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KEYNOTE SESSION

The new generation of Eurocodes – with a special look at Eurocode 5

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Summary

This document provides an introduction to the review process of the Eurocodes, especially Eurocode 5, the structure of the work and the committee and the targets of the revision progress. In addition, a short excursus is given on 'Ease-of-Use' and legitimate 'National Determined Parameters' (NDP). This paper provides experts not familiar with standardisation a clear overview of structures, targets and processes and is an invitation for further coordination and cooperation with engineers and code writers from other sectors and the area of product standardization.

Keywords: Standardization, Eurocode 5 – Design of Timber Structures, CEN/TC 250 – Structural Eurocodes

Introduction

The standard Eurocode 5 – or better all parts of EN 1995 – Design of Timber Structures – with Part 1-1: General – Common rules and rules for buildings, Part 1-2: General – Structural fire design and Part 2: Bridges – was published in 2004 after a long historical development starting in 1983 with a CIB/W18 report "Structural Timber Design Code".

Eurocode 5 is part of the family of Structural Eurocodes providing common European design rules for the design of structures with all main building materials creating the built environment. The Codes are nowadays implemented and applied in all European countries. They are especially helpful in Member States where no or few design rules were available, which was true in many cases for timber structures.

The Eurocodes are of high importance for a common European building market and therefore for planners, industry and craftsmanship working more and more cross borders. Finally they should provide a common level of safety in buildings, as there is no reason from the human perspective to provide different safety levels in Vienna, Berlin, Helsinki or Lisbon. But – 'the safety of the built environment' is under the responsibility of the European countries and 'safety' is sometimes related to costs, tradition, etc. Therefore, the Eurocodes provide the instrument of so called 'National Determined Parameters' (NDP) to be able to make adjustments to the foreseen national level. In addition, NDP's are e.g. necessary to allow adaptations to climate related loads. The NDP's are published in 'National Annexes' (NA) to the national editions of the codes by the responsible National Standardization Body (NSB), like AFNOR (France), BS (UK), DIN (Germany) or SIS (Sweden).

The European Commission has a strong interest on the further development of the Eurocodes to achieve a further matching of design rules in Europe. But it is recognized that there are nowadays high variations of NDP's and – in addition – a high number of 'Non-Contradictory Information' (NCI) given in the published NA's, demonstrating that rules are missing in the Eurocodes. In general, design rules need to be improved or to be expanded and, at the same time, additional design rules need to comply with the 'state-of-the-art'. Therefore – beside other targets – a main aim is a further harmonization and evolution of the European design rules for buildings to enable additional improvement of the European construction and engineering sector and a sustainable development of the built environment.

European Standardization

The Structural Eurocodes committee CEN / TC 250 and other liasions

First of all, it should be described how the Eurocode 5 standardization committee is arranged within the whole standardization body and which standardization committees affect the work of the Eurocode 5 standardization committee and vice-versa.

The home of European standardization is the European Committee for Standardization, in short CEN (Comité Européen de Normalisation). CEN is responsible for developing and defining standards at European level and it is officially recognized by the European Union and the European Free Trade Association (EFTA). 0

Within CEN different fields are included and several technical committees (TC) deal with different subjects. The technical committee working on the development and definition of the design rules of common building and civil engineering structures has been numbered as CEN/TC 250.

The built environment is affected by several other technical committees dealing with product standards, environmental subjects or fire safety aspects, influencing the development of the Eurocodes. With regard to timber structures, the CEN technical committees shown in Figure 1 influence the design of timber structures and therefore are exemplary liaison committees of CEN/TC 250.

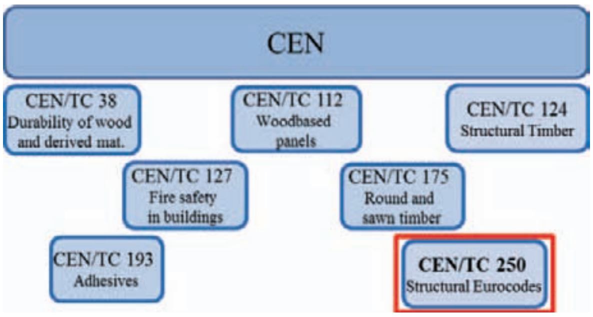

Figure 1. CEN technical committees connected to timber structures

For matters of coordination and flow of information, liaisons between CEN/TC 250 and these TC's are crucial.

The technical committee on Sructural Eurodcodes CEN / TC 250

CEN/TC 250 is additionally structured into different sub-committees.

As shown in Figure 2, established subcommittees (SC) represent the work with regard to the existing 10 Eurocodes (EC) and the upcoming Eurocode 11 for structural glass. The number of the subcommittee represents the number of the Eurocode, like SC 5 for Eurocode 5 – Design of timber Structures. Working groups (WG) provide support in different subjects, like policy guidelines, assessment and retrofitting of structures or robustness. Horizontal groups (HG) on fire and bridges combine all subcommittees of the Eurocodes.

CEN/TC 250 itself works as coordinating leader and surveys the work of all SC's, WG's and HG's. The secretariat for CEN/TC 250 is hold by BSI, the British Standards Institution, and supports the CEN/TC 250 Chairman, actual Dr. Steve Denton. Members of CEN/TC 250 are the SC, WG and HG Chairmen or Chairwomen as well as delegates from the different National Standardization Bodies of the Member States and representatives of some related European organizations.

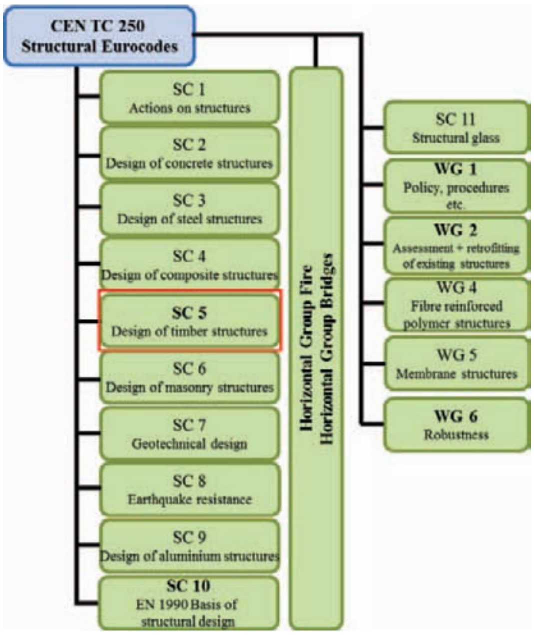

Figure 2. Structure of CEN / TC 250 Structural Eurocodes

The subcommittee on Eurocode 5 – Design of Timber Structures – CEN / TC 250 / SC 5

Every SC dealing with the further development of a Eurocode has its own structure. Below SC level, supporting working groups (WG) are established in order to divide the work into concrete subjects and to define responsibilities clearly. The SC 5 plenary decided to structure the work for the next generation of EC 5 into ten WG's. Figure 3 shows the ten WG's with their subjects and their WG Convenors.

For the division into several subjects, the main focus has been to divide into already existing parts of EC 5 (e.g. 'Fire' and 'Bridges'), to distinguish between timber design in general and design of timber connections ('Cluster' and 'Connections') and to concentrate on the new design items ('CLT', 'TCC' and 'Reinforcement'). Cross-laminated timber (CLT), timber concrete composites (TCC) as well as reinforcement are topics missing in the current EC 5 and need to be included to comply with the 'state-of-the-art'. WG 8 'Seismic design' has been established to support and expand the work of the technical committee on Eurocode 8, CEN/TC 250/SC 8. SC5/WG8 is working officially under SC8 – 'Seismic Design' as CEN/TC250/SC8/WG3 – the members are identically. WG 9 is dealing with the subject 'execution' which focuses on minimum requirements for fabrication, transport, erection, treatment and finishes to ensure that "what is designed is build". WG 10 is working on the first two main chapters of EC 5 covering basis of design and material properties. Focusing on the home countries of the WG Convenors, it is obvious that CEN/TC 250/SC 5 has made a good example on national variety and geographic coverage of Member States. The secretariat for CEN/TC 250/SC 5 is held by SIS, the Swedish Standards Institute. The ongoing work of SC 5 is as well as the work of all other SCs mirrored by National Standardization Committees in the Member States.

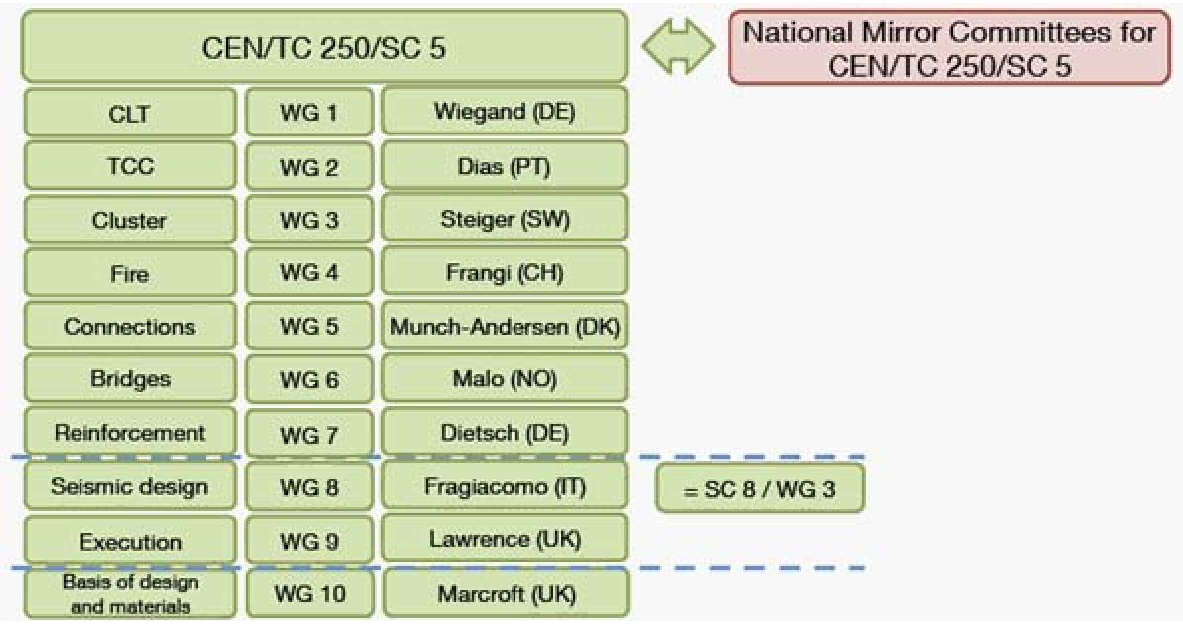

Figure 3. Structure of CEN / TC 250 / SC 5 Timber Structures

Process of the mandated work

Response to the mandate M / 515

In December 2012, Mandate M/515 had been finalized by the European Commission (EC) inviting CEN to develop a detailed standardisation work programme for the publication of the second generation of Eurocodes. This work programme has been sent to the EC as 'Response to Mandate M/515'. Besides user confidence (see Section 0) and reduction of National Determined Parameters (see Section 0) the work programme focuses on further harmonisation and inclusion of 'state-of-the-art' 0.

CEN/TC 250 leads the execution of the Mandate M/515 with regard to the design of construction works and, consequently, is responsible for the successful development of the second generation of the Eurocodes by using the support of the EC 0. The 'Evolution of the Eurocodes' project is the standardization project with the highest amount of funding in the EU ever.

The work programme is divided into four overlapping phases including certain tasks defined by task description, task reference and deliverables and differentiated by SC's, WG's and HG's of CEN/TC 250.

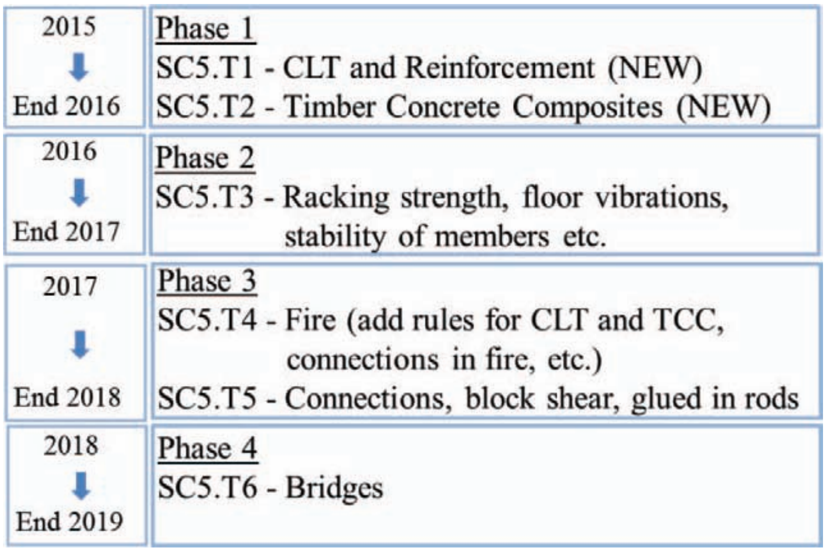

Figure 4. Structure and first planned timeline of CEN/TC 250/SC 5 tasks

The 'Response to the mandate' prescribes which tasks have to be taken into account in which phase. In Figure 4 the structure of tasks connected to CEN/TC 250/SC 5 (SC5.T1 – SC5.T6) is shown for the original planned timeline from 2015 until 2020. In between the timeline is a bit postponed by approximately two years. As the final funding decision is already taken and the work of the SCs is on time it is expected that no further delay will occur and the technical work will be finalized in 2022. The different phases demonstrate that it was foreseen to deal with new design items at first, before starting the process of the revision of existing items. The Evolution of Eurocode 5 in the field of CLT and TCC is already finalized and the modification and completion of the other parts of EN 1995 is now in process, see also clauses 4.3 and 4.5.

It is evident that the tasks are directly connected to the work of the SC 5/WG's listed in Figure 3. As a consequence, the division of CEN/TC 250/SC 5 work into working groups is inspired by the defined SC 5 tasks (see Figure 5).

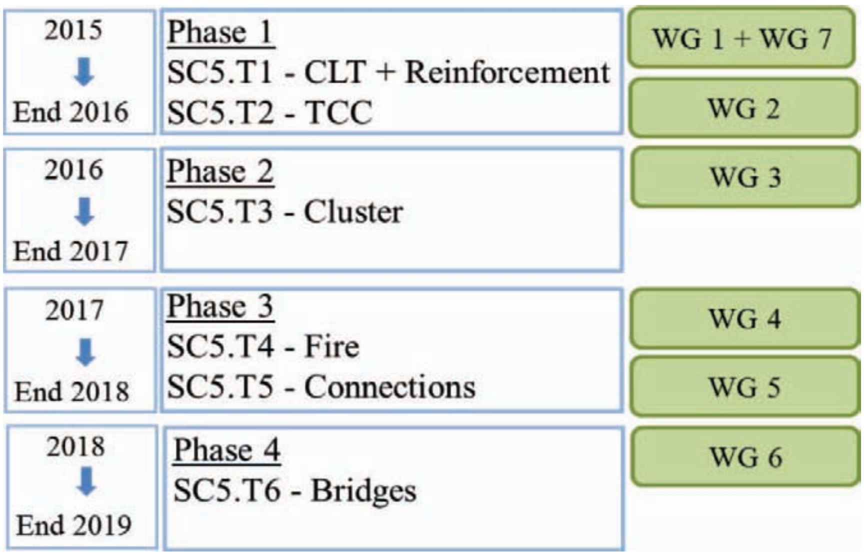

Figure 5. CEN/TC 250/SC 5 tasks connected to SC 5/WG's

Team work / Responsibilities

CEN/TC 250/SC 5 Working Groups (SC 5/WGs)

Working groups on new, revised and additional items in the field of timber structures are established within the subcommittee CEN/TC 250/SC 5. Experts from building authorities, key industry bodies and from the field of research and development of all Member States are members of these groups – sometimes even since the first generation of Eurocodes – and bring their knowledge as technical input into the working process. The technical proposals and discussions within the working groups started already in advance to the mandated phases, shown in Figure 5.

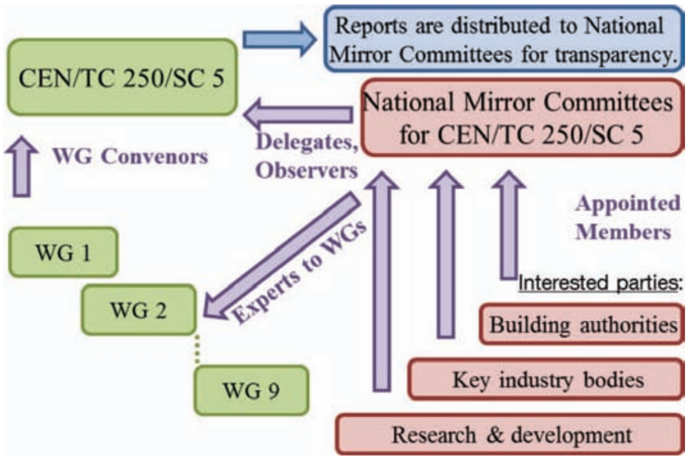

Figure 6. Delegations and experts of CEN/TC 250/SC 5

Figure 6 demonstrates how national mirror committees include representatives of interested parties and send them to participate in European standardization work as appointed members. Appointed national delegates – with one person being head of delegation – are sent by the NSBs to CEN/TC 250/SC 5 plenary meetings. The head of delegation is appointed to vote for the national delegation and represents only national opinions and matters. Observers need a permission for attendance and observing the meeting. Additional members are sent to participate in SC 5/WG's as experts, where it is expected to receive technical input to achieve the objectives of the working groups. The experts in the WGs are not bound to national votes.

The WG Convenors are responsible to inform the WG members about subjects discussed within CEN/TC 250/SC 5 which are relevant for the work of their group. The WG Convenors attend as WG representatives in SC 5 plenary meetings.

For reasons of transparency reports and important information are distributed in national mirror committees and, additionally, the heads of delegation are responsible for the flow of information between European and national level.

To score the flow of information within CEN/TC 250, reports are required for each meeting, written and sent by working groups and subcommittees. In Figure 7 these interrelations are summarized graphically.

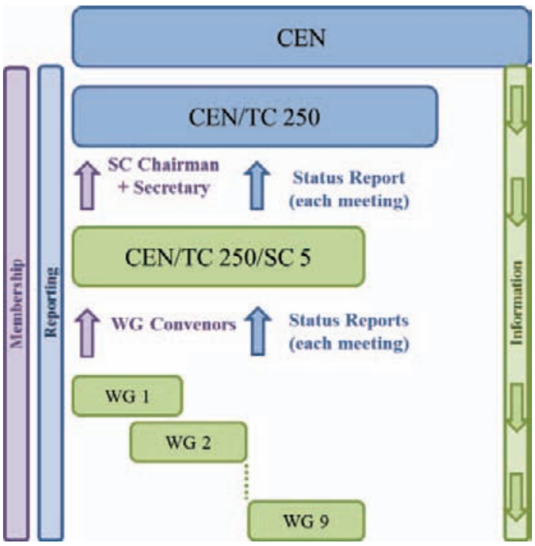

Figure 7. Organization and reporting within CEN

Convenors, Chairmen and Chairwomen attend meetings of one higher level as representatives of their group. Vice versa, requirements are transmitted and information is distributed one level lower.

