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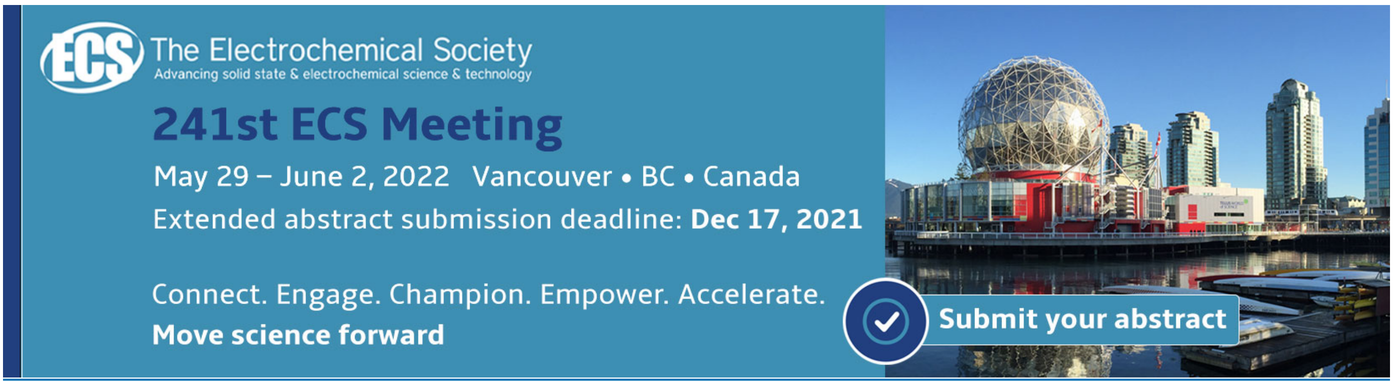

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CIB W040: International Surveys Considering Moisture Safety in Buildings During Design and Construction

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Abstract. We conducted comparative surveys of design consultants in three countries to determine current knowledge and experienced moisture problems. The study is part of the CIB W040 research roadmap needs analyses for realigning research efforts with stakeholder requirements for moisture safety. Survey results show that a third of construction projects in the last five years were affected by moisture problems, even though practitioners applied multiple preventative measures at least some of the time. Water installations caused approximately 20 % of the moisture damage. In each country, preventing moisture damage was necessary; the means to address problems varied, with no one dominating solution. Design and construction guidelines were more helpful than the building code requirements. Information is available, but designers need dedicated time and budget for implementing better moisture safety. A quantitative goal is to increase the frequency of moisture safety measures while increasing the availability of tools. The usefulness of selected measures and instruments is strongly case-specific. Subtopic analysis such as causes of moisture damage due to leaky water installations needs more detailed investigation. Further research is needed building upon the online survey results to develop intelligent tools preventing moisture damage in the design, construction, and building occupancy phases.

1. Introduction

The term moisture safety seems to be used mainly in Europe [1] and can be understood as the absence of moisture damage in buildings. A key target is to design, build, and maintain buildings in such a way that sufficiently low occurrence rates of moisture damages are reached while balancing efforts against achievements including economic aspects [2].

Moisture safety in buildings is an important topic because it is an essential requirement for good long-term performance of the building structures, good indoor environmental quality, and low building energy consumption. However, despite the progress made in the past decades in research, planning and construction methods and guidelines, moisture-related problems still occur in the building stock. Different studies have estimated that moisture problems occur in 2.5 to 80 % of buildings depending on the country, building type, use, age, and other factors [3-5].

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Moisture damages occur due to many different reasons, such as lack of information, poor instructions [1], careless implementation, cost savings, and/or time constraints, including a missing or discontinuous focus on quality assurance [6]. Problems also arise in older buildings as a result of moisture leakages and changes in the properties of materials [4, 7]. Also, climate change increases moisture stresses on structures during both construction and operation [7]. However, the best approach to manage the risks related to these topics depends not only on the physical phenomena itself but also on the current practices and needs in the industry as a whole [8].

