Moisture safety in wood frame constructions – What do we know today? – A literature overview

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Moisture safety in wood frame constructions – What do we know today? – A literature overview

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Summary

This paper intends to offer an overview of current knowledge in practical moisture safety in wood frame house. Books, journal articles, reports and other documents at different levels regarding moisture and moisture safety in different aspects are summarized. Possible gaps and flaws in existing knowledge, such as, lack of blind verifications of moisture safety calculation tools, the need to separate quantitative and qualitative issues in the moisture safety design processes and the fact that mould growth model handle the influence of duration in different manners are reported.

Keywords: Moisture safety, mould growth, wood frame constructions, literature overview

1. Introduction

1.1 Background

The interests of using wood frame constructions have increased during the last decade depending on the intention to build more carbon dioxide, CO2, efficient houses [1]. In Northern European countries there is also a tradition of wood frame houses and plenty of wood as raw material that can be used in buildings [2] [3].

Regardless what materials or design system is used there is a need to build moisture safe constructions. Moisture damages are linked to negative consequences, extra costs and cause sickness and bad health because of inadequate indoor climate and Sick Building Syndrome [4].

Today, there is a relative good basic knowledge in the area of building physics, moisture transport and factors affecting mould growth [5] [6] [7] [8] [9]. However, since moisture related damages still is common and cause high costs and bad indoor climate it may be questioned if there are areas with lack of knowledge and if or how knowledge in the moisture safety area are implemented in the building industry [4] [10] [11].

1.2 Aim

The aim of this paper is to give an overview of current knowledge in the moisture safety area in wood frame constructions. The intention is also to present new insights into underlying factors, results from field studies and strategies to avoid mould and moisture damages as well as to discuss mould models and calculation tools that can be used to predict mould and moisture damages in wood frame constructions. Furthermore, the paper aims to show weaknesses and gaps in existing knowledge and research in the moisture safety area and suggest direction of further research.

1.3 Limitations

The paper does not include a complete review of all knowledge in the field and it is instead more a kind of "state-of-the-art" that overviews and presents the latest knowledge. The study does not aim to discuss and evaluate basic building physic knowledge. Furthermore, it is limited to focus on wood frame constructions. Material data and boundary conditions are not considered. Additional steps have been taken to especially present literature that is useful and applicable to applied research and possible to use in real building constructions, without any further development. Some references are given in national languages such as Swedish, Finnish and German.

2. Literature search method

This paper consists of studies and research documents at different levels. The connection between and effects of qualitative and quantitative factors also make it necessary to include studies at different levels. Therefore the study includes doctoral theses and international reviewed journal articles as well as national institute reports, conference papers and master- and bachelor theses.

Initially, searches in open access data bases in the area were carried out, but mostly with poor results. The only open database that showed relevant and reasonable hits was Google Scholar. This may depends on that the topic of applied building physics seem to be primarily published for national use since the construction sector is strongly national. In the area of mould and moisture, the local climate has a big influence, and, consequently, only Nordic research is useful in the Nordic area. Furthermore, the construction sector acts conservatively and in a closed manner [10] [11], i.e. findings and knowledge are not supposed to be spread to competitors. Instead of a random literature search on Google Scholar, references and authors in known documents were used to find new relevant documents. A risk with this kind of search is that critical articles may have been excluded.

Furthermore, conference proceedings from the latest conferences in the area have been used and scanned. This has given both an overview of the present knowledge level and a good picture of the most recent research results that have been published.

The fact that some research in the area is connected to national experience or local conditions and traditions have made that national institute reports and master's and bachelor's theses also have been studied. In addition, the SP Technical Research Institute of Sweden database was used.

3. Summary of studied representative papers, articles and documents

Below are important facts from several studied journal articles, conference papers, thesis and other documents summarized in different groups depending on their content. A more detailed description of total 146 documents is shown in a separate report [12].

3.1 Laws, Rules and Regulations, Enquiries and National Investigations and Reports

By studying building laws, rules and regulations concerning mould and moisture in some European countries it seems that there is variation in demands, structure and limitations. Some countries focus on qualitative limits and some connect mould and moisture risks to inhabitant's health. Furthermore, there are countries that give recommendations, qualitative or quantitative, how to avoid mould and moisture related damages. In general, studied laws, rules and regulations seem to be underdeveloped compare to regulations in other building areas such as statics, availability, fire safety and energy use [13] [14] [15].

