Moisture as a source of indoor air contamination

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RATIONALE

Dampness / moisture accumulation into building structures or structural components, or on the surfaces of building materials, may lead to physical, biological or chemical deterioration of building materials. Subsequent damage and microbial or chemical contamination of the building may decrease the indoor air quality of the building. Dampness/moisture damage also poses a serious risk to the performance of the building structures (1). In epidemiological population studies, dampness/moisture damage has been associated with a number of health effects including respiratory symptoms and diseases and other symptoms (2, 3).

While exposure to microbial and/or chemical pollution and health outcomes are consequences, the common denominators for them are different forms of undesired moisture behaviour. The health effects associated with dampness/moisture damage seem to be consistent in different climates and geographical regions (4). However, the technical causes of dampness/moisture damage are often closely connected to the climate. The prevention and control of moisture problems should be addressed in early phases of building design and construction, and in the sustained maintenance of buildings.

This report aims to give an overview of moisture as a source of indoor air contamination, which is related to the health topic Asthma and allergy. Included in each chapter, the author(s) list most important (open) questions, which should be addressed in the discussions for this topic.

MOISTURE SOURCES

Moisture can migrate into and inside a building in several ways, depending on its state (vapour, liquid or ice/snow) (5). Moisture transfer is fundamentally based on a migration of water molecules migration in response to forces acting on them, including intermolecular forces, vapour pressure, and gravity (6).

In general, three major moisture source categories can be identified: the outdoors (e.g. air humidity, precipitation, moisture in the ground), the indoors (e.g. humans, water use), and wet construction materials. Common sources of moisture damage are, for example, roof leakage, flooding, leaking services (e.g. burst pipes, defective pipe joints), spillage (e.g. cleaning and washing activities), and construction moisture (e.g. fresh concrete structures, plaster, mortar, timber, etc.).

Moisture conditions in buildings and their surroundings are in a continuously fluctuating stage. Factors affecting moisture transfer include temperature, air/vapour pressure, and moisture content of the surrounding air and materials. The mechanisms of how moisture affects building structures and causes different forms of damage are generally known. As a consequence, risk of dampness/moisture damage can be estimated using meteorological data on moisture related parameters in outdoor air, information on the regional parameters, information on water production and activity indoors, information on the construction and structural design, and information on the performance of the building and its systems. It is far less understood how dampness/moisture damage alters the indoor air quality that is critical from a health point of view.

- How dampness/moisture damage alters the indoor air quality that is critical from a health point of view?
- Are the causal links between dampness/moisture damage related exposures and health sufficiently well known?

HOUSING CHARACTERISTICS ASSOCIATED WITH DAMPNESS/MOISTURE DAMAGE

Several housing characteristics have been associated with dampness/moisture damage. These include age, size and type of building, type of foundation, building frame material, amount of thermal insulation, lack of central heating, use of natural ventilation or poor ventilation, use of humidifiers, indoor RH, and overcrowding (4, 7-12).

Ventilation is a focal housing characteristic that has an important role in building moisture dynamics but is also associated with occupant health in general, especially at low air exchange rate levels (13). Ventilation may also play a crucial role affecting the concentrations of indoor air pollutants (14). If there are no indoor sources of pollutants, mechanical exhaust and supply ventilation systems with adequate air filtration can reduce concentrations of pollutants entering or infiltrating into a residence (15). On the other hand, inadequate outdoor air supply may associate with elevated concentrations.

- How could information about housing characteristics associated with dampness/moisture damage be translated into moisture protective policies?
- What is the role of ventilation in control of dampness/moisture damage?

OBSERVATIONS AND CHARACTERISTICS OF DAMPNESS/MOISTURE DAMAGE

Occurrence and characteristics of dampness/moisture damage can be estimated various ways. Most commonly, the estimates rely on observations made by building occupants or by independent inspectors. Depending mainly on material properties and the stress to which material is exposed to, there are many typical signs indicating dampness/moisture damage. These signs include condensation on cold surfaces such as window panes, or signs of staining, discoloration, peeling, blistering, shrinkage, or expansion of a building material, or decay from micro-organisms. However, it is also important to notice that dampness/moisture damage is often hidden and can not be observed without dismantling structures.