The investigation in this paper is carried out in the framework of CIB W040, an international Working Commission of the International Council for Research and Innovation in Building and Construction (CIB) [9], whose members focus on researching the efforts of heat, air, and moisture transfer in buildings. Current Working Commission members originate from 19 countries: Australia, Austria, Belgium, Canada, China, Czechia, Denmark, Estonia, Finland, France, Germany, Iran, Italy, Japan, Lithuania, the Netherlands, Portugal, Slovakia, and Sweden. Five stakeholder groups in the construction industry are being consulted using online surveys to include their needs in moisture safety research: architects and consulting engineers, builders and contractors, policymakers, building owners, and researchers [10].

The objectives of this study are to ascertain the gaps in knowledge and tools during the design process for practising architects and engineers. The results are evaluated to improve understanding, why moisture damages still occur despite the previous and ongoing efforts related to moisture safety. The study aims to use the results for new recommendations and research into building resilience for adapting existing tools to better suit designers. The overall goal is to improve moisture safety in both refurbished and new buildings.

2. Methods and Materials

This investigation focuses on the results of three surveys conducted from October 5, 2017, to May 2, 2018, of building physics professionals in Austria, Denmark, and Finland. A master online survey was drafted in SurveyMonkey focusing on moisture safety issues that architects and engineers encounter during design and construction. The online survey was translated from German, into English, Danish, and Finnish and distributed to the corresponding countries.

The surveys were conducted at

- The Austrian Building Physics Day 2017 on October 5, 2017, in Vienna, Austria,
- The Finnish Building Physics Conference on October 24–26, 2017 in Tampere, Finland, and
- The annual Danish Building Physics Day on May 2, 2018, in Copenhagen, Denmark.

Questions were categorized according to job position, responsibilities, and experience, frequency of moisture problems in the last five years, personal view importance of the issue, steps taken to address moisture problems during the design and construction phases, an assessment of the available resources to address moisture problems, and how moisture problems are addressed. The questions are in **Table 1**.

A total of 81 responses were received from all countries with 38 from Austria, 31 from Finland and 12 from Denmark. If a respondent had left more than half the questions unanswered, then the responses were excluded completely. The final number of responses included in the analysis are 36, 29, and 9, respectively for a total of 74 full responses. Not all participants identified their job type and design responsibilities. However, based on the given responses and conference attendance lists, most survey participants were either designers or building physics specialists with a minority of other professionals, such as construction managers, building officials, and graduate students.

Responses to Q1 to Q4 were given as percentages between 0 % and 100 %. Q5 is a twelve-part multiple-choice question with responses given on a five-point scale: never (1), seldom (2), occasionally (3), often (4), and always (5). Q6 had ten yes/no questions. Q7, Q8, and Q9 were answered as percentages between 0 % and 100 %. Q10 is a fifteen-part multiple-choice question with responses provided on a four-point scale: not at all important (1), somewhat important (2), very important (3), and extremely important (4).

Table 1. Survey questions about moisture safety with sub-questions.