Furthermore, studied Swedish national investigations show that there is a lack of knowledge in the moisture safety area and unclear responsibilities [10] [16]. Verified methods and calculation tools to predict and avoid moisture damages are also required [4].

3.2 Moisture Safety Design Mehtods

Different moisture safety design processes and methods to avoid moisture related damages have been found. Some methods concern qualitative issues, i.e. practical or basic knowledge, and some quantitative issues, i.e. measurable [12]. Only one moisture safety design method that concern both qualitative and quantitative issues and cover the entire building process has been found [17]. Studied quantitative methods focus on a maximum relative humidity with respect to duration limits to avoid mould growth in buildings [18] or use statistic methods calculating the risk of mould growth [19] [20]. There are also moisture safety design methods that focus on qualitative issues [21]. General guidelines in order to achieve high quality timber buildings where moisture related questions are briefly discussed have also been found [22].

3.3 Mould Growth Models

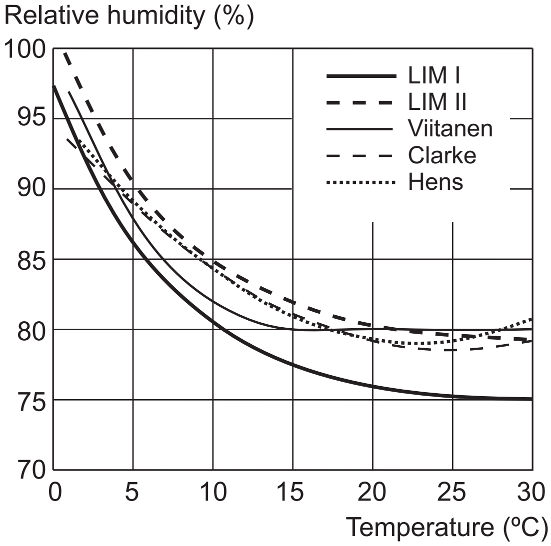

Fig. 1 Example of different mould growth models dependent on relative humidity and temperature [23].

There is a broad agreement that different material has various sensitivity to moisture and that temperature, relative humidity, and duration are the main factors affecting the risk of mould growth [23]. Several of mould growth models have also been invented based on those facts, as shown in Figure 1. However, the models have a number of different theories and models about reducing, if this is at all possible, the amount of mould growth during non-favourable mould growth climate conditions. Furthermore, different critical levels with regard to the effects of duration are presented and none of studied mould growth model include the influence of short time climate variations [24] [25] [26] [27]. The mould growth models mainly show if there is a risk of mould growth or not, without presenting underlying factors affecting the risk of mould growth and possible actions in order to avoid or reduce the risk of moisture damages [28].

3.4 Water Proofing Membranes in Wet Rooms/ Bathrooms

Bathrooms, and other wet rooms, are pointed out as an area where mould and moisture damages have high cost [4]. Many bathrooms with exterior walls made of wood in Nordic European countries have three different vapour resistance membranes. To avoid damages, the interior waterproofing membrane in bathrooms has to have a higher vapour resistance compared to the other vapour membranes in the wall. Studies show that many waterproofing membranes has to low vapour resistance compare to other vapour retarder membranes in the wall. Therefore penetrating vapour become locked in, between the interior waterproofing membrane and the vapour retarder, and creates mould damages [29]. Acceptable vapour resistance of weather or wind resistive barrier in the outer part of the wall depends on the vapour resistance on the other membranes and the exterior climate. Furthermore, the vapour resistance is often given by a test method that neglects the influence of high relative humidity. Unfortunately, waterproofing membranes have shown significantly higher vapour diffusivity if there is a high relative humidity, which naturally occurs in bathrooms. This increase the risk of moisture related damages in exterior bathroom walls [30].