Project Teams

In order to fulfil the objects of the work programme, groups of experts – so-called Project Teams (PT) – are established in a tender process launched parallel to the start of a new phase. The PT's consist of five members and one leader. They are responsible for a certain task of the work programme (e.g. SC5.T1 as shown in Figure 5) and therefore connected to a certain SC, WG or HG of CEN/TC 250.

They are responsible for the whole writing process of the new standards. This "editorial" work – which figures out in reality as an intensive technical work as well – has to be proceeded in very close cooperation with the work of the SC/WG's to achieve Eurocode drafts in compliance with the Mandate. In addition, the PT's shall provide background documents giving clarification and verification (e.g. scientific background) of proposed clauses, equations and design provisions. References to relevant sources like scientific papers, research projects or national standards shall help to record the input of this scientific background. 0

Needed qualifications of PT members are on the one hand sufficient expertise with regard to the development of standards and on the other hand professional background and experience in the corresponding field 0. The tender process is coordinated by NEN, the Netherlands Standardization Institute. Actual all necessary PTs are appointed (see Figure 5) the first two PTs have finalized their work. PT 3 'Cluster' is at the time being the Project Team with the highest progress level.

For matters of coordination and flow of information communication between SC/WG's and PT's is decisive to proceed successfully. While WG's are discussing about technical contents – design approaches, simplifications and the contents' structure – the PT's draft with the help of these contents the standard text and process the delivered background information. The work process and the draft process need be coordinated to guarantee the compliance of the mandated timeline.

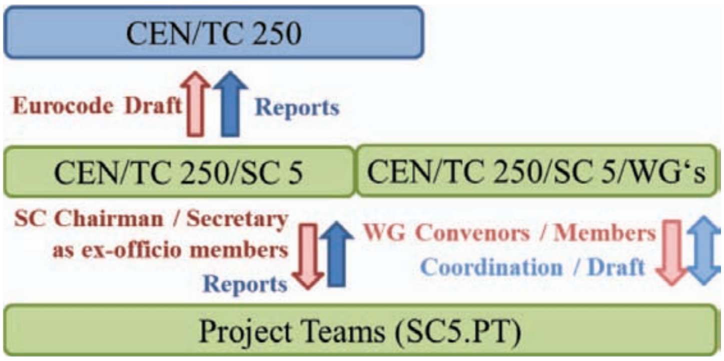

Figure 8. Responsibilities within CEN / TC 250 / SC 5

The CEN/TC 250 policy guidelines describe responsibilities of the different groups. Like already mentioned, SC 5/WG's and PT's should collaborate closely to enable a fruitful outcome. Consequently, WG Convenors and WG members may be included in Project Teams, as indicated in Figure 8.

The PT's for the different SC 5 tasks report directly to the SC 5 plenary, while SC 5 Chairman and Secretary are to be informed about upcoming PT meetings, which they can attend as ex-officio members. CEN/TC 250/SC 5 reports directly to the CEN/TC 250 plenary, including information of the ongoing work of the Project Teams.

The different Eurocode Drafts are written by the PTs under coordination with the SC 5/WGs and reviewed by the SC 5 plenary. Finally, CEN/TC 250/SC 5 gives acceptance of the Eurocode drafts to the PT's and sends the draft to CEN/TC 250.

Figure 9 demonstrates graphically the official procedure after finalizing the Eurocode drafts 0.

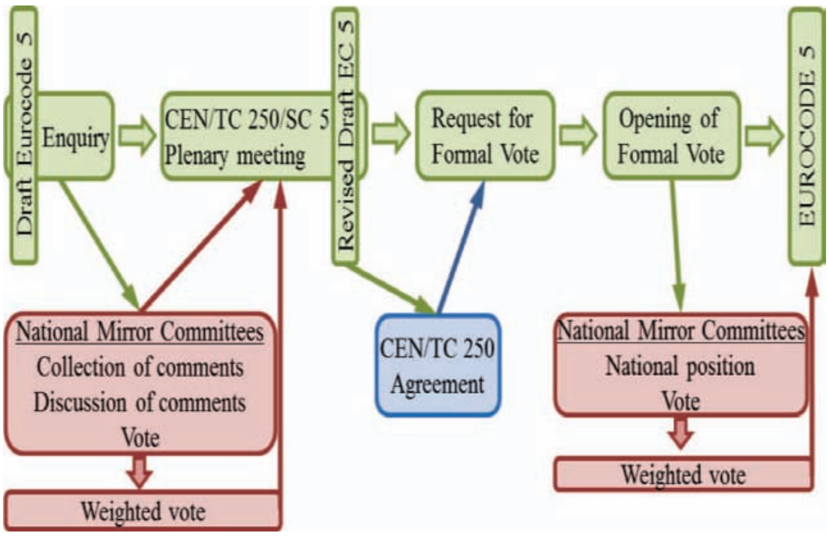

Figure 9. Official procedure after finalizing the EC drafts

When starting the enquiry process the national mirror committees are asked to collect and discuss comments on the Eurocode draft as well as to give a national vote. Approval of the enquiry requires simple majority and at least 71% positive weighted vote (abstentions not counted). The largest weightings are connected to the Member States France, Germany, Italy, Turkey and United Kingdom, in each case a weighting of 29 points out of 405. Iceland and Malta have the least weightings with in each case 7 points out of 405. 0

The enquiry timeframe lasts three months. Afterwards, the comments have to be answered by CEN/TC 250/SC 5 and are used to create a revised Eurocode draft. CEN/TC 250/SC 5 is responsible for the finalization of the drafting process by sending the revised draft again to CEN/TC 250. CEN/TC 250 takes the final decision to accept the new Eurocode 5 parts in coordination with all other Eurocodes and agrees to open the Formal Vote (FV). A positive assessment is needed during the enquiry otherwise a second enquiry has to be organized.

The FV asks the national mirror committees to give their vote as national position – this time – just as acceptance or rejection of the revised Eurocode draft. Only editorial comments are allowed during the FV. Again a weighted vote, requiring simple majority and 71% approval (abstentions not counted), is needed.

The future development of Eurocode 5

Enhancing 'ease-of-use'

After an intensive discussion within CEN/TC 250 a clear definition is now available to whom the Eurocodes are addressed. The Eurocodes are addressed to "Competent civil, structural and geotechnical engineers, typically qualified professionals able to work independently in relevant fields" 0.

This definition is included in a CEN/TC 250 document called 'Position paper on enhancing ease of use of the Structural Eurocode' 0 created to improve the 'Ease-of-Use' of the Eurocodes for practical users. This discussion point is relevant in order to improve harmonisation between the Eurocodes and to achieve long term confidence by the users. Examples for principles listed in the document are as follows:

- Clarity and understandability
- 'Ease-of-navigation'
- 'State-of-the-art'
- No fundamental changes to the approach to design and to the structure of the Eurocodes
- Consistency with product standards and standards for execution 0

On the one hand, the keywords 'clarity' and 'understand-ability' may give the idea of restructuring Eurocode 5. On the other hand, it is clearly described that fundamental changes to the approach to structure of the Eurocodes are to be avoided. Discussing the content of the new Eurocode 5 generation raised the question how the content with regard to simplified rules, scientifically based design methods and tabulated data should be balanced.

Tabulated data (e.g. factors and fixed values) or diagrams – developed to find results on the safe side – are easy to apply. They could be useful for preliminary and /or quick design, but have the disadvantage of increasing the amount of pages. Furthermore, the results are restricted to the boundary conditions of the tables. 0

Simplified design methods for standard applications have the advantage of being easy to understand – also for non-daily users –, easy to apply and short with regard to the amount of text. But simplified rules predict conservative results and sometimes they are even restricted to certain applications or within certain boundary conditions.

General scientifically based design methods have the advantage of being more advanced as well as more accurate and economic. They are often applicable also to new developments, but require higher effort for the user.

In general there is always a clash of interests between the wish of industry to be able to optimize as far as possible design of parts with high iteration factor and opposite the wish of engineers to have simplified methods for daily use available. A code should be able to deliver solutions for both directions. A limitation or shortage of pages is for sure not the a target of revision, as especially in the case of Timber Structures the pleasant development of the state-of-art has to be mirrored, especially design rules for Cross Laminated Timber (CLT) and Timber Concrete Composites (TCC).

CEN/TC 250/SC 5 decided therefore, that regulations and general design approaches shall remain in the main part giving the best knowledgeable information and making economically designed timber structures possible. Simplified rules and tabulated data might be additionally provided in the Annexes of EC 5 or in commented versions of EC 5. In single cases a vice-versa approach may be a better solution. Design rules which are used only by a limited number of specialists, like the design of trussed rafters with punched metal plate fasteners, will be given in Normative Annexes, to enable a better overview in the main part by concentrating it to the most used cases (20% of the design rules – relevant for 80% of daily use design!). This strategy should enable a neatly arranged structure of the main part, as mentioned before to ease the use of the codes for engineers not using all relevant parts every day. Most of the complaints received during revision process about 'difficult-to-use' were more related to navigation in the code than to technical issues.

Revision of existing parts

Systematic reviews of the existing parts were realised for all parts of Eurocode 5 in 2014 and 2015. Comments from all National Standardization Bodies (NSBs) on the first generation of Eurocodes were collected. This feedback gave indications, which design rules need to be improved or to be expanded for the second generation of Eurocodes.

Besides a long list on additional subjects, the following subjects will be taken into account as most important items.

- **Vibration of floors:** In the case of vibration of floors more general methods – also applicable for new developments as CLT or TCC – are needed.
- **Compression perpendicular to the grain:** For the design of compression perpendicular to the grain additional design requirements are to be added.
- **Racking resistance of walls:** Only one method instead of two different methods should be found within Eurocode 5 regarding racking resistance of walls.
- **Element stability:** More precise information on element stability need to be included.
- **Timber failure capacity in connections:** In the case of timber failure capacity of connections, it should be clearly differentiated between failure modes of one single fastener, a group of fasteners and the timber capacity surrounding the connection.
- **Rules for the 'execution' of timber structures:** Additionally needed rules for the 'execution' of timber structures is part of the work program of SC 5/WG 9. In addition TC 250 decided to remove execution rules from the main parts of the Eurocodes, which are not directly related to design rules. E.g. in EC5 rules for spacing of fasteners will stay in the Code, rules about 'Transport and Erection' will be deleted and integrated in 'Execution rules'. They will be published as a separate Eurocode part or as a 'Technical Specification' (TS) or as a separate European Standard (EN).

New titems

Additional design rules need to be included to cover the 'state-of-the-art' which is based on commonly accepted results of research that has been validated through sufficient practical experience.

The following subjects are to be included as most important new Eurocode 5 items.

- **Cross Laminated Timber (CLT)**
- **Timber Concrete Composites (TCC)**
- **Reinforcement**

In addition it is of great importance to reach a further harmonization between the product-, test-, value- and execution-standards, which is a vital part of 'Ease-of-Use' for practitioners.

Collection of National Annexes and review of NDP's

The Eurocodes provide 'National Determined Parameters' (NDP) to enable adjustments to the foreseen national safety level. The responsible National Standard Bodies of the Member States published so-called 'National Annexes' (NA) as addition to the Eurocode parts where NDP's as well as 'Non-Contradictory Information' (NCI) are included.

CEN/TC 250 has been collecting National Annexes of the Members States. At the moment most of the NAs have been collected. They are available for the corresponding subcommittees. The harmonization of the NDPs is analysed and published as well e.g. by the web page of the Joint Research Center (JRC), see www.jrc.ec.europa.eu.

NDPs are used to allow adaptations to climate related loads, to define national partial safety factors for materials and actions or limit values and to choose between modification factors, coefficients or design approaches. For improvement of 'Ease-of-Use' a reduction of the number of NDP's is vital. Therefore, CEN/TC 250 provided recommendations as guidance for the drafting process of the second generation of Structural Eurocodes [9]. In this guidance document the definition and background of 'legitimate' and 'questionable' NDP's are explained. Parameters connected to safety levels like partial safety factors or the time of fire exposure and classification of structures according to quality management requirements have to be kept as NDP's.

The CEN/TC 250 subcommittees shall now classify the NDP's. The following progress should be followed.

- Revision and categorization of NDP's
- Elimination of NDP's considered 'questionable'
- Report for rationalizing the retention or removal of NDP's

The different subcommittees worked on this categorization and elimination and submitted a NDP report to CEN/TC 250. As the timber sector used NDPs very economically in the past it is a minor problem for CEN/TC 250 SC 5.

Furthermore, the collection of NAs can be used to analyze the deviation of existing NDPs and the amount of national NCIs. Demonstrating the different national choices and outlining certain tendencies give an overview of the actual status of NDPs and help to classify 'questionable' NDPs. The investigations and analysis regarding NAs to Eurocode 5 are realized and provided by the authors at Technical University of Munich.

The collection of NAs and categorization or analysis of NDPs seems relatively undemanding in the case of timber structures when comparing the different Eurocodes with all its parts – Eurocode packages – and deducing the number of pages of NAs of Eurocode packages or the number of the corresponding NDPs. Figure 10 summarizes this numbers including also the number of pages of the Eurocode packages and demonstrating the amount of pages of the corresponding NAs by taking the associated German NAs.

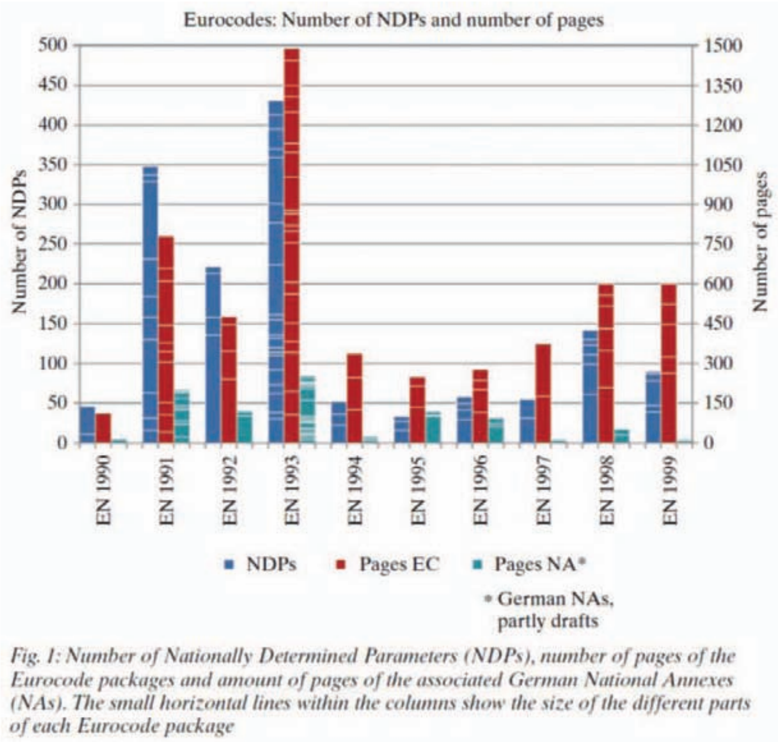

Figure 10. Number of NDP's, number of pages of the Eurocode packages and amount of pages of the associated German NA's 0

Consolidated versions to support the work

After the availability of the first results of the Project Team on CLT and Reinforcement and the Project Team on Timber Concrete Composites two different paths of publication are choosen by SC5. The draft on Timber Concrete Composites will initially be published as a Technical Specification (TS). The necessary work item by CEN is already available and a first enquiry is planned during first half of 2019. This way of publication enables engineers in practice to test the new standard before the final publication in the complete 'Design of Timber Structures' Eurocode package is forwarded in 2022.

As the new part of EN 1995-1-1 will be also not until 2022 the results of the first PT on CLT and Reinforcement are implemented in a 'consolidated version' which is used as a working document for SC5 and especially for the next Project Teams which are PT3 'Cluster' and PT5 'Connections'. The actual document contains the results of PT1 and the remaining current version of EN 1995-1-1:2010. The consolidated version will be next time redrafted with the results of PT3 and is in the respectively published version also a basis of work for PT4 'Fire Design – EN 1995-1-2' and for PT6 'Design of Timber Bridges – EN 1995-2'.

Conclusions

The work on the new generation of Eurocode 5 started mainly in 2014. It profits from a high level of interest among the Member States and the wood related community of industry, engineers, trade and public. Fortunately, the culture of discussion in the timber sector is very much fact oriented, free of personal sensitivities and based on a high level of confidence, respect and in many cases friendship. Even though, it is a long way to finalize the revision until 2022 and it is absolutely necessary to support the work from now until the end to enable an increased use of timber in the building sector. We ask all experts to support the development, e.g. by participating in commenting the drafts during enquiries.

In addition there is a very big support to identify and describe the actual state-of-the-art by the two COST actions COST FP1402 "Basis of Structural Timber Design" (www.costfp1402.tum.de) and COST FP1404 "Fire Safe Use of Bio-Based Building Products" (www.costfp1404.com). Both actions are finalized now and the results extremely support the standardization work.

Acknowledgement

Many thanks to anyone supporting the process of evaluation of the Eurocodes by active work in the committees, preparation of research & development reports, background documents, financial support, review of work stages, etc. Special thanks to the chairmen and teams of COST FP1402 and COST FP1404 for an unbelievable engagement and to Swedish Standards Institute (SIS) and the secretary of SC5, Annika Stenmark and her colleagues, supporting the work with excellent professionalism.

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Moisture safety of wooden buildings – design, construction and operation

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Summary

CLT (cross laminated timber) have accelerated the construction of multi-story timber buildings. Due to extensive size of the buildings and relatively fast assembly of the buildings, weather protection has not always been used. There are disagreements between the building industry and researchers how sensitive timber and wood buildings are to exposure of high moisture levels and water during storage at sites and construction. Based on results from several research projects both in laboratory and field, recommendations for procurement, storage and handling of timber during construction to assure moisture safety are suggested in this paper.

Keywords: Moisture safety; Massive timber buildings; CLT; Guidance; Mould growth.

Introduction

Due to the increased interest for wood buildings by the market, new technologies based on cross laminated timber (CLT) have been developed, enabling an evolution of high-rise buildings. The advantages of building with CLT are many from a lifecycle perspective, partly because of the low environmental impact (embodied energy), prefabrication, which means efficient production which reduces construction time, provides a better working environment, and minimizes waste. The construction and technology are imported from Central Europe, but the climate in the Nordic countries differ a lot from that in Central Europe. Lately a lot of attention has been paid to moisture issues, especially when CLT buildings are erected without weather protection. The suppliers claim that weather protection is not necessary, whereas the researchers fear that exposure to rain during erection might cause damages and problems with mould growth in the future. In some cases, it is practically impossible to arrange a weather protection since the width and height of the construction would require very complicated fasteners to cope with the wind loads from the tent. A guide with recommendations for procurement, storage and handling of timber during construction to assure moisture safety, based on former research studies performed by the authors, is presented in this paper.

Methods

A few years ago, there were two large national research initiatives on durability in wooden buildings "Future Wooden Buildings" and "WoodBuild". The outcome of these projects was presented in a number of scientific publications but also as recommendations to the building industry in Sweden. As part of the program, field and laboratory studies were performed to increase knowledge of the hygro-thermal conditions that wooden buildings are exposed to during their lifetime including both construction and operation phase.