Code	Question
Q1	**What percentage of construction projects in the last five years have reported moisture damage during construction?**
Q2	**What percentage of construction projects in the last five years have reported moisture damage in the occupied buildings during use?**
Q3	**What percentage of moisture damage has been caused by water pipe leaks?**
Q4	**How important is it for you to find ways to prevent moisture damage in buildings?**
Q5	**Which measures are taken to prevent moisture damage in current construction projects?**
i	The building owner has a clear goal to have no moisture damage in the building.
ii	The building owner has a responsible person for moisture damage-prevention.
iii	There is enough time allocated in the design phase to select constructions with no risk of moisture damage.
iv	There are specialists in the design team who specialize in "preventing moisture damage in the design".
v	A person has been appointed to be responsible for moisture damage-prevention in the design team.
vi	Construction companies have employees with training in "moisture damage-prevention during the construction phase".
vii	The nomination of a responsible person for moisture damage-prevention by every company involved during the construction phase.
viii	Regular inspection of the construction site for the prevention of moisture damage.
ix	Regular measurements of moisture damage prevention on the construction site.
x	Regular meetings on the construction site about the status of moisture damage-prevention.
xi	Issue an easily understandable manual about preventing moisture damage during building use.
xii	Regular evaluations of whether the manual is understandable, and the recommendations can be implemented.
Q6	**The building owner is determined not to have any moisture damage. What do you need to estimate the risk of moisture damage in different constructions?**
i	A proven method.
ii	Employees that are trained for preventing moisture damage.
iii	Data on typical construction mistakes.
iv	Data about the influence of quality assurance on the risk of moisture damage (e. g. locating air leakages) during the construction phase.
v	Product data to calculate the risk of moisture damage.
vi	An easily usable tool to conduct analyses.
vii	A generally understandable way how to document recommendations to the building owner.
viii	I do not lack anything.
ix	A method of how the result is communicated in the call for tenders.
x	Other. (Please specify)
Q7	**The official building code helps to select only those constructions which help to prevent the risk of moisture damage.**
Q8	**The standards/national guidelines are relevant to planning help to select only those constructions which help to reduce the risk of moisture damage.**
Q9	**The standards/national guidelines relevant to the construction of building constructions help to prevent moisture damage.**
Q10	**How important are the following measures to prevent moisture damage?**
i	The building owner is determined to have no moisture damage in the building.
ii	The building owner has a responsible person for moisture damage-prevention.
iii	There is enough time during the design phase to select building constructions with no risk of moisture damage.
iv	There are specialists in the design team who focus on preventing moisture damage in the design.
v	A person in the design team has been assigned to be responsible for preventing moisture damage in the design.
vi	There are generally accepted technical rules that document a verified method to assess the risk.
vii	Construction companies and/or contractors have employees with training in "moisture damage-prevention in construction".
viii	The nomination of a responsible person for moisture damage-prevention by every company involved during the construction phase.
ix	There are generally accepted technical rules that verify which constructions imply which risks.
x	There are textbooks available in schools, colleges, and universities that can be used consecutively to teach how to assess the risk of moisture damage in the design and construction phases.
xi	Regular inspection of the construction site for moisture damage-prevention.
xii	Regular measurements on the construction site for moisture damage-prevention.
xiii	Regular meetings on the construction site about the status of moisture damage-prevention.
xiv	Preparation of an easily understandable manual for preventing moisture damage during building occupancy.
xv	Regular evaluations to determine if the manuals are understandable and also to determine if they can be implemented.

The questionnaire results were analysed by first numerically coding the answers and calculating group- and question-wise mean values, standard deviations, median, and interquartile ranges in MS Excel. The "I don't know" answers (coded as zero) were removed from the data set. Both absolute and normalised values were studied, where the group mean (for the respective country and question group) was first subtracted from the mean-vote. Outlier detection was conducted by comparing normalised mean votes to 95 % confidence intervals calculated from the t-distribution. The statistical significance for differences in group means was calculated using Mann-Whitney U-tests utilizing the Python `scipy.stats` package. To study the sensitivity from sample size and choice of statistical test, also two-tailed t-tests were done. For the current data, the two methods produced the same conclusions.

3. Results

Figure 1 shows a box and whiskers plot regarding the experiences of survey participants towards moisture problems. See **Table 1** for the original questions.

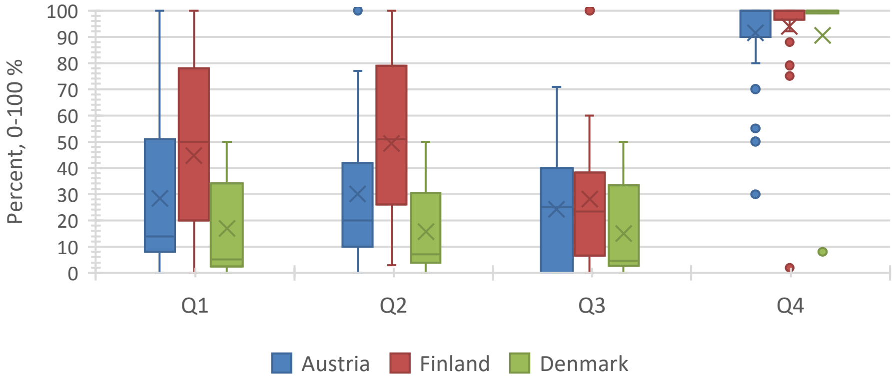

Figure 1. Responses to (Q1) the occurrence of moisture problems during building construction, (Q2) occupancy, (Q3) the portion of moisture problems caused by leakages from water pipes, and (Q4) the importance of preventing moisture problems.