Many damages also occurs dependent on detailing errors. Several waterproofing membrane systems have been tested for leakages in or close to installations, pipes penetrations or other details with bad results. None of the systems had acceptable solutions for detailing [31]. The influence of detailing errors is also shown in damages investigations where the main cause of damage was poor sealing around or close to the floor drainage point. An interesting result from a limited study shows that “amateur” work appeared to be better than work carried out by professional workers [32].

3.5 Airtightness in Buildings

The quality of airtightness in buildings mainly depends on good detailing and a building design or building system that allows good joints between airtight membranes. Plenty of examples with constructions detailing and solutions of how joints can be put together and sealed have been found, both as literature and in forms of mounting instructions from material industry [33] [34] [35]. There are also validations made of different sealing methods [36]. New materials, especially membrane tools for joints and detailing, seem to be constant developed by the industry. Furthermore, methods handling air tightness during the entire building process, including verifications, have been found [37].

3.6 Rendered Non-Drained and Unventilated Facades

It is well known that rendered non-drained wood frame walls without a ventilated cladding, so-called ETICS design, are a risk construction [38]. A great number of moisture damages have been found in houses with this design [39]. The main causes of damages are detailing error, poor workmanship and leakages of penetrating driving rain. Suggestions of possible moisture safe repairs for damaged walls [40] as well as studies showing the positive effects and importance of a well-ventilated air gap behind the claddings have been found [41] [42].

3.7 Moisture Risks During the On-Site Construction Phase

Recent Swedish field studies show that mould growth are noticed in wood frame houses that have become exposed to only one rain during the on-site production of wood element, even in cases where the mounting have been completed in one day. The risk of mould growth is highly dependent on the prevailing weather conditions during the on-site production until the house is made weather tight [43]. Furthermore, laboratory studies show that if sills or studs become exposed to rain during the construction phase they also become damaged by mould growth [44]. However, there are general and detailed methods, descriptions and measuring methods of how to control and handle moisture in wood material during the on-site construction phase [17] [43] [45].

3.8 Well-insulated Wood Frame Houses

Well-insulated constructions are generally more sensitive to mould- and moisture damages compared to less insulated constructions [46]. This depends on several factors such as higher amount of initial construction moisture, longer dry out times and a higher amount of cold parts in the construction. To build moisture safe well-insulated wood frame houses there have to be a well-ventilated and drained air gap behind the cladding, the influence of driving rain have to be considered and organic materials in the outer part of walls have to be protected by mould resistant thermal insulation. Furthermore, there is a need of an interior vapour barrier in cold climate and the outer parts of walls have to have vapour diffuse open materials to facilitate the dry out process of in-leaking water and initial construction moisture [8] [47]. However, the risk of increased moisture damage is not significantly higher in newly build Swedish cold attics since they are already normally well-insulated [48]. The influence of long wave radiation and the air ventilation rate in cold attics also have a major influence on the risk of mould growth damages in attics [49].

3.9 Air Flow Rate in the Air Gap in Ventilated Cladding

Different studies establish the need of a well-ventilated and drained air gap behind the cladding for several moisture safety reasons. The service life of the facade is positively affected of a well-ventilated air gap [50]. The dry out potential from both the façade and the wood frame wall on the inside of the air gap increase if the air gap is well-ventilated [42]. In case of a brick façade with a wood frame construction behind the air gap it is even more important to establish a proper air flow in the air gap, which gives a high air ventilation rate, in order to achieve a moisture-safe building [51]. A 25 mm wide air gap behind wood façades and a 50 mm wide air gap behind brick façades is suggested [42] [47] [52]. Furthermore, the importance of a well-ventilated air gap increases in well-insulated wood constructions. A well-ventilated air gap with vertical or perforated battens also has positive effects on drainage and decreasing the air pressure difference over the cladding [47].