Results and discussion

The main problem with wood and timber as a construction material is that it is sensitive to moisture and water causing mould and/or rot damages, as well as insect pests, which might cause indoor air problems but also structural failures shortening the life time of the building. During the construction phase there is a high risk of microbiological growth if the timber is exposed to water. If timber has been exposed to water or high moisture levels there the margins are small before mould starts to grow. At favourable conditions such as high temperatures and humidity, which is common during summertime, mould growth may start within a few weeks but if the timber gets wet, mould growth may occur within a few days. There are also risks for cracks due to shrinking when the wood dries, which may affect tight layers in the house. At low temperatures the mould growth is slower but at the other hand, the drying out takes much longer time. Also, well insulated buildings have a lower drying out potential than poor insulated buildings. Drying of timber is quite slow, especially if the water has been sucked into joints or connections between wood and other materials. There is a disagreement in the construction sector whether it is necessary to use weather protection when assembling wooden buildings. On the other hand, there is no doubt that timber must be protected from moisture and water. To neglect wetting or moistening of timber during construction could imply costs for repairing damages which must be calculated for. Such damages also involve cost for investigation, microbiological analyses, drying out, decontamination of surfaces or substitution of materials. If weather protection is not used, an extensive control of moisture conditions and microbiological growth on timber constructions is needed to assure moisture safety throughout the construction time. The risk of damages can be reduced by using weather protection.

Figure 1. Wooden buildings are built without weather protection.

Figure 2. Office building with CLT-frame is built without weather protection.

Conclusions

The recommendations are to assure that timber is not exposed to water or long periods of high relative humidity (weeks), which means that design of moisture safe, robust structures, weather protection and moisture safe handling of material at the building site and construction methods must be used. To neglect moisture safety could imply a high risk of damage with extensive costs for investigations, remediation or substitution of material, and time delays as consequences. If moisture safety is neglected, the advantages with wooden construction may be jeopardized when subjected to discussions about moisture risks and increased costs and environmental impact due to replacement of material in case of damages.

Acknowledgements

The research which form the basis of the recommendations presented in this paper was carried out within the research program "Framtidens Trähus" (Future wooden buildings) and "WoodBuild" founded by VINNOVA, Sweden's Innovation Agency.

Future of timber architecture

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Architectural Design and Timber Construction,
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The increasing possibilities for architects to work with wood

Wood as a building material has been very important till mid of 19th century, but then "modern" materials as concrete and steel got growing interest, wood disappeared more and more, research and technical development decreased. Today we are at the beginning of a revival. Planners and owners rediscover the qualities of the most important renewable material. Beside the benefits of sustainability the creative possibilities for architects are the reasons for this positive development.

The beauty of wooden buildings

Figure 1. IZM Illwerke Zentrum Montafon

Figure 2. IZM Illwerke Zentrum Montafon

Figure 3. IZM Illwerke Zentrum Montafon

The challenge and the chances with new construction methods in timber

The future of timber construction is PREFABRICATION

LCT One, Dornbirn

Figure 4. LCT One, Dornbirn

Figure 5. LCT One, Dornbirn

Figure 6. LCT One, Dornbirn

Figure 7. LCT One, Dornbirn

Figure 8. LCT One, Dornbirn

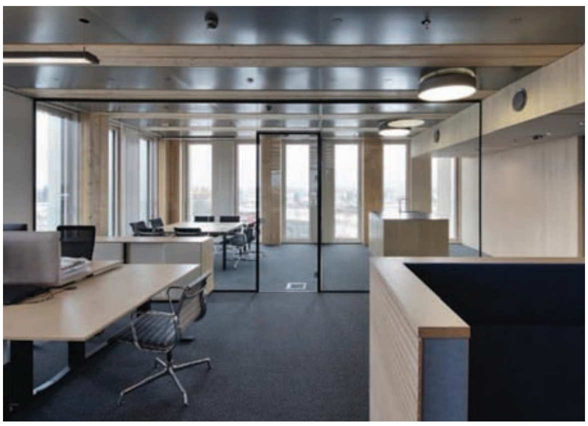

Figure 9. LCT One, Dornbirn

Climate adaptation of wooden roofs

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Summary

This paper summarises the main findings of a recent PhD Thesis aiming to increase the knowledge about moisture safety and air flow through the air cavity of pitched wooden roof structures. Experimental research, field measurements and numerical simulations have been used to assess and characterise the driving forces and resistances for roof ventilation. The work shows that pitched wooden roofs adapted to the Nordic climate of tomorrow need:

- Increased climate adaptation and moisture safety by improved air cavity design.
- Convection barrier when insulation thickness exceeds 200 mm.
- More knowledge and relevant documentation if BIPV roofing

Keywords: Building physics, wood structure, pitched roof, ventilated air cavity,

Introduction

Wooden frame structures are especially common in wooden houses in the Nordic countries. The roof structure is often constructed with a load-bearing system, referred to as wooden roof. Ventilated pitched wooden roofs with exterior vertical drainpipes and wood-based load bearing systems have to be ventilated. The purpose of the ventilation is 1) to remove heat transferred through the insulated roof structure possible causing snow melt and subsequent icing at the eaves and gutters, and 2) to ensure that excessive moisture is removed from the roof structure.

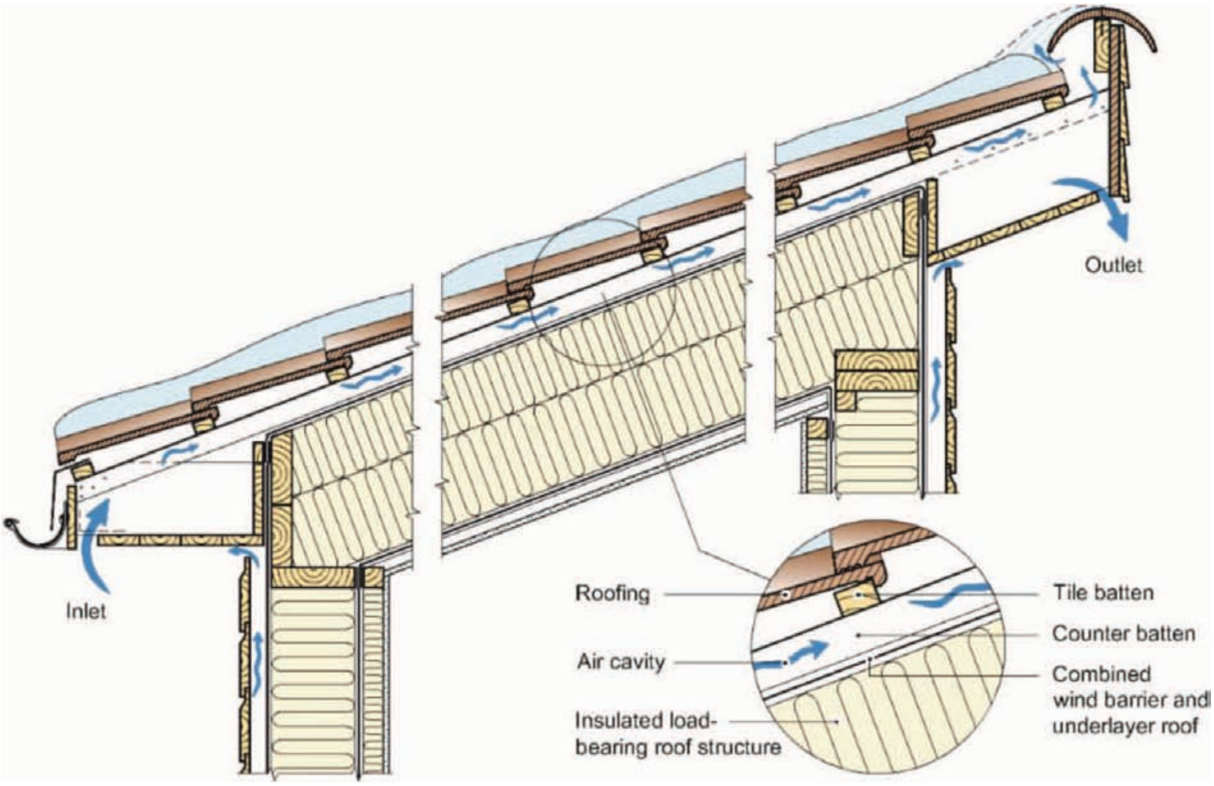

Figure 1. A ventilated lean-to roof structure with snow on the roof. The snow may reduce the air flow through the opening in the upper air cavity opening.

The objective of this study has been to increase the knowledge about moisture safety and air flow through the air cavity of pitched wooden roofs. One of the main goals has been to form a basis for development of design guidelines for large low-pitched wooden roofs (> 15 m x 15 m) applicable in the Nordic climate. Today, such roofs must be planned for each individual building project, which is not very efficient.

Methods

The main research methods applied has been assignment report review of the SINTEF Building Defect Archive, full-scale laboratory measurements, field measurements and numerical analysis. The Defect Archive includes assignment reports by SINTEF (former Norwegian Building Research Institute) mapping Norwegian building damages from the last 60 years. The study covers documents from the archive for the 10-year period from 1993 to 2002, which contains 2003 reports describing 2423 incidents or cases of defects.

The laboratory measurements includes measurements performed in a rotatable guarded Hot-Box and a large-scale test model of the air gap of a pitched roof. Field investigations includes measurements of the roof structure of a full-scale laboratory building, ZEB Test Cell Laboratory, as well as measurements of wind pressure coefficients at the facade of a test house located on a flat area in Tyholt in Trondheim, Norway.

Results and discussion

According to the Defect Archive, moisture from both precipitation and indoor air is the dominant source of roof damage. This is especially critical when we bear in mind a 10-20% increase in precipitation in the years to come in Norway and a slightly warmer climate. Hence, increased focus on risk reduction and moisture safety for building structures is needed.

Stricter building regulations and an increased focus on zero energy and zero emission- buildings make energy production on the building facades more relevant. Use of BIPV, especially on southern facing roofs can be a reasonable way to utilise roofs for energy production. However, the missing link between the PV and construction industry is a reason for the limited use of these systems. The main building physical challenges concerns rain-tightness of the BIPV-systems as well as snow covering and snow downfall hazards.

Natural convection inside highly insulated structures were found to significantly increase the heat transmission of roof structures. Natural convection may cause redistribution of moisture inside the insulation cavity. The effect causes higher moisture levels in the cold part of the structure. In order to reduce this risk, introduction of a vapour open convection barrier is recommended when the insulation thickness exceeds 200 mm, also for pitched roof structures

A measure to increase the ventilation of the air gap beneath the roofing is the design and dimensions of the counter- and tile battens. Increased counter batten height as well as use of round-edged tile battens was found to considerably lower the pressure loss. The study of local loss coefficients inside the air cavity of a roof and the study of wind pressure coefficients was performed in order to increase knowledge about the driving forces and resistances of ventilated roof structures.

Conclusions

The presented work is a step towards more climate adapted wooden roofs. Some possible approaches are proposed. However, further investigations are necessary. The main theme for further investigation is related to the design criteria for the air cavity.

Acknowledgements

The authors gratefully acknowledge the financial support by the Research Council of Norway and several partners through the SFI Klima 2050 (www.klima2050.no).

MOISTURE SAFETY AND HYGROTHERMAL BEHAVIOUR OF BUILDING ENVELOPE SYSTEMS

ETICS façade on timber framed wall – Swedish experience

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Summary

Façade systems like ETICS were round 1990 introduced in Sweden. This abstract gives a very short presentation of my view of the experience of this kind of facades in Sweden. My conclusion is that they should not be used in Swedish climate.

Keywords: ETICS, moisture safety, timber-framed wall

Introduction

Background

To build is an investment for the future. Increasing demands on energy use involves changes to the building envelope (roofing, siding, foundations) and installations. Such measures also change the way the buildings works. Unfortunately, sometimes the result is buildings with moisture, mould and indoor air problems – with a high cost to correct the problems.

When developing a new type of building, a number of factors must be considered simultaneously. This requires expertise in these areas. Not only the building's energy efficiency or CO_2 emissions but also its moisture control and indoor environment must be assessed and predicted.

ETICS façades on timber-framed buildings were introduced in Sweden during 1980:s and became a very common construction. After a while moisture problems were found in many of the wood-framed buildings constructed with ETICS or similar façade systems.

Objectives

The aim of this paper is to give a short general summary of the experiences of ETICS façades in Sweden.

Limitations

There are different types of ETICS façades with different levels of risk for moisture damages. In this short paper, only the principles are discussed. The experiences are limited to Sweden.

Methods

Moisture research Centre at Lund University and SP (now RISE) were in a very early stage involved in the work investigating the moisture damages coursed by ETICS and similar wall outer wall constructions. A very short summary of presentations and publications together with my own opinion and thoughts are giver here.

In order to give examples of the moisture effects in constructions similar to ETICS, the simulation program WUFI Pro was used.

Results and discussion

In a properly designed external wall, the different layers have different functions. At the outer side there is a rain cover in the form of some type of cladding, often wood, brick, metal or plastic material. Inside the cladding there should be a ventilated air space. Possible water leaks that enter through the facade layer should not be able to get further into the wall, but instead be allowed to dry out, either by ventilation or drainage. Next to the air gap is a layer which prevents air movement into the insulation. This type of façade, with separate layers for rain and wind protection is called two-step tightened facade. Next to the wind protection layer, there is thermal insulation, and next on the warm side, there are layers to ensure air tightness and vapour tightness. Warm moist indoor air should not be able to get out through the wall to the colder parts and cause moisture and mould damage. This type of exterior wall usually works well.

In Sweden, round 1990, we started to build external timber-framed walls with plaster directly on the insulation, without having a ventilated air space. These are called one-step tightened facades as rain and wind protection is to be achieved in a single layer. This type of external wall was proven to be very risky in terms of moisture safety. The design is based on the assumption that no water gets into the wall from the outside. Experience shows that this is not always achieved. When this type of walls are exposed to driving rain, water can get into the wall through leaks and cracks, especially in the connections between the windows to the exterior walls, the balconies and the fixings, such as needed for solar shading and exterior lighting. When moisture gets into the wall, it takes a very long time before drying out again, if at all. Extensive moisture damage may occur and reparatory measures are costly in such cases.

In the report 2009:16 from SP an investigation of more than 800 buildings with this kind of outer walls were made. The result shows that moisture, in many cases, enters the structure and cannot dry out in time to ensure the moisture safety.

How could this happen? Problems with this kind of walls were reported in articles from US. Why didn't we react in time?

After the alarm from Moisture Research Centre and SP still many companies continued to use this kind of construction. It was skipped by JM as late as 2016. The insurance companies reacted directly.

Were not simulations and risk assessment made before the new type of wall was introduced in Sweden? Perhaps, but in that case not the right way. If a 100% rain tight façade is assumed, the simulation result shows humidity in levels that would not give moisture damages. However, if even moderate leakage of rainwater through the outer façade is assumed, completely different results will be the case. Result from two examples of simulations with WUFI-Pro are shown, one with rain leakage and one without.

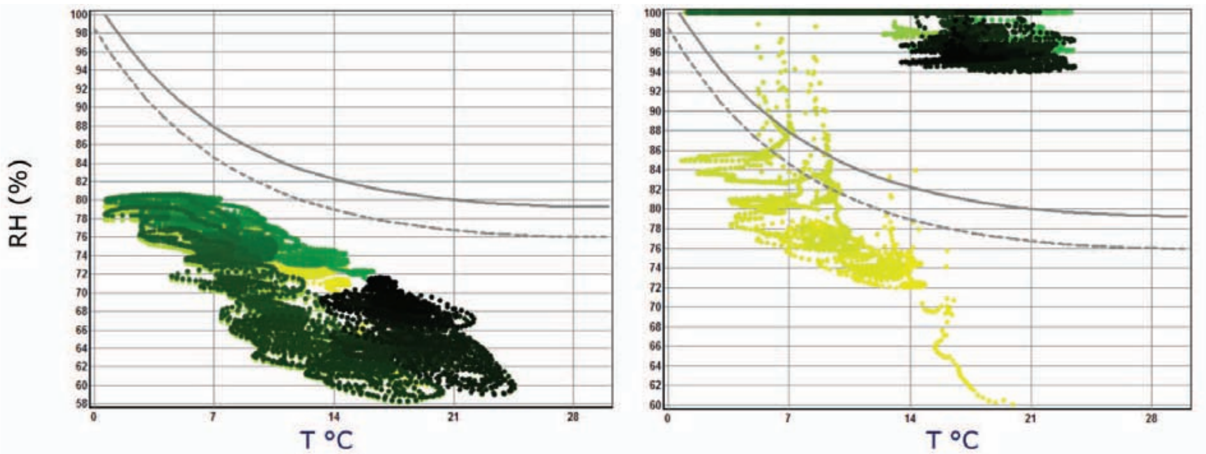

Figure 1. Isopleth diagrams for outside of wooden stud from calculations with WUFI. Without leakage (left) and with 0,2% rain penetration (right).

Conclusions

My conclusion is that you should not use this kind of construction, it is too sensitive to moisture damage. A ventilated, drain air gap behind the outer façade is a very cheap and effective way to increase the moisture safety in outer, timber-framed walls.

Hygrothermal performance of a wood-frame wall assembly for a high-rise building

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Summary

A 20-storey wood building is proposed in North Vancouver, an area with a high amount of wind-driven rain. The engineering feasibility is evaluated from aspects including structural performance, fire protection performance and hygrothermal performance. This paper focuses on the hygrothermal performance analysis of the proposed wall assembly. The impacts of different design variables and moisture loads are evaluated through a parametric study, which is based on hygrothermal simulation by WUFI. It is found that the critical aspect of the design is to manage the rain penetration passed through the 2nd line of defense, i.e. WRB.

Keywords: tall wood building; hygrothermal simulation; moisture management; wood-frame construction

Introduction

The proposed 20-story wood building is located in North Vancouver, an area with an annual rainfall of about 1.8 m. Therefore, it is important to design a robust building envelope to manage wind-driven rain and rain penetration. The split-insulated wall is proposed considering the exterior insulation will reduce thermal bridging effect and keep the wood structural elements at higher temperature, thus reduce risks for condensation caused by vapour diffusion or air leakage. Different design variables are studied through parametric study to evaluate the hygrothermal performance of the proposed wall assembly. Figure 1 shows a typical configuration of split-insulated wall assembly.

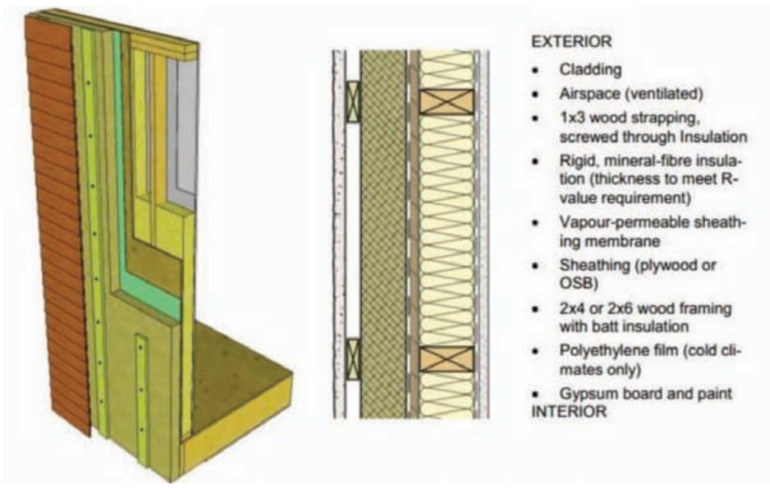

Figure 1. Wall section elements based on the split-insulated wood-frame wall assembly with exterior rigid mineral-fiber insulation (FPInnovations. 2013. Guide for Designing Energy-Efficient Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America. FPInnovations. BC, Canada).