There are only a few studies comparing occupant reports on moisture damage and on-site building investigations performed by trained inspectors, and even fewer studies assessing the variation between different inspectors' observations. Dharmage et al. (16) concluded that the data collected by questionnaires were accurate as compared to independent inspector's reports. Douwes et al. (17) suggested that occupants' reports were more reliable in estimating "dampness" than inspectors' reports. A conflicting study by Williamson et al. (18) reported occupants having a tendency to underestimate "dampness". Nevalainen et al. (19) concluded the same, suggesting one explanation to be a result of a trained eye of the inspectors to rate their observations together with their knowledge of what represents critical problems. Haverinen-Shaughnessy et al. (20) studied moisture damage observations made by both occupants and independent inspectors and concluded that the inspectors observed more damage sites than the occupants, and the overall agreement between the inspector and the occupants was poor, whereas the agreement between the two inspectors was higher.

Regardless of the observer, dampness/moisture damage observations can be further evaluated based on several characteristics. From the exposure point of view, according to two Finnish studies, characteristics of importance may include location of damage with respect to building occupants, duration of damage, type of damage observation (i.e. signs of visible mould, odours or other biological or chemical processes that may lead to indoor air pollution), and damaged material (21- 23).

- What is the measure of dampness / moisture damage and how it is verified?
- What are the most important characteristics of dampness / moisture damage with respect to occupant health?

PREVALENCE OF DAMPNESS/MOISTURE DAMAGE

Survey based prevalence estimates of dampness/moisture damage vary from approximately 2 to 85% depending on the study, climate and definition used; a large part of the variation may also be related to the method used in the estimation. Therefore, it is difficult to make European level estimates on the proportion of the population that may be adversely affected by dampness/moisture damage. For example, Eurostat (24) defines damp as "rot in the house or damp or leaky roof" and reports percentage of total population exposed to these types of problems in 13 countries varying between 4.2% (Finland) to 35.7% (Portugal) in 2001. However, the definition as such seems to exclude many types of dampness and moisture problems, which may be a reason why, for example, several cross-sectional studies conducted in Finland have reported much higher prevalence values (19, 21).

European community respiratory health survey investigated associations between housing characteristics related to dampness, mould exposure and house dust mite levels and asthma in 38 study centres in 18 countries (4). Centres were located both in Europe (14 countries), and outside Europe (four countries). The information on housing characteristics was obtained in an interview, and included information on water damage, presence of water collecting on the basement floor, and mould or mildew on any surface inside the home. During the year prior to the interview water damage was observed in 12.4% (range 4-32%), water on basement floor in 2.2% (0-16%) and mould or mildew in 22.1% (5-56%) of the dwellings.

LARES survey was undertaken in eight European cities in 2002 and 2003, consisting of data on roughly 400 dwellings from each city (25). According to the dwelling inspections conducted by trained surveyors, visible mould growth was detected in at least one room of almost 25% of all visited dwellings. Country specific data was not reported in the preliminary overview of LARES findings. Findings related to other dampness/moisture related variables (including smells of dampness and signs of condensation) were not included in the report.

Many global phenomena such as climate change and increase in energy consumption have been recognized worldwide. Increase in prevalence and incidence of asthma and other diseases possibly attributed by environmental factors has come under intensive public concern. All of these issues have links to dampness and indoor air quality. Needs for data improvements relate especially to the prevalence of dampness/moisture damage (population exposed), and causal links between exposures and health. Once the prevalence of dampness/moisture damage and the causal links are sufficiently well know, risk assessment can be conducted and correct policy actions can be taken to protect the public and their housing quality attributable to health. Current knowledge is sufficient to give practical advice for building owners and occupants for taking corrective and preventive actions in order to avoid dampness/moisture damage in buildings.

- What is the prevalence of dampness /moisture damage (population exposed) within EU?

REMEDIATION OF MOISTURE DAMAGED BUILDINGS

Dampness/moisture damage of buildings does not have a homogenous appearance but each building needs to be examined individually. Although there are uniform phenomena seen in the microbial contamination of the indoor environment and health effects of the occupants, the original causes of moisture problems and the possibilities to eliminate them vary.

One should emphasize the importance of continuous maintenance as the best practice to ensure good performance of buildings throughout their life span. Dampness/moisture damage should always be addressed in a timely manner, because extended duration may lead to more damaged buildings and create additional stress among the building occupants. Intervention studies have shown positive effects after remediation, or cessation of exposure, on occupants' health (26-28).