3.10 Moisture Calculation Programs

There is a need of reliable and user friendly calculation tools that could be used to predict and avoid moisture related damages [4]. Several moisture calculation programs with coupled heat- and moisture transport have been found [12]. Most of the programs use forward differential equations methods [6] [53] [54] [55] [56]. The availability of using forward differential equation method in real cases has been known since the 70´s. However, it has not been possible to apply this knowledge to real conditions because of the lack of computer capacity [53]. Some programs based on the finite element calculation method have also been found [12] [57]. Many programs seem to be based on the same general equations and then further developed from each other. Most of the programs also seem to be made for research purposes. Three, WUFI, DELPHIN and COMSOL, of eleven studied programs seems to be user friendly and could be used as moisture safety tools in the design phase by the industry. COMSOL is based on the finite element method [12]. COMSOL and DELPHIN are also perceived as more complex compare to WUFI. More complex two-dimensional versions also exist of some programs. There are plenty of studies where calculated values have been compared with measured values. Both independent and dependent comparisons made by the developer were found [6] [53] [58] [59] [60]. However, none of over 50 known studies seems to make blind comparison between measured and calculated values, i.e. not knowing measured results before the calculation is made [12]. Furthermore, some studies show the importance of using appropriate boundary conditions to get reliable results, such as air flow in the air gap and the influence of driving rain [40] [47] [58] [61] [62].

4. Summary, discussion and conclusions

The summary, discussion and conclusions intend to point out examples of relevant knowledge and to give examples of gaps where there is a lack of knowledge and suggest further research. Based on the studied journal articles, conference papers, dissertations, theses, standards, books and other documents, knowledge could be summarized and several conclusions could be established based on the contents of several documents.

In general it is obvious that there is lot of Swedish knowledge that only is national published and not widely spread to the international research society. It is also obvious that basic knowledge exists in the area of heat, moisture, moisture transport and mould models. However, there are several documents that establish the need of further research in the area since moisture related damage is common and has a great effect on both financial and health issues. Furthermore, the construction industry needs to carry out further work with regard to moisture protection in existing construction systems. Investigations also show that attitude, unclear responsibilities and deficiencies handling moisture safety issues in the industry are a part of the problem.

There is broad agreement about the main factors affecting the risk of mould growth. However, possible ways of reducing mould growth and its influence on health need to be further investigated as well as critical levels with regard to the effects and duration. The effects of short-time variations between critical and non-critical conditions also have to be further studied. Mould models also need to be further developed to direct or indirect show possible actions how to reduce or avoid the risk of mould growth in critical constructions.

Moisture safety design process is needed to reduce the risk of mould and moisture related damages. It is established that both qualitative and quantitative issues need to be considered in the moisture safety design process and it needs to be in focus and dealt with from the planning phase, throughout the entire building process.

New waterproofing membranes and systems with high quality joints in bathrooms need to be developed. There is also a need to ensure the vapour tightness when the membranes are in contact with high relative humidity. The difference in vapour resistance between different membranes in exterior bathroom walls also needs to be handled in the design and construction phase.

Generally there are good materials, tools and detailing solutions to build airtight constructions. It also seems to be a positive ongoing developing process with new materials and new tools in the material industry. However, it is always best to try to find design solutions with good opportunities for easy made airtight joints and membrane connections.

Experience and studies from rendered non-drained and unventilated facades with wood frame walls, so-called ETICS constructions, could be summed up with that those kinds of constructions should be avoided in order to build moisture safe wood frame constructions. The importance of a ventilated air gap behind the façade in order to reach a long service life is also established. No matter the design the influence of driving rain have to be considered, which can be made by a well-ventilated and drained air gap behind the façade.

It is possible to build wood frame constructions with high thermal resistance, but there is an increased risk of mould and moisture damage. A number of specific factors affecting the moisture safety of well-insulated wood frame houses have been identified and must be considered. For instance, the organic materials in the outer part of the wall needs to be protected, preferably by a mould resistance vapour diffuse open insulation board. Furthermore, the importance of a well-ventilated air gap behind the façade cladding increases with well-insulated wood frame walls.

Wood frame houses cannot become exposed to rain during the construction phase in order to safely avoid the risk of mould growth. By build under tent or concentrate the on-site construction to a day without rain in case of building element houses, this risk could be neglected. This is especially important in well-insulated houses which are more sensitive to moisture.

I order to predict and avoid moisture damage it is also shown that there is a need for user-friendly and reliable moisture calculation tools and methods. User-friendly tools exist but do not seem to be widely spread in the construction industry. However, none of the studied moisture calculation tools, no matter if they are commercial or used for research, seems to be verified to real conditions by blind comparisons.

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