On average, the survey participants reported moisture problems in 16-49 % of the cases in the past five years (Q1-Q2). The variation between answers was large, but overall, the occurrence rate of moisture problems was high. 15 to 28 % of all reported moisture problems were caused by leakages in water pipes, (Q3). Preventing moisture problems (Q4) was considered very important among all the participants almost reaching 100 % for all countries.

Figure 2 (left) shows the responses to Q5 about the frequency different measures are taken to prevent moisture damage in construction projects. A statistically significant baseline difference existed between Austrian and Finnish data, and Austrian and Danish data (two-sided U-test, $p < 0.05$), but not between Finnish and Danish data ($p = 0.54$). The differences can be due to reasons that are not directly related to building physics, but also, the scale included the answers “never” and “always”. The reported average vote for implementing different measures was on average about one scale step higher for Finnish and Danish data compared to Austrian data.

The mean vote for Q5/i in the Austrian data was outside the 95 % confidence interval, meaning that the Austrian respondents reported a higher frequency of building owners having a clear goal to minimize moisture problems in their buildings. Q5/i and Q5/vii in the Danish data were not classified as outliers but were close. In the latter, the respondents considered it rare for every company involved in the construction phase to have a dedicated person, especially for moisture damage prevention. The low mean vote in Q5/ii in the Danish data is not comparable due to a translation error.

The differences between individual moisture safety measures during construction projects were small when compared to the mean vote of each group (cf. **Figure 2**, left). An interesting phenomenon was that very few questions received high average votes (scale values 4 or 5). This can be interpreted that it was regular practice to carry out various moisture safety measures, but none of the proposed moisture safety measures was used regularly.

The results in **Figure 2** (right) shows the subjective effectiveness in percent of different required tools for risk assessment of different building constructions. The graph also shows where a lack of tools exists. The top average votes in the Austrian data were an easily usable tool (Q6/vi), a proven method (Q6/i), and data on the influence of construction-time quality assurance methods (Q6/iv). In the Finnish survey, the top needs were related to the availability of proven methods (Q6/i) and employees trained for preventing moisture damages (Q6/ii). In the Danish survey, the main needs were related to proven methods (Q6/i), trained employees (Q6/ii) and data on typical construction mistakes (Q6/iii). In all three surveys, the lowest vote was for Q6/viii: "I do not lack anything." No outliers were detected, but this was likely due to a large data variation.

Q5: Which measures are taken to prevent moisture damage in current construction projects?

Q6: What do you need to estimate the risk of moisture damage in different constructions?

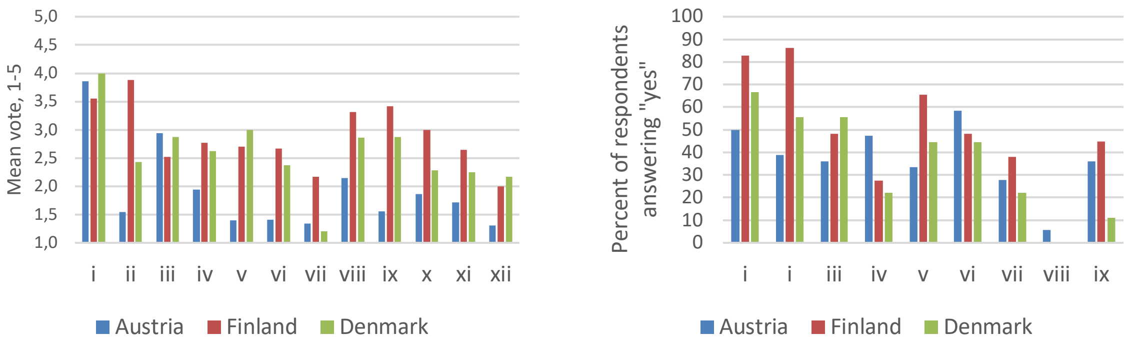

Figure 2. Mean votes on how often certain moisture safety measures are being taken (left). The percentage of respondents indicating that they need a specific approach to estimate the risk of moisture damages (right).

Figure 3 (left) shows the reported usefulness of the local building codes, and the design and construction guidelines to prevent moisture damages.

