-family (85%). It was found that design and execution errors represented the largest percentages, 74% in pitched roofs and 59% in facades and parapets. Regarding the priorities for action (maximum, large, medium, and minimum), associated with the anomalies identified, a large divergence in the frequencies of priorities for action was found between pitched roofs (4%, 0%, 87%, and 9%) and facades and parapets (11%, 30%, 40%, and 19%)

Source: Authors.

According to [20], whose paper focused on key mechanisms of water transport – capillary action, vapor diffusion, and condensation – rain was identified as the most addressed topic in the literature, highlighting its significance as a source of moisture in service.

In general, according to [21] in his systematic review paper, there is a strong link between building characteristics and moisture-related risk predictors, such as the age of the building, the building materials used, the type of ventilation systems, and other constructive characteristics. Maintenance and user behavior, through good ventilation practices such as opening windows, were identified as the main remediation strategies.

In the paper of [22], which identified constructive flaws in the external walls of residential buildings through the analysis of judicial reports (more than a thousand cases), the authors reported that most of the damage relates to moisture problems (58%), with infiltration (287 cases) being the most recurrent individual anomaly, followed by condensation moisture (215 cases). Given the above, the main mechanisms of water infiltration on the surfaces of building elements are percolation, capillarity, condensation, leaks, and drainage failures. These mechanisms cause damage such as dampness, stains, mold, deterioration, and corrosion, compromising both the integrity and the durability of buildings [23].

More research and specific statistics are needed to reduce the causes, costs, and effects of water-related anomalies in all areas of a building. Water damage is an international problem, but different aspects of water damage are emphasized depending on the broader construction problems that occur in different regions of the world [24]. Related to this fact, [25] highlighted that the factors that most influence the emergence of pathological manifestations are technical and human, with the main aspects related to the number of defects in residential buildings being inadequate maintenance, lack of quality workmanship, and deficient design.

Finally, an increase in the number of scientific papers related to the topic of hygrothermal stresses in civil construction is reported.

4. Conclusion

Among the pathological manifestations that most affect buildings, those resulting from hygrothermal stresses are among the most recurrent. These include stains (dark – resulting from the proliferation of microorganisms or whitish – resulting from the transport of $Ca(OH)_2$ in cement composites), corrosion of steel (reinforced concrete), detachment and disintegration of mortar coatings, paint, moss, and cracking, among others.

These types of pathological problems, among the negative consequences for the building, are usually linked to design and execution process failures, as well as to materials with inadequate behavior under the conditions of use. Finally, it should be noted that repair techniques for the damage found must be carried out immediately in order to minimize both financial costs and the generation of discomfort for the users of the buildings.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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