Careful remediation process includes solving the cause(s) of the damage, removing contaminated materials, good quality reconstruction, and follow-up measures (29). Attention should also be paid to protecting construction workers and building occupants against contamination released during the work. Assessing the success of remediation of moisture-damaged buildings focuses on these same issues, and it can be done utilizing various methods (30). During the whole remediation process, it is good to keep an open mind toward problems that may have remained unsolved, and return back to monitor and re-evaluate the success of the remediation as necessary.

One of the final decisions to be made is related to re-occupancy of the remediated facilities. On a rare occasion, either total or partial re-occupancy of a building may not be achieved. Such outcome could become realistic, if the remediation costs would exceed the value of the building and/or total reconstruction. It is also possible that a small portion of occupants become sensitized to building contamination, and in such cases sufficient levels of cleanliness may not be achieved at a reasonable cost. Depending on the number of such occupants, appointing new working / living space may be the most feasible choice.

- Can all damp / moisture damaged buildings be remediated cost-effectively (what is the measure of cost-effectiveness)?
- How is the success of remediation assessed?

PREVENTION OF DAMPNESS / MOISTURE DAMAGE

By estimating ambient temperature, pressure and moisture conditions, and moisture sources, loads and mechanisms of action, buildings can be designed and maintained so that under normal conditions, moisture will not cause damage (31).

In the design phase all equipment, components, and structure types chosen should be checked to be moisture safe during both construction and use. The conditions related to building site and the planned use of the building (level of usage, planned activities) should be taken into account. Basis for moisture control is provided by calculations, specifications or other information that also point out important details to be checked during construction. They include estimation of moisture loads the building is subjected to, technical properties required for materials and products, and design of structures and details (including their performance and risk characteristics and how the risks can be minimized). They take into account building tolerances, deformation, and duration of materials and structural components under the estimated moisture loads. Sufficient quality control measures should also be included (e.g. how and when moisture content of materials should be measured).
The design will establish instructions and routines for materials and components handling during transportation and of the building site, establishing a basis for control of construction moisture. It will also establish instructions on how the building should be used and maintained in order to avoid moisture damage. Special consideration is required for new, not tested solutions.

Following design phase, good construction site planning has a crucial effect on the control of moisture. Moisture control plans and actions should be included in the quality control of the construction site. All important checkpoints (e.g. based on estimated risks) should be defined by clear description of test methods, accepted values, tolerances, etc., followed by real time documentation. These checkpoints may include follow-up of drying out time, handling of materials and equipment, protection of structures and materials, and responsibilities of different parties and individuals in carrying out the plans and documenting the results.

A perquisite for successful moisture control is a realistic and sufficiently detailed timetable which allows keeping construction on schedule. Based on careful calculations and measurements, this timetable aims to promote construction moisture drying out as fast as possible by means of ventilating and heating when needed. For example, in a wet/humid climate, the most effective protection against rain is installation of the first layer of roofing, gutters, and downspouts. In cold climate, effective drying out is achieved by heating, which is possible when the frame of the building is closed (inc. windows and doors). These phases need special attention in scheduling and work planning in order to achieve as fast as possible progress. Unnecessary wetting of building materials during the storage and construction phases should be avoided.

- Is moisture control taken sufficiently into building design and construction process?
- Does moisture control planning require special expertise that is not currently fulfilled in the standard building design / construction operations?

MOISTURE CONTROL POLICIES

In order to minimize risk of dampness/moisture damage, long or frequent periods of high humidity (>80%) should not occur in any part of the building structures. Following moisture control policies and preventive measures that are generally incorporated in the building code in Finland will help to reduce risks (32) (however, they may not invariably prevent dampness/moisture damage in buildings):

Buildings shall be designed, constructed and maintained in such a way that moisture accumulation on building surfaces or inside the structures does not cause health risks for the building occupants or the occupants of the neighbouring buildings. Moisture control plans shall include sufficient maintenance procedures for all building structures and components.

Building structures and HVAC systems shall be built in such a way that vapour, water or snow from either indoor or outdoor sources can not harmfully get into the structures or indoor spaces. If necessary, structures and building materials should be capable of drying without moisture causing harm, or the drying should be ensured by a specifically designed method.

Building envelope should be sufficiently air tight so that it is possible to prevent uncontrolled air flows and control air pressure within the building as compared to outdoors. All spaces within the building that are meant to be ventilated should be designed and equipped so that the ventilation air flows through the entire space.