Method

The investigated parameters include orientations, design variables for the wood-frame wall assembly, cavity ventilation rate, three types of moisture loads (vapor diffusion, air leakage and rain leakage), water absorption coefficient of cladding and wind driven rain coefficient. The hygrothermal models with different values of the investigated parameters (as shown in Table 1) are created in WUFI, and simulations are performed for 3 years. The moisture content of wood sheathing is observed for performance evaluation.

Table 1. Parameters investigated in WUFI simulation

Orientation	N, E, S
Wall assemblies	With/without polyethylene film
	Plywood/Exterior grade gypsum board sheathing
	Western red cedar wood siding/fiber cement panel cladding
	Permeable WRB+mineral wool (combined permeance 975 ng/Pa.s.m^2)
	Permeable WRB+EPS (combined permeance 64.4 ng/Pa.s.m^2)
	Impermeable WRB+mineral wool (combined permeance 1.6 ng/Pa.s.m^2)
Cavity ventilation	0, 10, 50, 100 and 200 ACH
Moisture load	Vapour diffusion only
	Air leakage (1.5L/m^2·s) into the stud cavity
	1% rain leakage deposited onto the WRB/directly to sheathing
Water absorption coefficients of cladding	Default value: 0.001 kg/m^2.s0.5
	Half value: 0.0005 kg/m^2.s0.5
Driving rain coefficient R_2	Default value, R_2=0.2
	Half value, R_2=0.1
	Double value, R_2=0.4

Results and discussion

The simulation results show that the use of a class I vapour barrier, i.e. polyethylene does not inhibit the drying given that the rainy season is in the winter time when the vapour flow is from indoor to outdoor. The permeable exterior insulation and WRB allows drying outwards when rain leakage is assumed on the sheathing. For the Metro Vancouver climate, vapour retarder is required to control vapour flow and an interior vapour retarder with higher exterior vapour permeance may be appropriate. The influence of cladding ventilation is more significant for north and east orientation (higher amount of wind-driven rain) than south orientation (lower amount of wind-driven rain). The impact of air leakage depends on wall configuration. For the wall with high exterior vapour permeance, the air leakage increases the moisture content of wood sheathing when the vapour barrier is used while decreases the moisture content when the vapour barrier is removed. For the wall with low exterior vapour permeance, the air leakage slightly decreases the moisture content for both cases with and without vapour barrier. When the 1% rain leakage is deposited on WRB, there is no noticeable increase of MC in wood sheathing. When the 1% rain leakage is deposited directly on wood sheathing, significant MC increase is observed for north and east orientation. Given the high wind-driven rain load for this climate, the wall assembly won't be able to handle the 1% rain leakage load directly onto plywood for the North and East orientation. For south orientation, which receives lower amount of wind-driven rain, the impacts of driving rain coefficients and water absorption coefficient of exterior cladding are not significant. For north and east orientation, the influence of water absorption coefficient of the wood siding is more significant than the driving rain coefficient.

Conclusions

In conclusion, the proposed wall assembly can manage the moisture loads from vapour diffusion, air leakage and rain penetration passing through the first line of defense i.e. cladding. The critical aspect of the building envelope design is to manage the rain penetration passed through the 2nd line of defense, i.e. WRB, the rainwater deposited directly on the sheathing. The reduction of wind-driven rain exposure by building form and details such as overhangs, balcony projections should be considered.

Acknowledgements

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Validation of the MRD mould model by attic case studies in northern Sweden

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Summary

The purpose of the study was to investigate how well the MRD-model (Mould Resistance Design) could predict mould growth in three cold attics within long periods of time (1961–2012). Comparing the measurements and the results from the simulations showed great differences regarding the mould growth depending on the simplifications used in the model. Of critical importance was the choice of leakage simulation and where the moisture from the leakage was placed in the construction. The study could not validate MRD model as such but it was clear that the simulation could produce realistic data given a set of realistic parameters.

Keywords: Building physics; moisture, mould growth, HAM-model, wood frame attics, simulations, in situ measurements

Introduction

There are several models for predicting the mould growth in wood. The models are based on different assumptions and sometimes calibrated against in situ measurements or laboratory measurements. One of these models is the so called MRD-model (Mould Resistance Design). This model is mainly calibrated against laboratory measurements. The purpose of the study presented here was to investigate how well the MRD-model (Mould Resistance Design) could predict mould growth in roof structures within long periods of time. Three cold attics were investigated situated at Malmberget within Gällivare Municipality in northern Sweden.

Methods

The 17 houses that was originally part of the attic investigation were built around 1960–1965. Samples of surface wood were taken at three locations in the structures: beams in the floor, joints and wood ceiling during the winters 2011–2012. These samples were analysed with microscope to measure a mould index from 1 to 4. Other relevant data bout leakage risk, construction etc were also collected. Three attics (nr 4, 10 and 13) were chosen for a more detailed investigation using the heat and moisture simulation program WUFI 6 Pro, see an example in Figure 1.

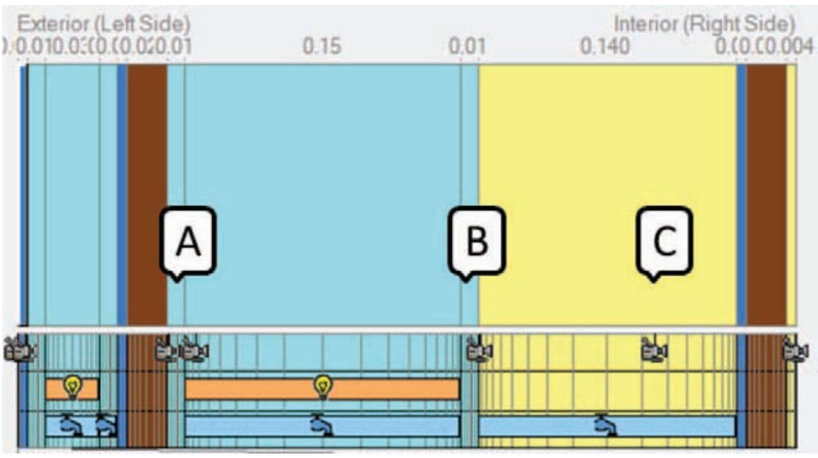

Figure 1. WUFI simulation model for attic nr 4 showing the measuring points.

To be able to simulate the attics, climate files for the period 1961–2012 was constructed. Important parameters that were investigated were e.g.: Ventilation Air leakage from inside, Moisture load due to air leakage, Position of this leakage in the structure (insulation or air space).The output from the simulations were then used in the MRD model to produce mould indexes for the period. The mould index was investigated at position A, B and C in figure 1.

Results and discussion

The maximal measured mould index for the attics varied between 0 and 4. Figure 2 shows a simulation of attic 10 with moisture load in the airspace as an example of that the results were in the vicinity of the measured results.

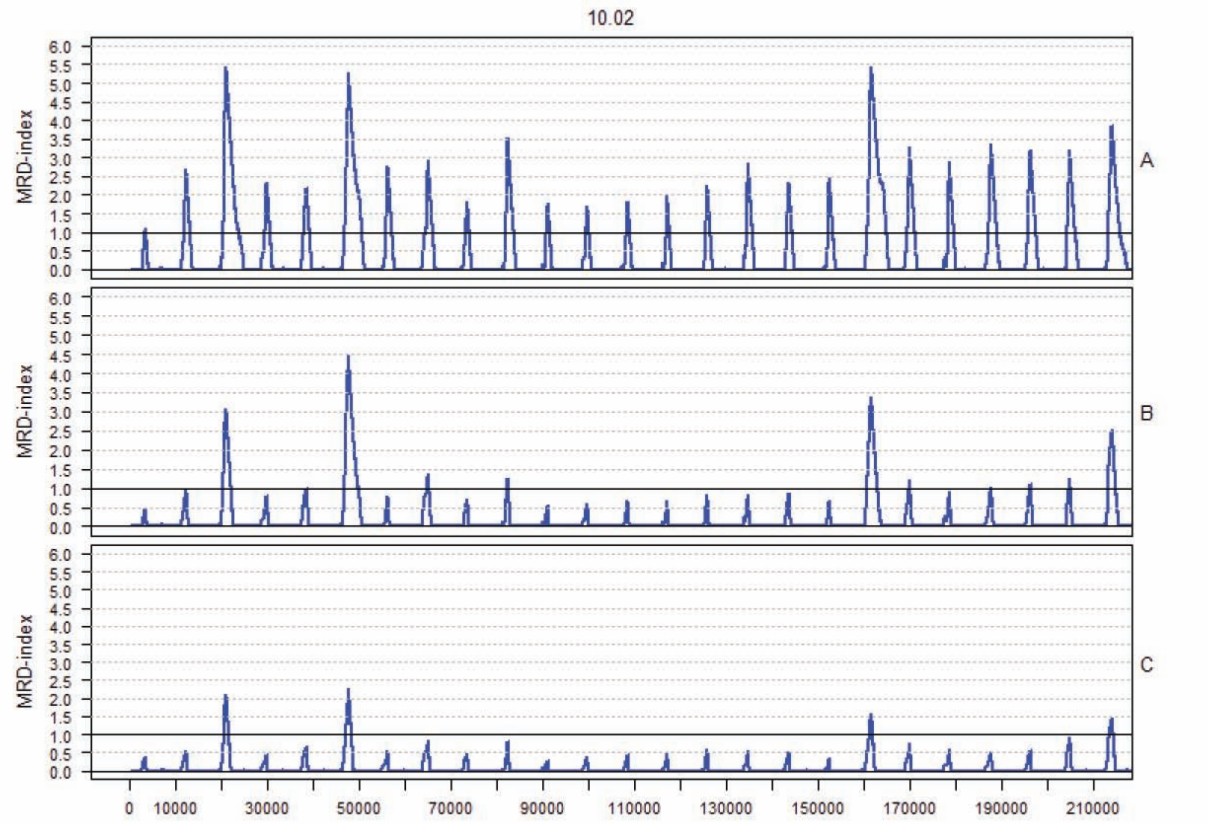

Figure 6. Mould index for attic nr 10 with ventilation=7.5 h^{-1}, air leak=1 l/s m^2 and moisture load= 11 500 g/m^2 year over oct to april and placed in the ventilated airspace in the attic.

Conclusions

Comparing the measurements and the results from the simulations using the MRD-model showed great differences regarding the mould growth depending on the simplifications used in the WUFI model. Of critical importance was the choice of leakage simulation and especially where the moisture from the leakage was placed in the construction. The measurements were clearly showing mould growth and this was also simulated for a chosen set of parameters. From the study the MRD model can not be fully validated but it is clear that the model can produce realistic data given a certain set of realistic parameters.

Acknowledgments

LKAB Fastigheter and Kirunabostäder.

Influence of local weather conditions on ventilation of a pitched wooden roof

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Summary

This paper investigates the influence of temperature and wind conditions on ventilation of the air cavity beneath the roofing in a full-scale pitched wooden roof construction. The relevant roof construction is equipped with instrumentation for temperature and air velocity measurements. The findings show distinct periods of below-ambient temperature and positive condensation potential in the ventilated air cavity of the roof. The measurements imply that the materials in the roof regulate the humidity in the air cavity. Large negative peaks in the condensation potential indicate dry-out of the construction.

Keywords: Pitched roof; Wood construction; Air cavity; Ventilation; Condensation

Introduction

The Norwegian climate is characterized by extreme variations and large geographical and seasonal differences, which put large demands on Norwegian building envelopes. Pitched wooden roofs, widely used in Norway, are constructed with ventilation beneath the roofing in order to 1) remove excessive moisture from the roof construction, and 2) remove heat in order to prevent melting of snow on the roof and subsequent formation of ice. This paper is a continuation of a study performed by Gullbrekken et al. in 2017. The aim is to study the influence of temperature and wind conditions on ventilation of the air cavity in a full-scale wooden roof construction. Key issues are to investigate how the temperature in the air cavity depends on the outdoor climate and to examine the condensation potential (CP_i) that follows below-ambient temperature periods in the air cavity.

Methods

The study was carried out on a full-scale experimental laboratory building situated in Trondheim, Norway. The building has a wooden roof construction with eaves-to-eaves ventilated air cavities beneath the roofing. The structure of the roof is described in Figure 1. The air cavities are equipped with instrumentation for temperature and air velocity measurements. Outdoor temperature and wind exposure are recorded at a weather station located above the ridge of the roof. Four air cavities, two at the northern and two at the southern side of the roof, were studied during five different periods in 2016–2018.

Results and discussion

The measurements demonstrated long intervals of below-ambient temperature in the ventilated air cavity, ranging from 6% to 97% of the time for the different periods studied. Lowest values were found in summer and in winter if snow was covering the roof. Highest values were found in winter when snow was not covering the roof. Low outdoor temperatures and days with clear sky may have contributed to large cooling of the roof in the latter winter period. Differences in CP_i was found when comparing the southern and the northern side of the roof. This is illustrated in Figure 2, which shows variations in CP_i during a period in March 2016. Longer intervals of positive CP_i and smaller negative peaks in CP_i at the northern side of the roof imply higher risk of condensation at this side. A higher CP_i was also seen for the rear side of the roofing than for the middle of the air cavity. In general, the observations showed that CP_i in the air cavity was very dependent on the temperature and radiation conditions present. A relationship between variation in wind and variation in CP_i was also observed. It was found that wind speeds were very low, i.e. < 1 m/s, during most of time when the CP_i was positive. This implies that wind speed is of importance for the condensation situation in the air cavity. The periods of below-ambient temperature in the air cavity were larger than the periods of positive CP_i. This indicates that the oriented strand board (OSB) at the rear side of the roofing was absorbing condensate due to its hygroscopic properties, reducing the risk of visible condensate. Due to the large negative peaks in CP_i, the surface will experience dry-out. Hence there is little concern that moisture absorbed will lead to damages in the OSB.

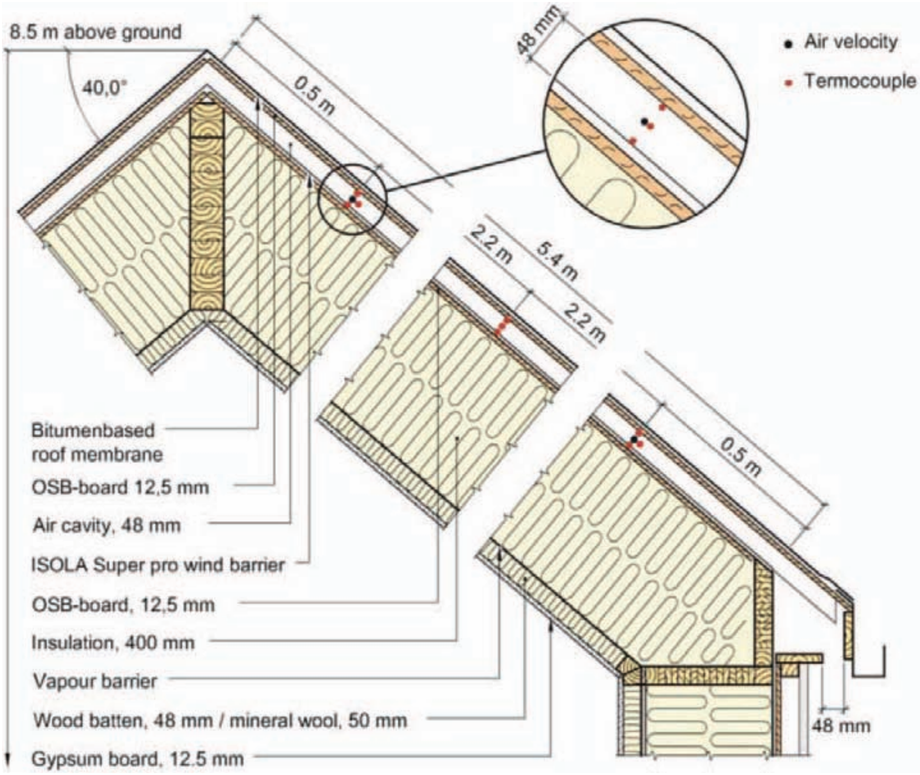

Figure 1. The roof structure at ZEB Test Cell Laboratory.

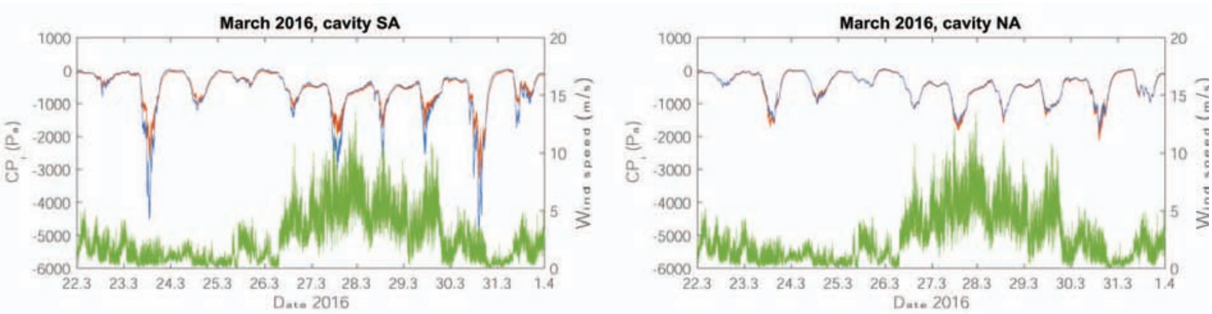

Figure 2. Variation in CPi (for two different cavities) and wind speed in March 2016.

Conclusions

The study of the roof on the ZEB Test Cell Laboratory shows distinct periods with below-ambient temperature in the ventilated air cavity. Positive CP_i is measured during long periods, especially in spring, autumn and winter without snow. Large proportions of the periods with positive CP_i have wind speeds less than 1m/s. The periods with below-ambient temperature in the air cavity are larger than the periods with positive CP_i. This implies that the materials in the roof absorb moisture and regulate the humidity in the air cavity. However, large negative peaks in CP_i indicate dry-out of the construction.

Acknowledgements

The authors gratefully acknowledge the financial support by the Research Council of Norway and several partners through the SFI Klima 2050 (www.klima2050.no)

The effect of repeated moisture cycles on the air tightness of traditional clamped vapour barrier joints

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Summary

In this study it has been investigated whether and to what extent, repeated moisture cycles affect the air leakage through clamped overlap joints in the vapour barrier layer.

Keywords: vapour barrier, air tightness, clamped joint, building envelope

Introduction

Typical building envelope constructions, both in Norway and other countries, use clamped joints as a traditional way to attain airtight joints in the wind- and vapour barrier layer. The airtightness of clamped joints depends on several parameters including geometry of the wooden batten, type of fixing and center to center distance of the fixings. Some of these parameters have already been investigated in several laboratory studies. However, the effect of several years of cyclic shrinking and swelling of wood materials used in clamped joints and their influence on the airtightness of the building envelope, have not yet been investigated. The aim of this study is to investigate how the airtightness of clamped vapour barrier joints are affected by several drying and wetting cycles caused by moisture variations in indoor environment.