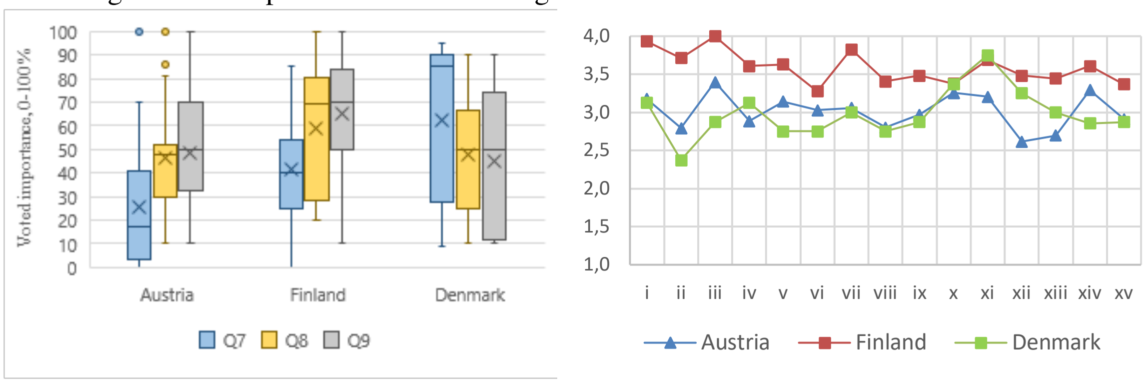

Figure 3. Self-assessed value of the local building codes (Q7), local planning guidelines (Q8), and construction for moisture damage prevention (Q9), (left). Self-assessed importance of 15 different measures to prevent moisture damages (Q10) (right).

Figure 3 (right) shows the reported importance of different measures to prevent moisture damages. Overall, practically all the listed measures received high average votes, as either very important or extremely important. Regarding measures to prevent moisture damage (Q10), there was only one outlier: regular inspections of the construction site (Q10/xi) in the Danish data. Otherwise, the differences were small compared to variation, but regular moisture measurements on-site (Q10/xii) and regular meetings about moisture problems on-site (Q10/xiii), received below-average votes in the Austrian data. Allowing enough time in the design phase to select moisture safe structures (Q10/iii) received relatively high votes in both the Austrian and Finnish data. The results imply that the survey participants recognised that a wide variety of measures is important for preventing moisture damages in buildings.

4. Discussion

It is important to note that the results do not directly reflect the overall occurrence of moisture problems in each country, or between countries. The results show the opinions and experiences of the survey participants at the building physics conferences. However, compared to existing literature, the results highlight that at least 20 % of buildings exhibit moisture problems [11].

The sample size in Austria and Finland is statistically significant for the event participants who are experienced, moisture-safety experts. The survey results may have a positive bias, as they focus on building physics conferences. The attendants are highly interested in seeking new knowledge about moisture safety. The respondents are responsible for dealing with moisture-safety issues in their companies and organizations with access to the best tools and guidelines.

In comparison, a survey of 809 German design consultants showed that 62 % of respondents frequently performed heat and moisture calculations during the design process. However, 32 % seldom did, and 6 % reported never calculating moisture risks [12]. Just under half of the respondents, 47 %, never pursued professional certification or workshops to prevent damage to the building envelope [12] while the other 53 % had taken courses within the last five years.

Sokic [13] conducted a moisture safety needs analysis of Austrian construction management in 2018. Austrian construction managers depended strongly upon the experience of skilled workers for preventing moisture damage during the construction and operation of residential concrete buildings. When skilled tradesperson lacked knowledge, they were most receptive to hands-on workshops and training. Like the design consultants, construction managers stated that time pressure and decisions made by other stakeholders were often a cause of high moisture safety risk during both construction and operation.

The most important design document about moisture safety in Austria is the ÖNORM B 8110-2 Standard from 1 January 2020 [14] which requires a hygrothermal simulation according to EN 15026 for all cases not included in the list of proven moisture safe construction assemblies. As the Glaser Method according to EN ISO 13788 [15] was valid in Austria to verify moisture safety in the energy certificate calculations until the end of 2019, only a few design consultants changed over to the new standard. It may be considered that Austria is currently in a transition period for moisture-safety planning. Some key actors are currently considering moisture safety training on a national level for practitioners to learn how to include the new moisture prevention requirements in the design process. Few offices currently have hygrothermal simulation software like WUFI.

