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Factors governing the development of moisture disorders for integration into building performance simulation

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ABSTRACT

Excessive levels of moisture in buildings lead to building pathologies. Moisture also has an impact on the indoor air quality and the hygrothermal comfort of the building's occupants. A comprehensive list of the possible types of damage caused by moisture in buildings is discussed in the present paper. Damage is classified into four types: damage due to the direct action of moisture, damage activated by moisture, damage that occurred in a moist environment and deterioration of the indoor environment. Since moisture pathologies strongly depend on the hygrothermal fields in buildings, integrating these factors into a global model combining heat air and mass transfers and building energy simulation is important. Therefore, the list of moisture damage types is completed with a proposal of factors governing the risk of occurrence of each type of damage. The methodology is experimented on a simple test case combining hygrothermal simulations with the assessment of possible moisture disorders.

1. Introduction

An excessive level of moisture in buildings compromises construction quality. Moisture also has an effect on indoor air quality and the thermal comfort of the occupants. It is a possible source of pathology in buildings. As such, the subject has already been covered in a number of papers; generally, the existing literature can be divided into two categories.

Firstly, the most popular approach is the *inductive* (or bottom/up) approach. This means that when a specific moisture disorder is observed, modelling and/or experimentation are used to understand the physical behaviour leading to the disorder. Many examples can be found in the literature. For instance, in [1], experiments and modelling are used to understand rising damp in walls and find adapted treatment. Numerous studies have investigated mould growth. Viitanen et al. carried out experiment on mould growth on wood to develop a dynamic model based on temperature, moisture content and susceptibility of materials to mould [2]. Many other valuable contributions developed a similar methodology, starting with moisture disorders and proceeding to modelling. This approach is beneficial and advanced expertise is required to analyse moisture disorders. Nevertheless, within this category, the research is in general limited to only one type of damage (condensation, mould growth or indoor air quality, etc.). Not all types of potential moisture disorders are taken into account.

The second category is the *deductive* (or top/bottom) approach, which uses the predictive modelling to prevent moisture disorders. The first step used numerical modelling to calculate hygrothermal fields in buildings. Then the results are analysed to identify conditions of high moisture risks. If such situations are identified, then further investigations are required. The objective is to choose a robust building design, safe from moisture disorders, which is not new and is advantageous for designers. However, nowadays building designers have only empirical and technical guides to prevent moisture disorders as exemplified by [3–7]. These books are designed for construction engineers and workers. To progress in building science, the next step is to try to bridge the gap between research and practice. In this sense, extending building performance modelling to assess whether a solution will be free of any moisture-related damage is one of the important steps. The practical advantage is obvious: for example, retrofitting a building, designers would use modelling to determine whether risks due to moisture might appear during a building's life.

Therefore, the ambition of the present study is to contribute to the development of the second, *deductive*, category of research, by proposing tools enabling the designer to evaluate the moisture safety of a design by using predictive modelling. The present study focuses on hygrothermal phenomena. First, different types of moisture damage expected in buildings are detailed. For each type of damage, the most relevant models and evaluation techniques

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Nomenclature

Latin letters

b	thermal conductivity supplement (W m^2/K kg)
C	criterion (–)
E	Young modulus (Pa)
Icl	clothing index (Clo)
K_l	liquid permeability (s)
Q	thermal load (W)
L_v	enthalpy of evaporation & condensation (J/kg)
M	mould growth index (–)
Met	body's metabolic production [1 Met = 58 W/m^2]
P	pressure (Pa)
P_v	vapour pressure (Pa)
P_c	capillary pressure (Pa)
R	mechanical resistance (Pa)
L	length (m)
T	temperature (K)
t	time (s)
U	heat transfer coefficient (W/m^2 K)
w	water content (kg/m^3)
X	key factor (–) Greek letters
η	swelling coefficient (mm/m)
δ_v	vapour permeability (kg/m s Pa)
λ	thermal conductivity (W/m K)
ξ	moisture storage capacity
ρ_0	density of material (kg/m^3)
σ	stress (N/m^2)
τ	indicator of risks (S.I.s)
τ^{max}	max period of risks (s)
ϕ	relative humidity (%)
ν	Poisson ratio (–)

Latin Subscript

a	air
$comf$	comfort
$corr$	corrosion
dew	dew point
exp	expected
$freez$	freezing point
mec	mechanical
rm	radiant
$swel$	swelling
$tens$	tensile strength
$crit$	critical
$damage$	moisture damage
s, in	inside surface
out	outside
in	inside
v	vapour
0	dry conditions

found in the literature are discussed. Based on the existing research, indicators for the development of each type of moisture damage are proposed, to be integrated within building performance simulation tool. The indicators are not defined here to predict the precise location or the extent of the damage but are determined to anticipate all the potential risks. The particular point of the indicator definition is discussed in Section 2.

Then, according to [3], damage types are classified into four groups depending on the role of moisture:

1. In the material, the water molecule directly acts on its physical characteristics. This is called *damage due to the direct effect of moisture*.
2. Migration of moisture and variations in the water content are observed through the wall. Depending on this water content gradient and its dynamical variation, frost damage can occur. This is called *damage through moisture as the vector*.
3. In the third group, the *damage occurring in a wet environment* depends on the level of water content but is independent of the water content gradient in the material. For instance, high moisture content, combined with high temperature will lead to mould growth.
4. In the last class, moisture conditions in the rooms of buildings are studied and the *damage caused by moisture in the indoor climate* is considered.

After the first part describing the methodology and defining the indicators, this paper is structured in four above-mentioned parts, referring to the four groups of moisture disorders. Each section concerns one specific moisture disorder and is subdivided into two subsections. The first subsection, *State of the art*, gives a short review of the existing knowledge and models of moisture disorders. The second, entitled *Indicator*, proposes an indicator for the development of the moisture-related damage. Given that the general aim of this study is to improve predictive buildings performance simulation tools, the proposed indicators are integrated within a Heat, Air and Moisture (HAM) model. The feasibility of a global model, able to assess the possibility of moisture disorders, is illustrated in the last section.

It should be underlined that the objective was to include as many damages as possibles; consequently numerous complex physical phenomena were considered. The challenge lies in defining a possible equilibrium between different risks, without going deeply into one particular phenomena. We believe that such methodology is very important for future design of building, for energy retrofitting of existing and heritage buildings, as well as for new constructions.

2. Methodology

The first aim of the present paper is to elaborate a comprehensive group of indicators describing the development of moisture-related damage. The second aim is to enhance predictive tools in their capability to predict moisture-related disorders, using previously elaborated indicators. To meet these objectives, the indicators should combine two apparently divergent criteria. First, the indicators should be sufficiently relevant to assess the possibility of the development of damage. Second, they should be simple enough in order to be integrated within building performance simulation tools. The choice was then made to elaborate indicators able to anticipate and provide warning, in the context of HAM modelling, of potential moisture risks. They are not meant to model damage or its location precisely. If the indicators show a risk, a number of dedicated tools can be used in further studies to analyse more specific damage in greater detail. To meet these objectives, the paper refers to existing research on moisture disorders. In addition, practical studies, guides, standards and exchanges with experts are used to define the indicators.

In this study, the definition of the term *indicator* is based on the FD X 50-171 standard. Thus, an *indicator* is defined here by the association of a *key factor X* and a *criterion C*. A *key* or *governing*