Methods

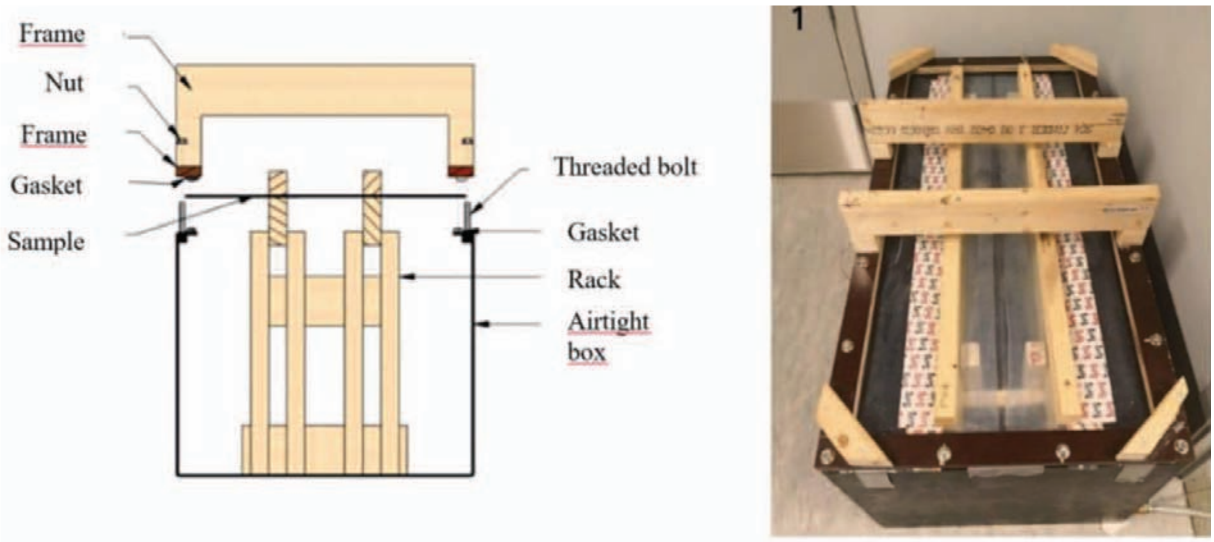

Figure 1. Assembly of the sample to the airtight box for air lekage testing. To the right is shown the final testing with taped joints.

A laboratory test has been carried out, with a total of 63 air leakage tests, being carried out on 9 test samples, consisting of overlap joints of 0.15 mm polyethylene film clamped between a 48 x 48 mm wooden batten and a 48 x 98 mm stud, se Figure 1. Each sample was tested seven times after repeated drying and humidification, where the moisture values of the sub-cycles were chosen to represent the annual variations of indoor relative humidity. The laboratory test materials were mounted with machine nails with various center spacing (150 mm, 300 mm and 450 mm), with three samples each. The overlap joints of the vapour barrier were in the end of the test sealed with adhesive tape, revealing to what extent this over a longer period of time will be beneficial.

Results and discussion

The results showed that the first drying cycle (from summer to winter conditions) resulted in significant increase of air leakage for all the sample variants. Throughout the moisture cycles, a further strong leakage development for center to center nail spacing 450 mm was observed, which was less for 300 mm, and non-existent for 150 mm. See example of results in Figure 2 for 450 and 300 mm nail spacing. The gain of using structural adhesive tape was found to largely depend on the level of perforation resulting from the nails and their center distance. Adhesive tape on the joints resulted in the greatest reduction in leakage numbers where the center distance between the nails was high. However, with shorter center distance the use of tape only decreased the air leakage between 22–39%, revealing the fact that a large part of the joint leakage is through the nail perforations.

An estimation of the relative importance of air leakage through this type of overlap joints were made for a small and large type of building. The relative importance was not found to be big, since the estimated total air leakage through the overlap joints at 50 Pa accounts only for between 6–8% (single family house) and 0,7–0,9% (office building) of the passive house requirement.

The results also showed that although there is a positive effect of taping the overlap joint, the effect seems to be reduced by air leakages through the fixing holes of the nails through the vapour barrier.

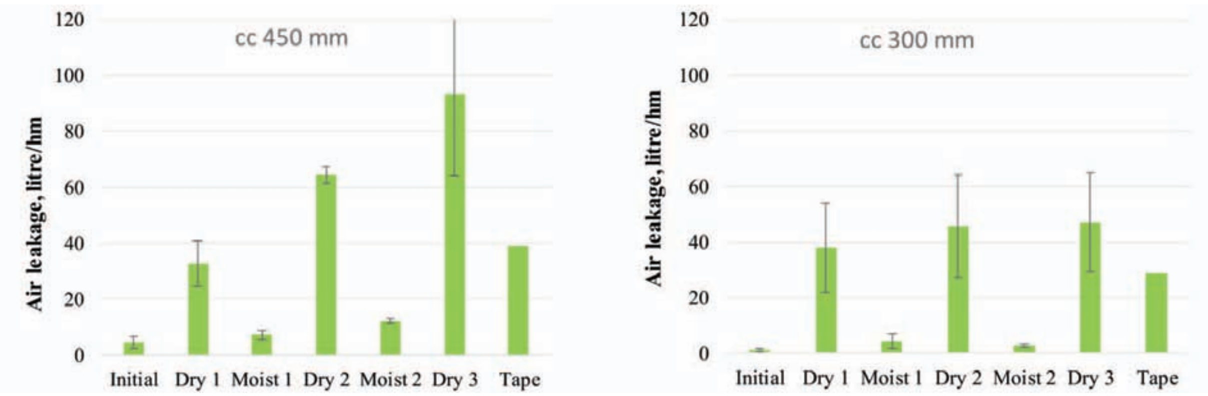

Figure 2. Average air leakage (including standard deviation) through the different samples during the drying and wetting cycles.

Conclusions

The results showed that the first moisture cycle (drying) resulted in significant increase of air leakage for all the sample variants. Throughout the moisture cycles, a further strong leakage development for center spacing 450 mm was observed, which was less for 300 mm, and non-existent for 150 mm. The gain of using structural adhesive tape was found to largely depend on the level of perforation resulting from the nails and their center distance. Adhesive tape on the joints resulted in the greatest reduction in leakage numbers where the center distance between the nails was high. However, with shorter center distance the use of tape only decreased the air leakage between 22–39%, revealing the fact that a large part of the joint leakage is through the nail perforations.

Moisture proof cathedral roofs, the risk of mould using a vapour retarder

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Summary

Mould growth in cathedral roofs at four locations in Sweden was investigated using 9 consecutive years as boundary climate for a simulation with WUFI 6 Pro. The study included an investigation of whether a variable vapour retarder could reduce the risk of mould in a cathedral roof even if the ventilation behind the rain protection was reduced. The study used the Mould Resistance Design model for calculating the mould index. The simulations showed that the difference between a variable vapour retarder and vapour barrier was very small, in most cases non-existent thus making it necessary to keep a ventilation in the air gap.

Keywords: building physics, cathedral roof, mould, simulation, sloped roof, ventilation, vapour retarder.

Introduction

Cathedral roof (also called sloped roof or cathedral ceiling) is a common construction in Sweden and other regions with cold climate. The cathedral roof can be constructed in different ways, e.g. with or without ventilation below the roof sheeting, with open or air tight insulation material, vapour barrier or vapour retarder on the inside etc. In order to study the risk of mould, cathedral roofs placed in Lund, Stockholm, Borlänge and Luleå was investigated using simulations. The study focused on the roof beams and included an examination of whether a variable vapour retarder could be used to reduce the risk of mould growth. The purpose of a vapour barrier is to contribute to the air tightness and moisture diffusion resistance of the construction and is placed close to the interior surface. A variable vapour retarder has vastly decreasing moisture resistance when the relative humidity increases, e.g from Sd = 25 to 0.3 m. The relative humidity is generally highest during the warm months of the year. This allows the construction to dry out against the inside, as opposed to using a fully vapour-tight barrier.

Methods

The study was done using WUFI 6 Pro to calculate heat and moisture transport for Lund, Stockholm, Borlänge and Luleå, with climate data from 1990–1998, ie nine different years in four locations. Cathedral roofs in Sweden usually have wooden roofing with roof bearing beams go in the roof direction of the roof.

In the study, a sensitivity analysis was made where different parameters were varied individually and in some simultaneously. The parameters that were specifically studied were: Rain penetration to the wood roofing (0.2–1%, base case = 0.2%), Ventilation in the air gap (4–30 ach/h, base case = 30 ach/h), Rainwater absorption rate (0.4–0.9, base case = 0.4), Color of tiles (white-black, base case = red), Air leakage through vapour retarder (equivalent to 0.3 l/s m^2 – 1.0 l/s m^2 at 50 Pa, base case = 0.3 l/s m^2), Thin board (porous fiber board – hard board with Sd = 0.5 m, base case = porous fiber board), Vapour barrier or variable vapour retarder (base fall = vapour barrier), Insulation dimension (300–500 mm, base case = 400 mm).

The MRD (Mould Resistance Design) is a tool developed at Lund University for assessing moisture safety in a building's thermal envelope regard microbial growth. With the model a Mould index (or MRD-index) can be calculated. When this index is >1 this risk of mould growth is high.

Results and discussion

The results showed that the location was of great importance. In Lund the risk for mould growth was greatest and in Stockholm, Luleå and Borlänge the risk decreases successively.

Figure 1 shows the MRD-index sensitivity analys where the x-axis is a dimensionless number indicating where in the interval a certain parameter is chosen. The most important parameters were the ventilation rate in the air gap, the outside colour of the roof, how much and where the rain water penetrates the structure, and the moisture resistance of the thin board creating the air gap. The air leakage from the inside was of great importance if the thin board had a high moisture resistance

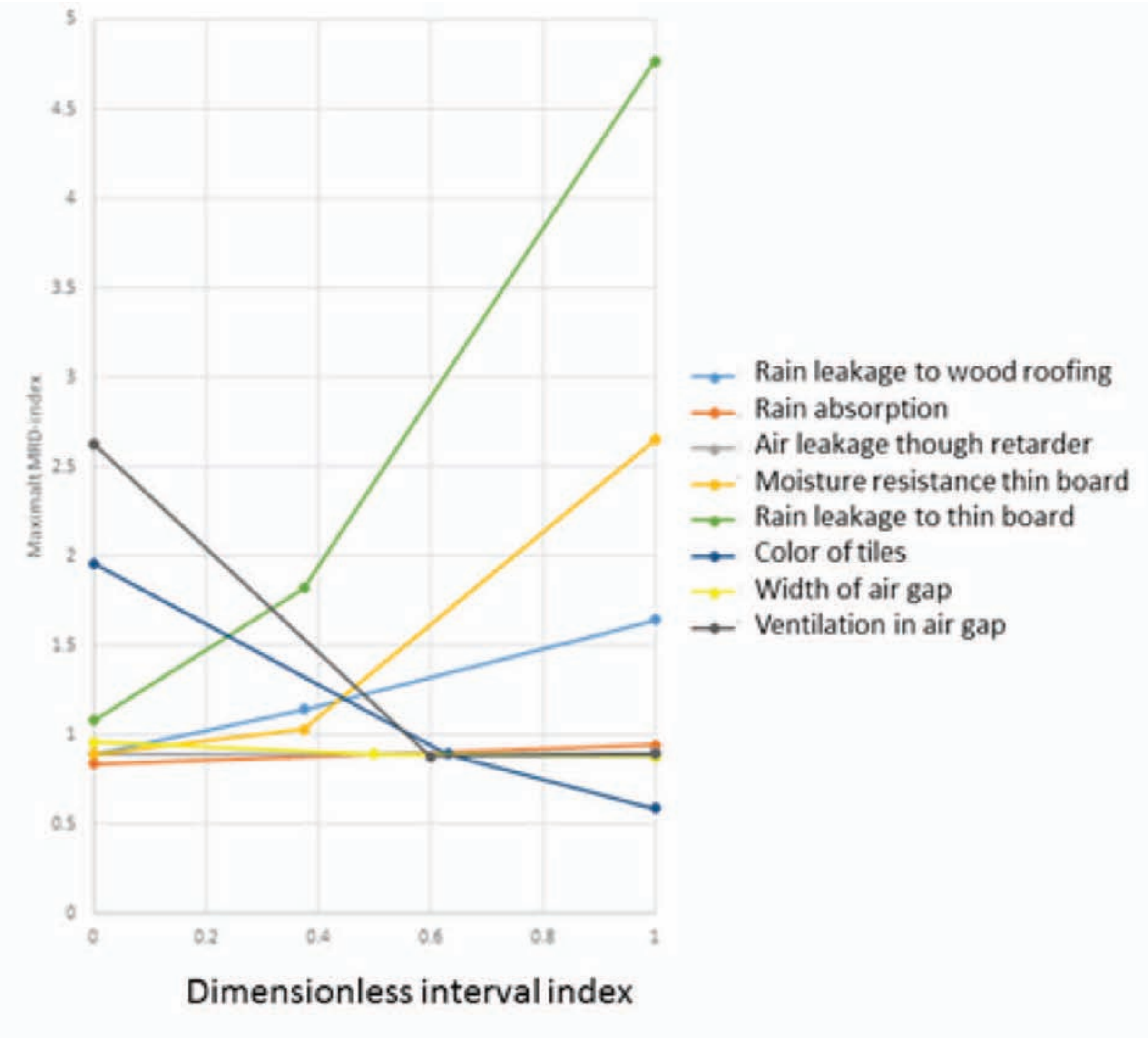

Figure 1. Sensitivity analysis for some important parameters using the variable vapour retarder. The x-axis has a dimensionless unit where x=0 means the lower limit in the interval for a particular parameter and x=1 means the upper limit.

Conclusions

The calculations showed that the base case had a low mould growth risk in all locations. Difference between the variable vapour retarder and a traditional vapour barrier was very small, in most cases non-existent. In this type of cathedral roof, with a ventilated air gap, a variable vapour retarder is not motivated. The calculations showed that some important parameters are possible to affect during the design phase. The choice of air gap forming thin board was important, It is important to choose a board with a low moisture resistance. The colour of the roof was also an important parameter that is easy to influence. A dark outer roof surface was better from a moisture safety point of view. If the air gap is built sufficiently high, conditions for a good ventilation which was necessary for reducing the MRD index, is secured.

Moisture safety of the construction with VCL using Hygrobrid technology

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Summary

The purpose of this work is to introduce the new patented Hygrobrid technology for moisture variable vapour control layers (MVVCL). The new iable membrane has directional permeability capabilities. This technology ensures better safety for every construction even when moisture levels are high during construction phase and also when the structure is subjected to extreme moisture during use. This technology minimises moisture development within the structure and maximises moisture transport out of the structure. This work is presenting the performance difference between 1st, 2nd and 3rd generation moisture variable membranes based on the computer simulation.

Keywords: Hygrobrid; Building physics; moisture variable; vapour control layer; diffusion tight flat roof, diffusion tight pitched roof, reverse diffusion

Moisture and direction variable vapour control layer with Hygrobrid technology

There are currently many different moisture variable vapour control layers available on the market. The first generation of vapour control layers with moisture variable diffusion resistance has a small spread between high and low diffusion resistance. Since then, they have been further developed so that the 2nd generation vapour control layers have a larger spread of the diffusion-equivalent air layer thickness (S_d-value).

Moisture variable vapour control layer with Hygrobrid technology is 3rd generation of MVVCL-s. Besides the moisture variability, this vapour control layer has an additional function, that it shows a different sd-value at the same ambient air humidity, according to the direction of the diffusion flux. This way, the effect of the moisture variability is reinforced. Moreover, the infusion of the water vapour in the construction is reduced due to the elevated S_d-value at a higher room air humidity (e.g. building moisture).

Methods

The simplified Glaser method according to DIN 4108-3: 2014 and SIA 180: 2014 is not applicable for an external vapour-tight, green flat roofs and vapour tight pitched roofs in wooden construction with inward laying moisture control layer. In addition, such a simplified method cannot be used to analyse different parameters in terms of building physics. In such cases, reference is made to hygrothermal simulations (EN 15026: 2007; WTA 6-2: 2014). The roofs types are to be examined is calculated with the software Delphin 5.9. The following examination will demonstrate the performance of the newly developed 3rd generation vapour control layer with Hygrobrid technology in comparison with other moisture variable vapour control layers with small and large spread.

Results

Safety margin with mineral fibre insulation for flat roofs

The safety margins of the wood composite moisture (OSB) when using the different vapour control layers are shown in Figure 1. When using mineral fibre insulation and considering the convection (LDK B, h = 10 m), the the 3rd generation MVVCL has a safety margin up to 1.1 M-% as compared to other vapour control layers.

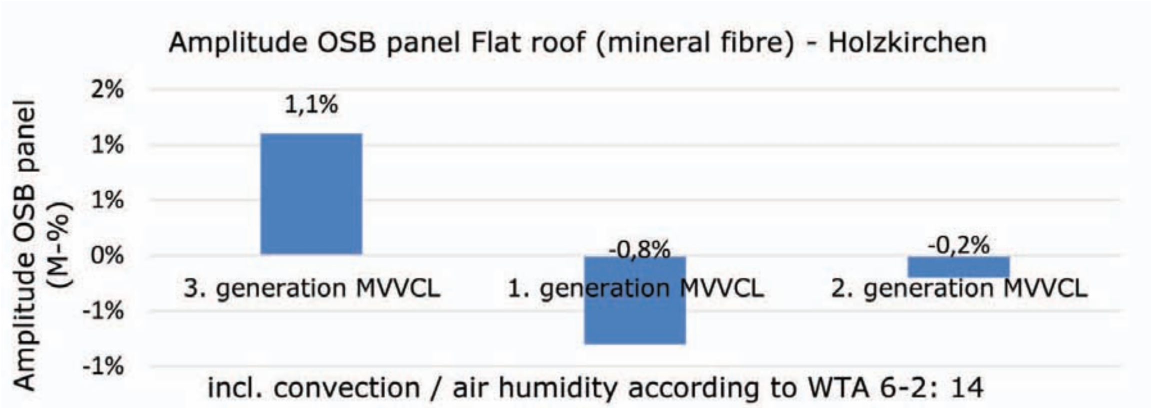

Figure 1. Safety margin of an external vapour-tight flat roof with different vapour control layers and mineral fibre insulation. The SIGA-*Majrex* is the only one with a safety margin to the limit value. The others exceed the limit value of 18 M-%.

Safety margin for pitched roofs

The moisture variable vapour control layer of the 1st generation at 40° in a steady state has a small safety margin of 1.2 M-% relative air humidity (Figure 2). However, it exceeds the limit curve in the first year of the simulation. The moisture variable vapour control layer of the 2nd generation can be constructed up to a roof inclination of 60°. In case of a 40° and 60° inclined, north-oriented roof, the safety margin of the 3rd generation VCL will be again compared with the moisture variable vapour control layer of the 1st generation and 2nd generation (Figure 2).