In Finland, moisture and mould problems have received much attention in recent years. The higher values in the Finnish data might be related to this, but on the other hand, tight construction schedules and reluctance towards additional investment costs are still major challenges, which can lead to shortcomings in moisture management. Several guidelines for both new construction and renovation have been and are being developed to avoid moisture problems. The Kuivaketju10 (dry chain 10) in Finland is a system promoting moisture safety in buildings based on ten broad moisture safety categories for managing moisture at different project phases [16].

Danish building regulations have specified procedures since 2008 preventing moisture accumulation during design and construction in new buildings and retrofit [6]. Buildings must utilize a variety of measures to avoid high moisture content during construction to assure that the moisture content at building handover does not promote mould growth. The building regulations refer to guidelines to assist with the moisture-safety decision-making process assessing humidity risks in different classes. However, the use of the guidelines is scattered and voluntary.

Sweden has established the ByggaF methodology for documenting and communicating moisture safety considerations as a holistic approach throughout the construction process to major stakeholders [8]. A standardized process to include moisture safety issues throughout the process could potentially significantly reduce the number of buildings experiencing moisture problems during all stages.

There has been increased interest in specific areas of moisture safety, such as building airtightness. A widespread opinion is that concrete and masonry buildings are tighter than wood buildings. Building airtightness is highly dependent upon design details and quality of execution by the construction company. If similar enthusiasm could be developed towards all the aspects of moisture safety, then the overall situation would be much different from today.

5. Conclusions

The current article may serve as a scientific reference documenting that design consultants in three European countries still do observe moisture problems in buildings. Approximately one of three construction projects in the last five years were affected by moisture problems in Austria, Denmark, and Finland, even though practitioners apply state of the art measures to prevent moisture damage to some extent. One in five moisture problems is most likely attributed to water installations.

A considerable variety of factors influencing moisture safety were seen as generally equally important. Future efforts for improving the planning environment must consider – at least – each of the factors covered by the survey. Practitioners must be prepared to deal with a plethora of influences in a piecemeal improvement approach. Design and construction guidelines helped supplement the building code requirements.

Differences in answers between countries are statistically significant, for instance, regarding the importance of dedicated personnel involved in a project. However, the differing weighting between countries may be due to influences not seen in the surveys, such as socio-economic aspects, building traditions, or building vernacular, especially when considering wood construction. Significant differences regarding the underlying causes of moisture problems in different countries may not be inferred from the survey. Construction traditions may have mixed uses of materials, such as wood roofs in either concrete or masonry buildings.

Respondents have stated that the information about moisture safety is available, but that dedicated time and budget are required for better moisture safety in buildings during the design and construction phases. The Finnish respondents reported that practically all the topics were very important with especially high percentage values for moisture problems in construction and building use. The number of problems related to water installations was approximately 25 %.

The survey addressed moisture safety on a general level and did not specify details such as mould growth on different building materials. To varying degrees, mould can grow on gypsum plasterboards, wood, and concrete. A major difference is that the load-bearing functions of concrete and masonry are usually not jeopardized by moisture saturation as with timber construction.

A quantitative goal resulting from the current survey is to raise the percentages of applied moisture safety measures while reducing the lack of available instruments. However, the usefulness of selected instruments will be strongly case-specific. Accordingly, subtopics such as reasons for problems due to leaky water installations should be analysed in more detail. Other methods than an online survey may be more effective such as the Delphi Method applying an interview technique of expert panels.

In addition to the professional groups surveyed here, other needs analyses (e.g., policymakers, building owners, tenants) are necessary to establish moisture safety in buildings. Furthermore, factors such as climate change, evolving building uses [17], economic status [11], and potentially increased respiratory illness due to the COVID-19 pandemic [7] should not be neglected.

These survey results form the basis for drafting a new iterative process towards a research roadmap considering the needs of practising architects and engineers for CIB W040 to determine the research questions for improving building resilience and to manage the risk of building failure through improved moisture safety, and for disseminating knowledge about moisture safety effectively.

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