All soil, organic material and debris that can rot or grow mould or otherwise harmfully deteriorate should be removed from the building site before construction. Building elevations should be designed so that surface and ground water can be controlled. Rising damp from the ground should be controlled by sufficient drainage, capillary layers, and/or water proofing.
All spaces, equipment, structures and materials susceptible to and/or severely or repeatable exposed to moisture should be built so that they can be inspected and maintained easily and cost-effectively during their designed life-span. Building materials susceptible to moisture should be protected. Structures under water pressure should be protected with sufficient waterproofing. Building materials exposed to water should be able sustain their qualities. Harmful seepage of water into or through the structures should be stopped. Harmful effects of possible moisture and water damage should be minimized by channelling all leaks to become visible and by preventing moisture accumulation in hidden locations.

Building materials and components should be protected against moisture during transportation, storage, and construction. Building materials should be allowed to sufficiently dry before covering or coating them with anything that may slow or prevent drying.

MORE SPECIFICALLY

Rain and surface water should be directed away from the buildings. In such locations where ground water levels or soil properties may cause a risk for rising damp related problems, such drainage systems should be built that can stop capillary flow of water and keep ground water levels sufficiently low with respect to the floor and wall structures.

Crawl spaces should be sufficiently ventilated so that humidity does not harm a structure's function and durability; and designed/constructed so that water does not accumulate underneath the building and that the crawlspace can be inspected thoroughly. Crawlspaces should be clean of debris and organic material that can decay.

External wall structures and adjoining structures should be sufficiently air tight and vapour resistant so that convection or diffusion does not cause moisture content within the wall to rise too high. Both building moisture and moisture from indoor and outdoor sources that may occasionally get in the structures should be able to dry out without causing damage or health risks. Windows, doors, ventilation equipment and other installations, and adjoining roof, balcony and other structures should be designed / constructed so that rain water or snow can not get into the structures and accumulate.

External wall structures should join to the foundation and floor structures so that moisture migration or accumulation into wall structures is prevented and that the wall can dry out via the lower end, if necessary. Moisture transfer from floor to wall structures should be stopped by a capillary breaking layer in between the structures.

All wall structures that are built against the ground should have sufficient water barriers that prevent water from getting into the structures.

Roof membrane should prevent rain water and snow from getting into roof and upper most floor structures, walls, and interior spaces. The membrane should sustain loads caused by climate changes, snow and ice, and maintenance work. Roof must be designed / constructed so that water is directed away without causing harm to the building.

Upper most floor and ventilation of the roof should be designed / constructed so that moisture does not harmfully accumulate due to diffusion or air flows and so that the structures can dry out, if necessary.

Bathrooms and other rooms with high water usage and/or moisture loads should be designed / constructed so that water in any form can not migrate to the adjoining structures and rooms. Walls and floors should be protected with sufficient water barriers. All free water should be directed to drain / sewage system.

Plumbing and sewage equipment and HVAC equipment and adjoining systems should be designed, constructed and equipped so that possible water leaks can be noticed in an early phase. Piping, ducts and equipment should be located, insulated, and protected so that water in the systems does not freeze and that water does not condense on the surfaces or that the condensed water can be directed away without causing harm.

- Is moisture control sufficiently incorporated into building codes across Europe?

SUMMARY OF THE MOST IMPORTANT QUESTIONS RELATED TO MOISTURE

- How dampness / moisture damage alter the indoor air quality that is critical from a health point of view?
- Are the causal links between dampness / moisture damage related exposures and health sufficiently well known?
- How could information about housing characteristics associated with dampness / moisture damage be translated into moisture protective policies?
- What is the role of ventilation in control of dampness / moisture damage?
- What is the measure of dampness / moisture damage and how it is verified?
- What are the most important characteristics of dampness / moisture damage with respect to occupant health?
- What is the prevalence of dampness /moisture damage (population exposed) within EU?
- Can all damp / moisture damaged buildings be remediated cost-effectively (what is the measure of cost-effectiveness)?

- How is the success of remediation assessed?
- Is moisture control taken sufficiently into building design and construction process?
- Does moisture control planning require special expertise that is not currently fulfilled in the standard building design / construction operations?
- Is moisture control sufficiently incorporated into building codes across Europe?

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