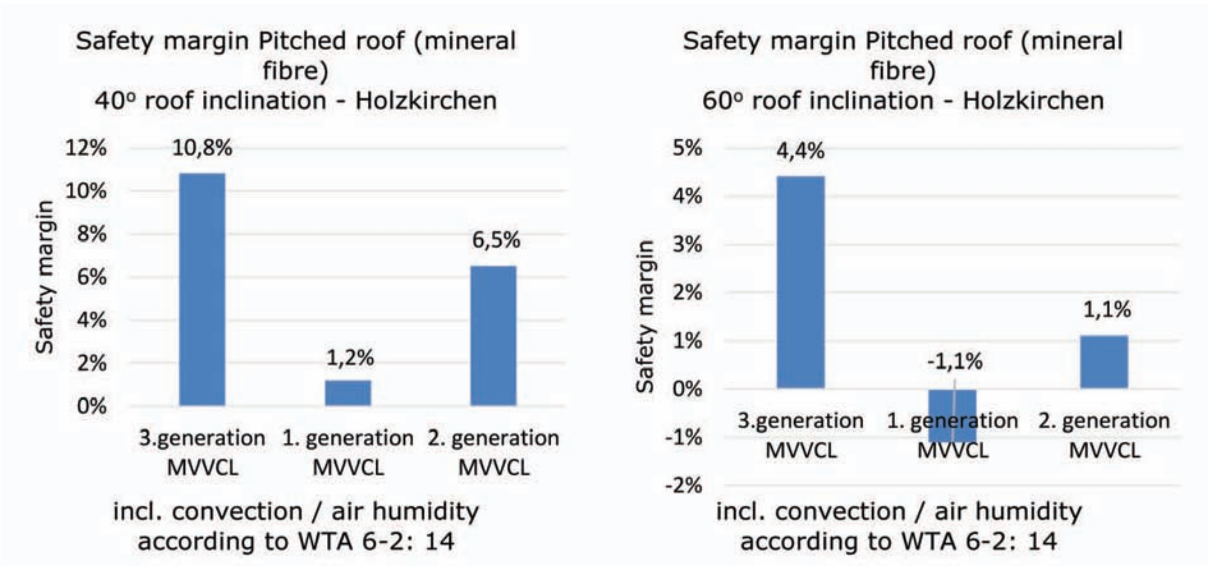

Figure 6. Safety margin of an external vapour-tight pitched roof (north orientation) with different vapour control layers in function of roof inclination (left: 40°, right: 60°).

Conclusion

The 3rd generation moisture variable vapour control layer with Hygrobrid technology, which has additional function that the sd-value changes according to the direction of the diffusion, has many application areas. The behaviour of the VCL has a positive effect on the moisture balance of an external vapour-tight and green roof. It has also a positive effect on the moisture balance of an external vapour-tight pitched roof. Even in case of these unfavourable conditions, there is still a re-drying capacity. As compared with the moisture variable vapour control layers of the 1st and 2nd generation, it has a high drying potential and therefore more applications for different constructions.

Timber construction in winter – how to achieve a protected timber structure

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Summary

Increased relative humidity levels are present on most building sites during the colder period of the year. These conditions have an influence on the moisture content of materials used in timber-frame constructions. On the one hand, it is important to identify and discuss the sources of this moisture in order to reduce the total amount of moisture. On the other hand, the structures should be protected during the construction phase as well as during the lifetime of the building. A suitable hydrosafe value and the proven durability of humidity-variable behaviour are preconditions for a long-lasting structure.

Keywords: humidity-variable vapour retarder, airtightness layer, hydrosafe value, service life > 50 years, German approval, durability

What is different about a building site in winter?

High-quality timber-frame homes have the advantage over masonry buildings that they are built using dry materials. Prefabrication allows for a high degree of protection for building components against weathering during the construction phase. However, most buildings are a mixture of masonry and timber structures. Here there are more demanding requirements with regard to moisture protection, as structures are generally built on site in this case.

Influence of moisture

The overall aim for the protection of timber structures is to protect them against moisture over the construction's entire service life so that buildings will provide a comfortable indoor climate to users for many years, combined with low energy consumption.

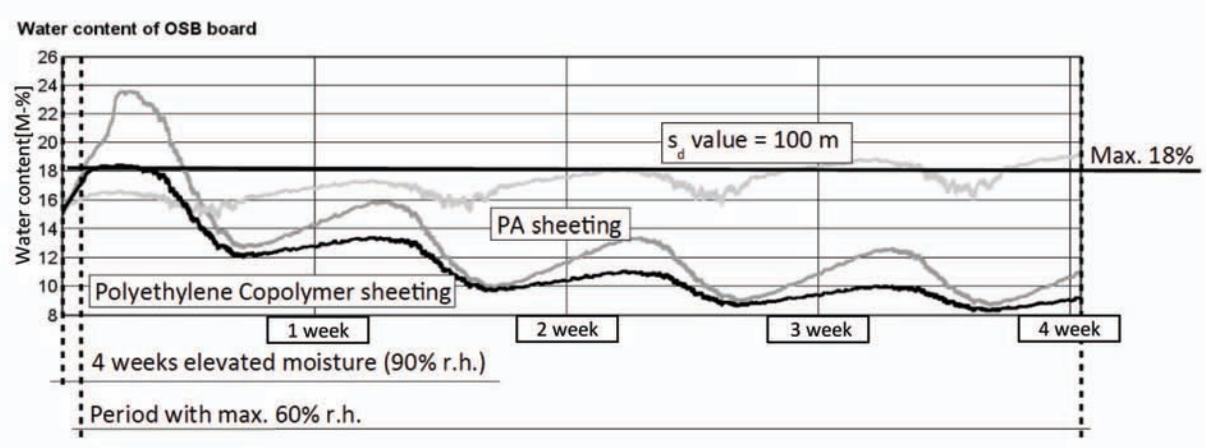
In this regard, attention must be paid not only to the service life where the building will be actively used and lived in, but also to the construction phase itself. As a result of the large amounts of moisture that are present in masonry structures, the construction phase can lead to an indoor climate characterised by moderate temperatures combined with high relative humidity.

Achieving protection for building components by planning

For this reason, timber protection starts with the selection of suitable materials and the planning of an intelligent sequence of layers from a building physics viewpoint, so that the structure will remain dry. The selection of the inner airtight layer plays a decisive role here, as its secondary property – its vapour-retarding effect – has a significant influence on the moisture content of the materials in building components.

A flat roof during the construction phase

To model the influence of increased building moisture (90% r.h.), a flat roof construction was considered hygrothermally over a period of 4 weeks with various vapour retarders. Under identical conditions, the material humidity in an OSB panel increases to as much as 18 M-% during this period (up to the dashed line in the graph) with various vapour retarders (humidity-variable Polyethylene Copolymer sheeting, humidity-variable PA sheeting and s_d value = 100 m).



Water content of OSB board

A maximum moisture content of 18 M-% is regarded as non-critical in the long term for timber materials.

After this period, the relative humidity is significantly reduced to a maximum of 60% by constant ventilation. The OSB panel in the structure with PA sheeting continues to absorb moisture as winter persists and reaches a moisture content of almost 24 M-%. This significant exceeding of the limit value over a number of months can affect the static properties of the OSB panel and can favour the formation of mould.

If the same component with the Polyethylene Copolymer sheeting is considered, only a small overshoot of the 18 M-% limit occurs in the OSB panel. This is not critical, as it only occurs for a short time during construction. After this, the moisture content reduces from year to year – this structure is reliable because the Polyethylene Copolymer sheeting with its hydrosafe value of 2 m at 70% r.h. provides sufficient protection, even with increased construction moisture.

If a vapour barrier with a s_d value of 100 m is used on the inside, the component initially appears to be non-critical. However, moisture enters over subsequent years due to unavoidable leaks, meaning that the moisture content of the OSB increases to above 18 M-% in the long term. This component is very susceptible to damage and is no longer in adherence with generally recognised engineering practice in Germany.

Protection for components through long-term performance

The inner airtight layer has an important protective function, as it regulates the moisture balance of timber components. The issue of the long-term functioning as a vapour retarder and airtight membrane arises in this context. European standards, with the ageing testing specified in EN 13984, provide a solution for membranes with constant diffusion resistances. However, this cannot be used for humidity-variable vapour retarders. The German Institute for Civil Engineering (DIBt) has developed a test procedure for humidity-variable vapour retarders that confirms the long-term performance of humidity-variability over a period of at least 50 years.

Conclusion

With a suitable hydrosafe value and verified long-term humidity-variable performance, modern timber-frame structures can remain free of moisture damage during the construction phase and over the building's entire service life.

A case study on construction of CLT building without preliminary roof

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Babette Liseth Kuus, site technician[2]; Villu Kukk, doctoral student[1]
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Summary

This paper is focused on cross-laminated timber (CLT) and the influence of moisture properties dynamic during installation process in Estonian climate. Moisture safety principles are designed based on case study of comparable activities – 4D standpoints and on-site water content monitoring. On-site water content monitoring was performed on installed CLT elements and parallel polygon specimen. Polygon testing was arranged with reduced size CLT elements with different conditions – opened to climate, protected from precipitations and covered with film. According to on-site results, highest moisture risk regions were identified and activities for moisture safety principles were composed.

Keywords: CLT; timber; water content; moisture safety; building quality.

Introduction

This case study is based on Viimsi State Gymnasium building as a pilot project of CLT-element usage in further typical design of state schoolhouse in Estonia. CLT-elements designing has been noticeably growing for the last decade in all leading European countries. Although, CLT has equivalent scale of mechanical properties compared to several other main construction materials, using timber brings up the severe moisture safety issue. According to common knowledge, the upper safe limit of water content in timber structures is considered 17% by mass, overcome leads to critical state to fulfil the moisture safety of CLT elements in construction. This is generally the starting position for moisture damage such as volume changes, strength decrease and potential irreversible decomposing fungus progress in timber structure.

In this case study instead of setting up temporary weather protective tent during installation process higher risk was taken. CLT-elements were protected only by packaging film installed in production process to ensure factory (Peetri Puit OÜ) declared water content 13% ± 2% by mass. Additional canvas covers were added selectively on-site to protect CLT elements from direct precipitation till roof construction was waterproof.

Figure 1. CLT floor elements covered by packaging film and stored on-site before installation process (left). Overall view of CLT element installation process (right).

Methods

The set up for this case study was to predict and map out most critical positions of CLT elements opened to weather conditions during installation process with minimal precautionary measurements for moisture safety. Preliminary on-site activities were composed according to FPInnovations 4D principles – deflection, drainage, drying and durable material. After CLT-element installation process water content was monitored using pin electrode moisture meter (Extech MO290) with 10 mm and 85 mm height pins. Parallel polygon testing with reduced size CLT elements (300 x 1000 x 60) mm was performed as stated previously, both vertical and horizontal direction included. During water content monitoring period actual climate parameters were measured. In laboratory additional capillary water absorption in compliance with element direction was measured.

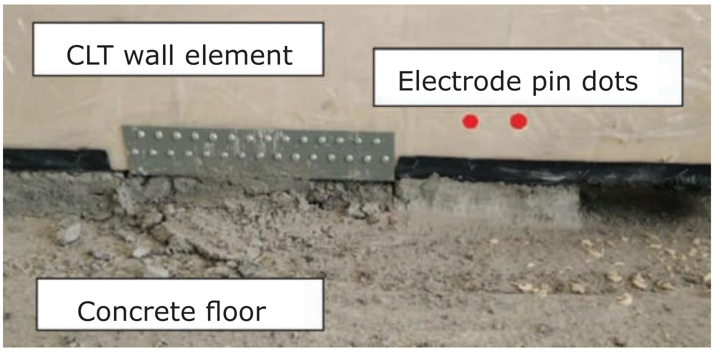

Figure 2. High moisture risk position – CLT wall element and concrete floor joint and moisture meter electrode dots (left). Polygon testing area of uncovered and opened to climate reduced size CLT elements (right).

Results and discussion

Installation process of CLT elements was performed during relatively high precipitation period. Pre-planned 4D moisture safety principles were mostly followed and CLT elements resulted with water content up to 15% by mass. Yet decreasing dynamic was apparent in time due to sorption process. However, compared to polygon testing and opened to climate horizontal CLT element after higher precipitation reached to moisture content over 25% and lasted several weeks before decreased below 17% limit with short pins. Taller pins and internal moisture showed below 25% water content after precipitation but dried out till 17% over a month. The logic was similar with wall elements but approximately 10% lower water content. According to internal and surface moisture difference brings up the importance of water content measurement depth of CLT elements. According to laboratory capillary absorption results of CLT elements it can be stated that prolonged direct water contact can reach up to 40% of water content by mass in a week which is a clear signal for high risk areas in the context of moisture safety.

Conclusions

According to this case study implementing 4D moisture safety principles on CLT element building process performed well. If direct water contact was immediately eliminated from CLT elements, additional high relative humidity (RH >80%) didn't put moisture safety at risk and no visual mould or fungus growth appeared. However, it can be stated, that highest moisture risk regions are horizontal floor elements and floor-wall joins. Critical on-site positions didn't exceed the upper safe limit (17%) of water content in CLT elements.

Acknowledgements

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Development of airtightness of Estonian wooden buildings

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Summary

The field measurements of airtightness in Estonian detached and apartment buildings conducted between 2003–2017 were combined into a large dataset for further analysis. The buildings were classified based on building structure, number of storeys, year of construction, energy classification and compactness factors. A subset with all wooden buildings (313 in total) was statistically analysed to determine the average (median) air leakage rates at 50 Pa and tested (Kruskal-Wallis test with post-hoc Conover test) for significant differences within the grouping factors. As expected, the median air leakage (q_{50}) of older buildings between 10.7 and 13.9 m³/(hm²) has decreased to 1.1 m³/(hm²) after the minimum requirements for energy efficiency have taken effect. A more detailed analysis on newer buildings showed that quality of the workmanship combining systematic measurement routines as well as prefabrication, yields significantly lower median air leakages compared to on-site construction. Similar differences were found between buildings with lightweight timber construction and log houses. Surprisingly, the compactness of the building envelope and the number of storeys did not have significant effect on airtightness. For use in energy calculations, the base values of air leakage rates for each group are calculated and presented accounting for variation of measurements.

Keywords: Airtightness; air leakage; pressurisation test

Introduction

A well-insulated, airtight and thermal bridge free building envelope is a key factor for nearly zero energy buildings (nZEB) that becomes mandatory from year 2021. Minimising heat losses and combining a thermally optimised building envelope with the passive use of solar energy allows a significant reduction in the heat load and heating energy demand of residential buildings. However, increased insulation thickness in timber constructions creates a serious risk of moisture accumulation inside the construction and deterioration of the building structure if the air leakages are not minimised or avoided.

Studies have shown that the overall air leakage of the building envelope, even in modern buildings, depends mostly on the building quality and on factors, such as construction type, building size, building compactness, prefabrication technology etc. Statistical estimations based on measured data for a given construction types and building practices can be used as an input data for whole building energy calculation prior to actual air leakage measurements although the average airtightness of existing building stock and the variation within subgroups can be different in different countries. In this study a large set of airtightness measurements of Estonian wooden buildings are statistically analysed to determine the average and base values for air leakage rates at 50 Pa within the grouping factors related to construction type, building complexity and quality assurance.

Methods

The database of air leakages was combined based on the results of different measurements carried out between 2003 and 2017 (in total 522 buildings). The subset of all wooden buildings (in total 313 buildings) was statistically analysed to determine the average (median) air leakage rates at 50 Pa and tested (non-parametric Kruskal-Wallis test with post-hoc Conover test) for significant differences within the grouping factors. The buildings were classified based on construction type, the number of storeys, age group, energy classification targets and compactness factors of the building envelope. Additionally, on-site building practice was compared to prefabricated lightweight timber construction, and handmade log buildings to prefabricated log buildings.

Results and discussion

As expected, the median air leakage (q_{50}) of older buildings between 10.7 and 13.9 $m^3/(hm^2)$ has decreased to 1.1 $m^3/(hm^2)$ after the minimum requirements for energy efficiency have taken effect (figure 1). The base values for age groups were 17.8 $m^3/(hm^2)$, 26.8 $m^3/(hm^2)$, 9.5 $m^3/(hm^2)$ and 3.0 $m^3/(hm^2)$ respectively in chronological order. A more detailed analysis on buildings (137 in total) built since 2009 described the effect of different factors on air leakage (Table 1).

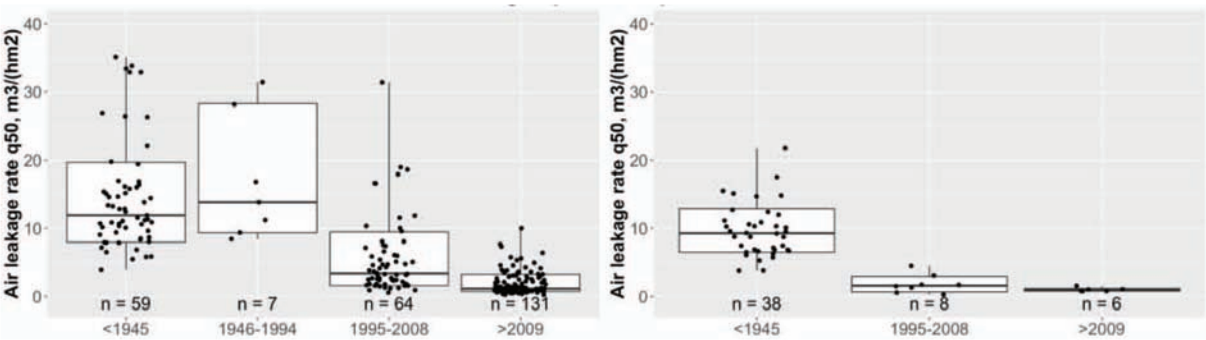

Figure 1. Air leakage rates (median with 0.16/0.84 quantiles) of detached (left) and apartment buildings (right) based on year of construction.

Table 1. Effect of different factors on air leakage rate and its base value.

Wooden houses built since 2009	No of buildings	q_{50}, $m^3/(h \cdot m^2)$	$q_{50,base}$, $m^3/(h \cdot m^2)$
1-storey	34	1.1	3.4
multi-storey	103	1.1	3.0
Energy class A	6	0.5	2.0
Energy class B	10	0.7	2.1
Energy class C (minimum)	121	1.2	3.2
Log-building	46	2.2	3.9
Lightweight timber	91	0.9	2.6
irregular measurements	35	2.8	5.1
systematic measurements (>5)	102	1.0	2.0

The lightweight timber construction had significantly lower air leakage compared to log houses. Systematic measurement practice also contributed to significantly lower air leakages. Surprisingly, the analysis showed no significant difference between buildings with different compactness factors or different number of storeys. Due to large variation in measured values, the base values are much higher than average air leakage rates.

Conclusions

The airtightness of Estonian wooden buildings has improved by a factor of 10 since the minimum requirements for energy efficiency have taken effect. Prefabrication with light-weight timber construction technology seems to be superior to on-site building and log-wood building technology. The compactness factor and number of storeys did not have a significant effect on air leakage referring to the fact that if systematic quality assurance with a proper air tightness concept is used, the geometric and structural complexity of the building envelope is no longer a key factor while achieving air tightness.

Acknowledgements

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Field measurements of a MHM envelope with ETICS

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Summary

This study is focusing on evaluating construction moisture level in MHM panels during the construction period and analysing the hygrothermal performance of an MHM external wall. Measurements were taken on site from external wall elements of a private residence, which were under construction. The results of measurements showed that construction moisture reached up to almost 45% of moisture content (MC) in MHM wall panels at the beginning of construction period. From measurements of the wall assembly, no mould growth threat was found during the construction period.

Keywords: MHM panel, construction moisture, hygrothermal performance

Introduction

Massiv-Holz-Mauer (MHM) is a solid wood panel consisting of untreated boards that are attached together cross-wisely by aluminium groove pins. The structure is similar to the cross laminated timber (CLT), only MHM laminations are jointed together with aluminium pins and wooden boards in laminations are grooved from one side for giving better insulation properties to the panel. This study is focusing on evaluating construction moisture level in MHM panels during the construction period and analysing the hygrothermal performance of an MHM external wall. Construction moisture in MHM walls may occur when panels are exposed to rainwater and water leaks.

Methods

All measurements were taken on site from external wall elements of a private residence. Construction period of residence started at the beginning of the summer 2017 and first measurements were taken in mid-autumn after the MHM panels were installed. External wall structure was composed with external thermal insulation composite systems (ETICS), see Figure 1, b. MC was measured from the bottom chord or lower part of MHM wall panel from the most critical locations where water leakages were occurred (Figure 1, a). Temperature (*t*) and relative humidity (RH) were measured between material layers and the inner and outer surface of the external wall (Figure 1, b). *t* and RH measurements on site were used to make a calculation model for a given external wall with simulation software Delphin 5.9.3. Calculation model was made for analysing hygrothermal performance by using calculation method which considers Finnish Mould Growth Model through mould index classification according to EN 15026, 2007.

a) b)

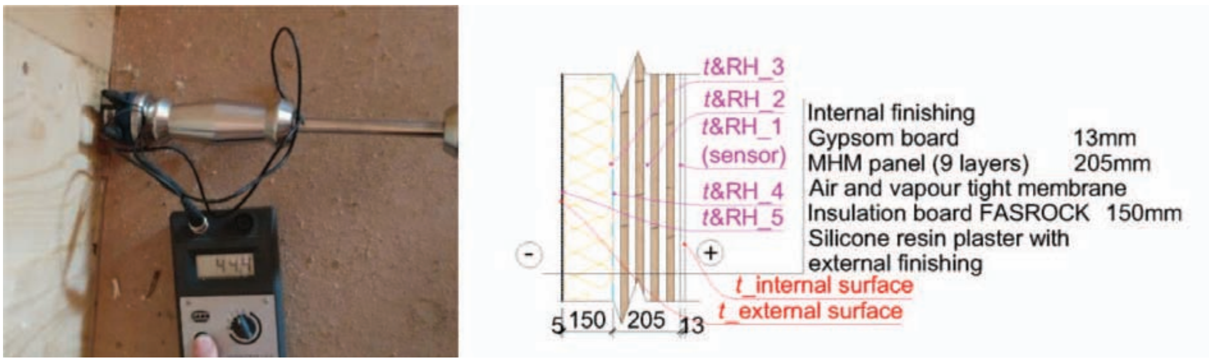

Figure 2.1. MC measurement device (a), external wall section with sensors placement (b).

Results and discussion

First MC measurements were taken on 20.10.2017 and results showed that MC varied in most critical points from 45% to 30%. Visible it was seen that the most critical points in the lower parts of wall panels were wetted or on the surface, there were spots indicating to wetting. In some locations could be found darker blue stains which may have been indicative of the initial formation of the mould in the wood surface. Second MC measurements were taking a month later on 24.11.2017 from the same critical locations. Results showed that MC was dropped to 29% to 19%, about 15% to 10% of moisture loss within one month. MC was not measured before the MHM wall panels were covered with gypsum boards and therefore there is no information what MC the wall panels had in critical locations before service time. However, proceeded measurements showed that MC in MHM panels can rise to very critical level due to water leakages during the construction period, but also moisture drying rate from the panels is fast when using auxiliary equipment such as air dryer.

The results of *t* and RH between external wall materials layers are shown in Figure 1. Results were collected from 20.10.2017 to 10.05.2018, altogether 203 days. The results showed that most critical point in wall structure was between insulation board and external plaster (layer 5). During first three months the average RH in layer 5 was 91% and average *t* 2.5 ºC. Later in that period both *t* and RH were decreasing. For evaluating possible mould growth risk in layer 5 the critical RH was calculated and found as 93% at given *t*. This showed that the potential risk for mould growth did not exist in given external wall measuring point. Calculation model has not been done yet and results will be presented in the full paper.

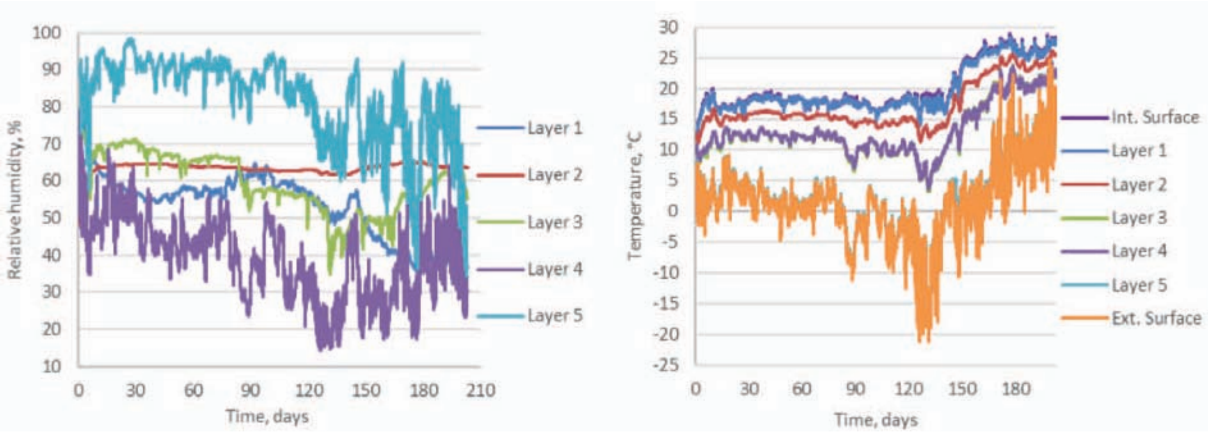

Figure 3.1. Measurements of RH (left) and T (right) between external wall material layers.

Conclusions

In this study, the construction moisture level in MHM panels during construction period was evaluated. Based on the results it was noted that during construction period MHM panels were exposed to water leakages and high MC existed. Also, the fast drying rate of moisture from panels was noted. Measurements of *t* and RH between external wall materials layers did not show any potential risk for mould growth by initial evaluation, nevertheless, calculations model needs to be done for more precise results.

Acknowledgements

This research was supported by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant TK146 funded by the European Regional Development Fund, by the Estonian Research Council with Institutional research funding grant IUT1-15, and by the Personal research funding grant PRG483, Moisture safety of interior insulation, constructional moisture and thermally efficient building envelope". The author wishes to thank Estonian manufacturer of prefabricated timber frame houses EstHus OÜ for the cooperation.

ENERGY PERFORMANCE OF BUILDINGS

Comfort assessment of two nZEBs in Norway

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Summary

This work presents the results of a survey and measurement campaign carried on in two wooden buildings in Trondeim, Norway. These are one tower in a student accommodation complex, the Moholt Allmenning, constituted by five CLT towers of 9 floors each, and a mixed CLT-and-timber-frame educational building, the Haukåsen kindergarten. Both buildings comply with the Norwegian Passive house standard and the kindergarten complies with the BREAAM certification as well. Questionnaires focussing on the buildings' users thermal, acoustic, and visual comfort, and on the IAQ were submitted. Measurements of the indoor operative temperature and CO_2 levels were performed. The measurements showed that both buildings are in the NS 15251 Class I with regards to the thermal environment, in both summer and winter. The questionnaires that the perceived dissatisfaction is somewhat higher than that assessed in the measurements, leading to a lower rating, especially in the student housing. One of the most reported issue in the student housing was the noise level, which resulted in 28% of student dissatisfied.

Keywords: Cross Laminated Timber, nearly Zero Energy Buildings, Thermal comfort, IAQ.

Introduction

Both the Moholt Allmenning Tower B and the Haukåsen kindegarten comply with the Norwegian passive house requirements set in the NS 3700. The delivered energy use recorded by the BMS in 2017 were 80 kWh/m² and 46 kWh/m² in the Moholt Allmenning Tower B and the Haukåsen kindergarten, respectively. The Molholt Allmenning and the Haukåsen kindergarten use less energy than the limits defined in the TEK17 and these are 95 kWh/m²y and 135 kWh/m²y for residential buildings and kindergarten, respectively. Both buildings are in the energy-class A, according to the energy classification in Norway.

Method

Onsite measurements of indoor air temperature (dry and wet bulb), relative humidity, CO_2 level, and air velocity were taken during different days in January and February 2018 for the heating season, and in August and September 2018 for the cooling season. Given that the student apartments are all identical in the Moholt Allmenning towers, an apartment located at the 4th floor of the Tower B was chosen as the representative space. The measurements in the Haukåsen kindergarten were taken in the common area at the first floor, and in the classroom in the ground floor.

In February 2018, a survey on the users' satisfaction of the indoor environment in both buildings was sent to the 632 students of the Moholt Allmenning and to the 11 employees of the Haukåsen kindergarten. The survey consisted of an anonymous online questionnaire where the informants were asked to rate their perceived thermal sensation, IAQ, noise level, and illuminance satisfaction, for a total of 11 questions, of which 8 were rating-scale question-types, and 3 were open questions.

Results and discussion

Moholt Allmenning Tower B

The average operative temperature is 22.8 °C in winter (max 24.2 °C and min 21.6 °C), which is very close to the average Class I comfort temperature (C1 average = 23.3 °C). The summer average operative temperature is 21.8 °C (max 23.5 °C and min 21.1 °C), which is within the Class I temperature band. Therefore, the reference room complies with the EN 15251 Class I with respect to the thermal environment, in both summer and winter. The measured average CO_2 level is 410 ppm in winter and 355 ppm in summer, which were both within the Class II IAQ range (min 350 ppm, max 500 ppm) for most of the measurement time in winter, and for half of it in summer. The measurement of the relative humidity gives an average of 22% in winter (RHmax = 31% and RHmin = 17%), and 52% in summer (RHmax = 61% and RHmin = 34%). The questionnaire was answered by 173 students.

Haukåsen kindergarten

The average operative temperature is 21.0 °C in winter (max 22.1 °C and min 18.3 °C), which is close to the Class I average comfort temperature (21.8 °C). Similarly, the summer average operative temperature is 21.0 °C (max 22.9 °C and min 20.3 °C). Therefore, the thermal environment in the reference rooms comply with the EN 15251 Class I for almost all the measurement time in winter, and for 100% of the measurement time in summer. The measured average CO_2 level is 497 ppm in winter and 395 ppm in summer, and these were both in compliance with the Class II IAQ range (min 350 ppm, max 500 ppm). The IAQ lied within Class II for 63% of the measurement time in winter, and it was in Class I for 34% of the time in summer. The measurement of the relative humidity gives an average of 21% in winter (RH_{max} = 26% and RH_{min} = 15%), and 4% in summer (RH_{max} = 59% and RH_{min} = 33%). The questionnaire was answered by all the 11 employees of the Haukåsen kindergarten.

Table 1. Summary of the questionnaires.

Acceptability of:	Moholt Allmenning	Haukåsen
Overall indoor environment	81%	90%
Thermal environment	92%	90%
Indoor air quality	76%	80%
Illuminance level	92%	100%
Acoustic level	72%	91%
Odour intensity	76%	90%

Conclusions

Both buildings are in the NS 15251 Class I with regards to the thermal environment, in both summer and winter, and both buildings are energy-class A. With regard to the IAQ, the Moholt Allmenning complied with Class II during the heating season, and between Class I and Class II in the cooling season. The Haukåsen kindergarten complied with Class II in the cooling season, and between Class II and III in the heating season. The averaged measured CO_2 concentration was below 500 ppm in both buildings. According to the questionnaires, the thermal environment was rated acceptable by at least 90% of the respondents. The IAQ was reported as acceptable by 76% and 80% of the respondents in the student housing and the kindergarten, respectively. The most reported issue in the student housing was the noise level, which resulted in 28% of student dissatisfied. More measurements are needed in the students' room of the Moholt Allmenning to verify if the dissatisfaction with the IAQ corresponds to high levels of CO_2.

Acknowledgements

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Nearly zero energy wooden buildings: day-care centres from NERO project

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Summary

The NERO project develops and demonstrates nearly Zero Energy Wood Buildings design process and procurement models with reduced cost for large-scale use in the northern climatic conditions and on performance level of nearly zero and beyond. On site and nearby renewable energy system solutions are studied in order to provide real addition of renewable and energy production of on-site energy system.

This paper is focused on data collected from existing nZEB day-care centres, in order to be able to assess possible differences between predicted and actual energy and indoor environmental performance. Building structures, service systems and the indoor climate and energy performance of five day-care centres were investigated in Estonia, Finland and Norway

Keywords: nZEB, wooden buildings, energy performance, indoor climate.

Introduction

The European energy policy pushes the member states to transform building stock into nearly Zero-Energy Buildings (nZEB). If the real measured building energy consumption is much higher than the predicted consumption during design, the performance gap hinders the realisation of energy conservation targets. To guarantee nearly zero or a very low amount of energy use, the building envelope and service systems should be very effective. Better information about effective energy performance measures helps design and construct buildings with a smaller performance gap. More information is needed on what kind of building properties are required in different countries to guarantee fulfilment of nZEB requirements.

The NERO project (https://neroproject.net/: Cost reduction of new Nearly Zero-Energy Wooden buildings in the Northern Climatic Conditions) will build down this barrier by demonstrating cost effective methods and solutions that are based on lifecycle analysis of both costs and energy performance.

Methods

The energy use, indoor climate, and building envelope structures were investigated in five day-care centres (Table 1) in Estonia, Finland, and Norway.

Table 1. Characteristics of building envelope

	Estonia 1	Estonia 2	Finland 1	Finland 2	Norway 1
Thermal transmittance *U*, W/(m² K)	0.10–0.20	0.06–0.13	0.09–0.17	0.08–0.15	0.08–0.09
Windows *U*, W/(m² K)	1.00	0.85	1.00	0.84	0.80
Airtightness q_{50}, m³/(h·m²)	3.8	0.6	2.0	0.36	0.14
Heating source	Gas boiler	GSHP	Gas boiler	GSHP	GSHP
Heat recovery efficiency	75 %	67–88 %	67 %	76 %	85 %
Specific fan power kW/(m³/s)	2.0	≈2.0	1.85	1.9	1.3

Results

During the heating season, the room temperature corresponded to indoor climate category I or II criteria 87–100% of the time, Fig. 1. During the cooling season correspondence to indoor climate category I or II criteria was much smaller: 21–54% of time in Estonia, 15–37% in Finland, and in Norway 100% of the time. Thermal environment during the cooling season is in indoor climate categories III and IV because the measured room temperature was lower than the minimum temperature for indoor climate category II. The overall indoor environment was very good as occupant satisfaction was 90% or more.

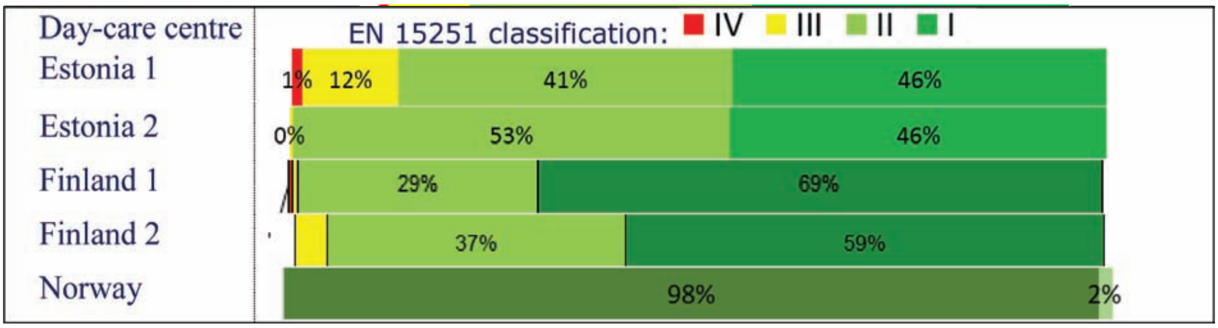

Figure 1. Thermal comfort results in studied day-care centres during heating season.

Energy use in the Norwegian day-care center was lower than designed. In other day-care centers, measured energy consumption is higher or even significantly higher than designed values. The energy performance certificate was two to four classes lower in the studied buildings, Fig. 2 left. The performance gap varied between 25–67% and it was larger in more energy efficient buildings, Fig. 2 right. Potential causes of the higher actual energy consumption are caused by differences between measured and designed solutions, the methodology of the energy calculations and the differences in user behaviour.

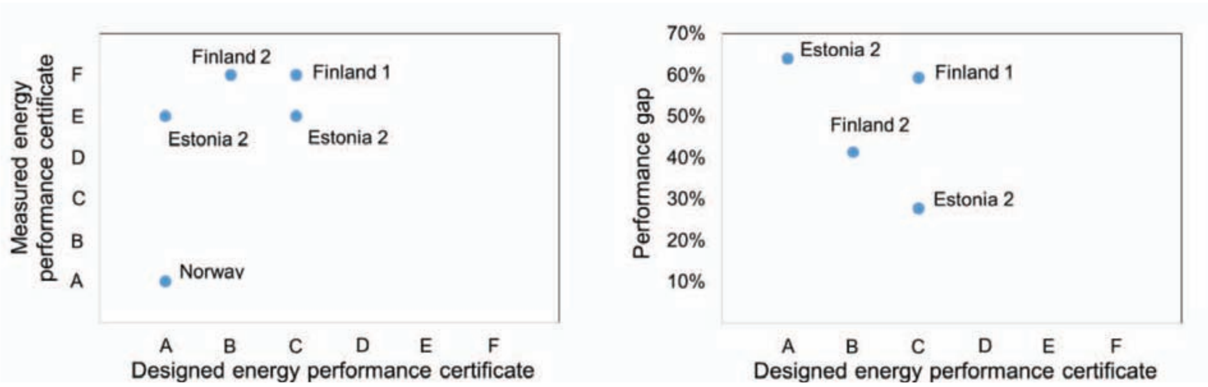

Figure 2. Comparison between designed and real measured energy performance certificate (left) and dependence of performance gap on designed energy performance certificate in buildings where energy performance targets were not fulfilled.

A more accurate and robust commissioning, design and construction process is needed for future nZEB day-care centers.

Acknowledgements

This research utilises measurement data from H2020 project No 754177: "NERO – Cost reduction of new Nearly Zero-Energy Wooden buildings in the Northern Climatic Conditions". The research was co-financed by the Centre of Excellence ZEBE, grant TK146 funded by the ERDF, and by the ERC with funding grants IUT1-15 and PRG483.

Primary energy and economic performances of cost-optimal retrofit measures for a Swedish building

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Summary

In this study the cost-effectiveness of various energy renovation measures for a Swedish district heated building from the 1970s is explored for different economic scenarios. Final and primary energy savings of the cost-effective energy renovation packages for the building are analysed. The cost-effectiveness analysis is based on a double-stage optimization method, considering total and marginal investment costs of renovation measures as well as associated net present values of total and marginal cost savings. The final energy savings of the measures are calculated on hourly basis and the associated primary energy savings are analysed considering the full energy chains. The results show that significant final and primary energy savings can be achieved when energy renovation measures are implemented for the building. This analysis demonstrates that heat and electricity demands in existing Swedish building could be reduced considerably with cost-effective renovation measures.

Keywords: Energy renovation; cost-effectiveness; final energy; primary energy; economic scenarios.

Introduction

Sweden aims to achieve net zero GHGs emissions by 2045, and has targeted to reduce energy intensity per heated building floor area by 50% by 2050 with 1995 as baseline. Space and tap water heating account for 55% of the total energy use of the Swedish residential and service sector, where district heating is common form of heating. A large number of Swedish apartment buildings were constructed during the Million Homes Program between 1965 and 1975, and are projected to undergo major renovation within the coming years. Many of these buildings have high specific final energy use, as they were built before energy efficiency was emphasized in the Swedish building code. Therefore, there is a large potential to reduce final energy use in a significant share of the Swedish apartment building stock with energy efficiency retrofit measures.

In this study, the cost-effectiveness of energy renovation measures for a district heated building under different economic scenarios is investigated. Final and primary energy savings of the cost-effective energy renovation packages for the building are analysed for the different scenarios.

Methods

This study integrates dynamic energy balance simulation, economic modelling and system analysis to investigate the cost-effectiveness of different building energy renovation measures and associated energy savings. A typical Swedish multi-family concrete-frame building with 3-storey living area and a basement below ground is used as a case-study. The building is from the 1970s and contains 27 apartments, with a total heated living floor area of 2000 m^2. The energy renovation measures analyzed for the building are: improved insulation for attic floor, basement walls, and exterior walls; improved windows and doors; resource-efficient taps; heat recovery of exhaust ventilation air; energy-efficient household appliances and lighting. Annual heat and electricity demands of the building without the energy renovation measures are calculated to be 272 MWh and 65.8 MWh, respectively, for the climate of Växjö.

Final energy savings of the measures are calculated on hourly basis for the climate of the city of Växjö, in southern Sweden. The cost-effectiveness analysis is based on a two-step approach, considering total and marginal investment costs of renovation measures as well as associated net present values (NPV) of total and marginal cost savings. As a first step the energy renovation measures are analysed and cost-optimised individually. Based on this, packages of energy renovation measures are analysed in the next step. Three economic scenarios are used in the analyses: *sustainability scenario* with real discount rate of 1% and annual energy price increase of 3%, *intermediate scenario* with real discount rate of 3% and energy price increase of 2% and a *business-as-usual* (BAU) scenario with real discount rate of 5% and annual energy price increase of 1%.

The primary energy savings of the cost-effective energy renovation measures are analysed for the district heating system in Växjö, considering the full energy chains.

Results and discussion

Table 1 presents the packages of cost-effective renovation measures for the building under the different scenarios, for a time horizon of 50 years. Ventilation heat recovery (VHR) system is cost-effective under only sustainability scenario while exterior wall insulation is not cost-effective, for all the scenarios.

Table 1. Packages of cost-effective energy renovation measures under different scenarios.

BAU	Intermediate	Sustainability
Efficient taps Efficient lighting & freezer 50 mm basement insulation 1.2 W/m² K windows	Efficient taps Efficient appliances (all) 250 mm basement insulation 1.2 W/m² K windows	Efficient taps Efficient appliances (all) 250 mm basement insulation 0.9 W/m² K windows 400 mm attic insulation VHR system (centralised system)

Table 2 summarizes the energy savings as well as the investment costs and NPV of cost savings for the cost-effective energy renovation packages. The final and primary energy savings as well as the economic benefit of the cost-effective energy renovation are largest for sustainability scenario and lowest for BAU scenario. The economic benefit for sustainability scenario is about a factor of 2.5 to 4 compared to the other scenarios.

Table 2. Final and primary energy savings, total investment costs, NPV of cost savings and differences between NPV of cost savings and total investment cost of the cost-effective renovation

Scenario	Final energy savings (MWh/yr)	Primary energy savings (MWh/yr)	Total investment costs (k€)	NPV of cost savings (k€)	NPV – Total investment costs (k€)
BAU	124	128	128.3	313.5	185.2
Intermediate	138	130	172.3	473.7	301.4
Sustainability	189	180	380.9	1129.6	748.7

Conclusions

This study shows that significant final and primary energy savings can be achieved when energy renovation measures are implemented for existing Swedish buildings. The final energy savings, including heat and electricity, for the cost-effective energy renovation package varies between 37% and 55%, depending on the choice of real discount rate and annual energy price increase. The economic viability of the renovation measures is sensitive to the economic regimes especially discount rates and energy price increase. In summary this analysis shows the importance of different energy renovation measures and economic-related parameters in achieving large energy savings in Swedish buildings cost-effectively.

Influence of window details on the energy performance of an nZEB

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Summary

This paper examines the influence of window frame thermal transmittance, window frame height and window installation depth on the energy demand of an nZEB. The purpose was to identify whether window frames influence the net heat demand of an nZEB and by how much margin. The results show that decreasing the thermal transmittance and height of the window frame have a significant effect on the energy demand of the nZEB. The effect of optimising window installation depth is insignificant. However, it can further improve the energy performance. The study gives valuable information for design decision making process.

Keywords: energy performance of buildings; nZEB; timber construction; windows; window installation optimisation

Introduction

There have been significant advances in glazing technologies and there have been studies about the window-to-wall ratio and glazing properties, but the effect of window frame properties and window installation is still less researched. It is necessary to understand whether the influence of these is significant in a nearly zero energy building (nZEB). In this study, two parameters of the window frame were further examined – the window frame thermal transmittance and the width of the window frame. Additionally, an optimisation task was carried out to determine the influence of the window installation depth. It was hypothesised that the impact of window frame properties is significant on the energy balance of the nZEB. A single-family prefabricated timber nZEB located in Estonia was used as a reference building for this study.

Methods

Energy balance & two-dimensional heat transfer simulations

Energy balance simulations were done using PHPP software, which utilises the monthly method specified in ISO 13790:2008. The boundary conditions were in accordance to the Estonian methodology for calculating the energy performance of buildings.

The linear thermal transmittance (LTT) and the temperature factor (f_{Rsi}) of the window installation junctions was found according to ISO 10211:2017, ISO 10077-1:2017, ISO 10077-2:2017, ISO 6946:2017 and ISO 13788:2012. LBNL Therm 7.6 was used for the simulations.

Reference building as nZEB and LEB

The single family nZEB with 148 m^2 heated area has a very well insulated thermal envelope, including windows with very good thermal performance. To determine whether the studied effects are specific to very efficient buildings, an additional less energy efficient model of the building was proposed with construction corresponding to typical prefabricated low-energy (LEB) buildings in Estonia.

Window frame properties and window installation analysis

For determining the influence of the thermal transmittance of the window frames, a hypothetical window frame was proposed with 11 cm as the width of the frame section. The U_f value was incrementally changed from 0.5 W/(m^2·K) to 1.4 W/(m^2·K) in the energy balance calculation. A similar approach was used for the analysis of the influence of the frame width. The U_f value of 0.8 W/(m²·K) remained unchanged, but the frame width was incrementally changed from 5 to 14 cm and in relation to that the shading of glazing was also updated in the model.

To determine the influence of window installation depth, a series of heat flow simulations were done. The window placement was changed in 14 steps from the outer edge to the inner edge of the window reveal for both building versions. The net heat demand was calculated for each step, considering the changed shading and window installation LTT.

Results and discussion

Increasing the window frame thermal transmittance from 0.5 W/(m²·K) to 1.4 W/(m²·K) increases the net heat demand by 42% on the nZEB version of the reference building (from 16.3 to 23.1 kWh/(m²·a)) and by 27% on the LEB version (from 29,6 to 37,5 kWh/(m²·a)). The variation of the window frame width from 5 to 14 cm results in the increase of the net heat demand from 15.8 to 19.8 kWh/(m²·a) on the nZEB (increase of 25%) and from 28.2 to 34.0 kWh/(m²·a) on the LEB (increase of 21%). The variation of the window installation depth results in the variation of net heat demand between 16.6 and 18.2 kWh/(m²·a) on the nZEB and between 28.6 and 29.4 kWh/(m²·a) on the LEB.

It is apparent that the actual window frame product is important. It is advisable to notice window frame dimensions also, as the influence of window frame width to the building net heat demand is significant.

It is observed that the lowest window installation LTT values are achieved for window positions roughly in the centre of the window reveal for both the nZEB and LEB. However, this has an insignificant effect on the overall heat demand compared to the influence of window frame thermal transmittance or the influence of the window frame height. Furthermore, it is counteracted by the increasing shading effect of the window reveal once the window is positioned deeper into the wall construction. The negative influence of shading is even more pronounced on the nZEB because of its thicker walls. This is because the influence of the solar gain on the overall building energy balance is greater than the influence of window installation LTT. Thus, it is preferable to install the windows towards the outside of the wall construction, but in such a way that the temperature factor f_{Rsi} is within safe limits. Further optimisation of the installation thermal bridge has little effect and one can omit this in the planning phase of the building, thus simplifying the process.

Conclusions

The results show that the window frame thermal transmittance and the width of the window frame have noticeable effect on the total energy demand of the building. However, the influence of window installation depth is insignificant. Nevertheless, it is suggested to install the window more to the outside of the wall construction to minimise window reveal and overhang shading. Concurrently it is important to keep the temperature factor within safe limits. If that is ensured, further optimisation work is not particularly beneficial.

Acknowledgements

This research was supported by the Estonian Research Council with Personal research funding PRG483, Institutional research funding grant IUT1-15, Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant TK146 funded by the European Regional Development Fund. The authors would also like to thank Sense OÜ for cooperation of providing data and details about the reference building.

RENOVATION OF BUILDINGS

Towards upgrading strategies for nZEB-dwellings in Norway

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Summary

The aim of this work has been to explore the typical Norwegian housing typologies and some important characteristics of the building envelope for housing from the different decades studied. This is an important foundation in the work of upgrading strategies for dwellings to nZEB level. The results show that the building norms and practices throughout the years has made dwellings more moisture resilient with an increased drying out potential through mechanical ventilation, control of the air change rate and more vapour open wind barriers of the building envelope. The continuing work will suggest a methodology for risk reduction of moisture problems by upgrading.

Keywords: Building physics; Moisture resilience; Energy upgrading of buildings; nZEB; Dwellings.

Introduction

Norwegian residential buildings are largely detached wooden houses, 60% of which are detached houses built between 1960 and 1990 and are by now 30–60 years old. This building stock is now rapidly reaching a stage where major renovations need to take place. The large number of completed detached houses in the 1960s, 1970s and 1980s, together with strict rules from the Norwegian Housing Bank for obtaining mortgages, have led to the building typology of this period being quite homogeneous.

According to the Norwegian government, all new buildings should be built according to nZEB level by 2020. The European Union Directive 2010/31 set a specific definition of this level.

To save energy in the building sector, it is necessary to increase the focus on upgrading of the existing building stock. The energy use of Norwegian single-family houses was 30 TWh in 2009. By upgrading the building envelope of detached houses built before 1990, a potential energy saving of 8 TWh was found.

This publication is in relation to the Norwegian research project OPPTRE – Energy upgrading of wooden dwellings to nearly zero energy level. "The goal for OPPTRE is to propose a nearly Zero Energy Buildings (nZEB) level for the renovation of wooden dwellings to an upgraded energy performance with low costs and low carbon footprint."

Methods

This study is conducted primarily as a literature and document study.

Norwegian building rules* from the last 60 years have been used, as has the Norwegian knowledge system Byggforskserien (The Building Research Design Sheets) and Trehusboka (The Norwegian Wooden House Book). Norwegian technical approvals for building products over the last 30 years have also been used. A technical approval indicates that a construction product is considered to be suitable for use and meets the requirements of the building regulations for the uses and conditions specified in the approval document.

The study is limited to Norwegian dwellings, but it is likely that the study and findings herein will have a great transfer value to other countries with a long history of wooden houses.

* Norwegian building rules from 1965-2017 available from: https://www.regjeringen.no/no/tema/plan-bygg-og-eiendom/bygningsregelverket-fra-1965--20172/bygningsloven/id2590707/

Results and discussion

Since 1950, there have been increasingly strict building regulations concerning the technical demands for building parts. In recent decades the revisions have been more frequent but the minimum demands for heat insulation of building parts have, to a large extent, been constant since 1987. However, during this period, the requirement for the air change rate of the building envelope has been lowered from 4 to 1.5 h-1. The increasing focus on building infiltration has led to a positive focus on air tightening, especially air tightening of the wind barrier. An airtight wind barrier is, together with an airtight vapour barrier, not only a measure to save energy, but also a measure to avoid building defects caused by, for example, convection of warm, humid indoor air through the structure.

An nZEB upgrading of a dwelling implies a need to focus on additional insulation on the exterior or interior face of the existing construction and the overall consequences of this. The upgrading measures can often be performed in different steps. In order to secure high architectural and technical performance, joints between the different building parts have to be planned. One typical practical example is that additional exterior wall insulation affects the roof overhang of the specific building and should be accounted for when the roof is upgraded.

In addition to lowering energy consumption, the addition of insulation in different building parts is increasing the moisture mould growth potential of these constructions in general. However, by replacing the existing wind barrier with a modern product (vapour open foil), the vapour resistance of the wind barrier is lowered and the dry-out potential of the construction increases. In addition, these modern wind barriers often imply a lower air permeability of the construction, which increases the moisture robustness. Installation of balanced ventilation is lowering the humidity level of the internal air and hence further increasing the moisture robustness of the construction.

A risk assessment tool based on fault tree analysis could be applied and a way forward, considering the moisture safety of the existing and upgraded solution to make it easier to get a simplified overview of the situation and to make correct choices for different constructions.

Conclusions

The results of this work show that building norms and practices throughout the years have made dwellings more moisture resilient, with an increased drying-out potential through mechanical ventilation, control of the air change rate and more vapour-open wind barriers in the building envelope. Based on this, the work to follow this will suggest a methodology for risk reduction of moisture problems by upgrading. Previous work suggests that upgrading in line with nZEB level can be reached by upgrading in line with the Norwegian building regulation or by upgrading to the requirements of NS3700. However, upgrading to the current building regulations requires installation of more renewable energy production on the dwelling in order to balance the energy consumption.

Acknowledgements

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Low energy consumption façade pilot project

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Summary

The aim of this project was to create a pilot project based on experience acquired from different international projects in to manufacture and assemble a timber-based element system for improving energy efficiency of buildings for renovation projects. Project took place in 2015, during which a façade on a building built in 1970's was retrofiited with a timber-based insulation panel system, designed over a point cloud model of the façade was manufactured, transported, assembled and set for monitoring.

Keywords: façade; energy efficiency; renovation; timber-based element system.

Introduction

Current method of façade retrofitting with additional heat insulation is time consuming and does not always prove the desired efficiency levels, also the options for using different finishing solutions for facades is limited, thus rendering often poor aesthetic qualities for the retrofitted facades.

Usage of timber-based panels not only provides more finishing options, but also thicker insulation layers, optimal window placement and faster construction rate. The goal of this project was to create pilot research object based on experiences acquired from international project "TES (Timber Element System) Energy Façade" which studied timber based element system for improving energy efficiency of building envelope mainly for renovation projects to monitor its performance in longer run and exposure to the real service conditions.

Methods

Existing facade

The building in question is a two-storey university building, built in 1970's from hollow clay bricks with a total area of approximately 135 m^2. The façade had three major aspects that caused additional problem solving during the design phase, first being brick and concrete window casings around each of the 10 windows (see Figure 1), second – reinforced concrete reinforcing elements constructed later in order to support testing equipement and third being an open gas line protruding about 300 mm from the existing façade.

Figure 1. The façade in question, note the window casings, reinforced concrete elements and gas line.

Design approach

Taking into account international experience and practical considerations, a decision to design the panels based upon 3D scan measurements was made early on in the design process. 3D model, based upon data from the point cloud (see Figure 2), was used as a basis for dimensions.

Design process was done in 3D, using CAD software, creating a 3D model of the panels, insulation material, connections, windows and cladding, ensuring precision both in dimensions and material quantities. For bigger projects, work using BIM solutions is a favourable condition, however, due to scale of this project and competences of involved partners, this solution was not extensively used.

Panel monitoring

Real-time data monitoring of air temperature, air humidity and surface temperature was conducted by means of digital sensors embedded in different places across the panel, additionally a visual inspection of panels for fungal damage and other visually detectable damage.

Results and discussion

Real-time data monitoring has not revealed any major spots for dew point formation or unfavourable moisture conditions within the panel. Visual inspection of panels revealed fungal damage and discoloration of thermally modified cladding elements as well as insignificant delamination of cladding elements.

Conclusions

Retrofitting of existing building, using timber-based panels can be feasible provided that higher U-values, more complex architectural solutions and faster assembly time is desired.

Price per square meter of timber-based panels is highly dependent on chosen cladding material, since cladding material constituted around 25% of total panel costs.

After three years of service it is visible, that conditions within the panel and between the panel and existing wall are optimal and no formation of dew point was observed.

Fungal development and discoloration of thermally modified cladding material suggests problems with untreated thermally modified timber caused by factors to be researched further on.

Acknowledgements

Research was carried out within the project "Research of wood materials with increased ecological value" Investment and Development Agency of Latvia, project No.L-KC-11-0004 co-financed by the European Union within the project framework of the European Regional Development Fund.

Testing of moisture safety and energy performance quality commission process of nZEB renovation

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Summary

In the current study relevant components of known quality control programmes were applied to assure the compliance of nZEB renovation results of apartment building where prefabricated timber frame insulation elements were used. The results of quality control are showing that inspection and analysis before and after renovation are essential for sustainable outcomes of nZEB renovation with timber frame insulation elements.

Keywords: moisture safety; hygrothermal performance of buildings; nZEB deep renovation; prefabricated timber frame insulation elements; quality commission

Introduction

It is necessary to pay special attention to the moisture safety measures in the design and building processes of highly-insulated buildings. It depends not only on selection of materials but on technologies used and measures taken as well. The aim of this study is to present results of complex analysis of designed and built solutions of nZEB renovation with prefabricated timber frame insulation elements of typical apartment building made of concrete large panels as possible ways of quality commission of nZEB renovation.

Methods

The building type studied is a 5-storey apartment building with a total area of 4318 m^2, constructed in Tallinn, Estonia at 1986. The thermal transmittance of the existing envelope before renovation was U=0.9–1.1W/(m^2·K). The building envelope (walls and roof) was insulated with prefabricated timber frame insulation elements with total thickness 340–380 mm (see Figure 11). After the nZEB renovation designed thermal transmittance U_{wall}=0.11–0.12W/(m^2·K), U_{roof}=0.10W/(m^2·K), U_{window}≤0.80W/(m^2·K).

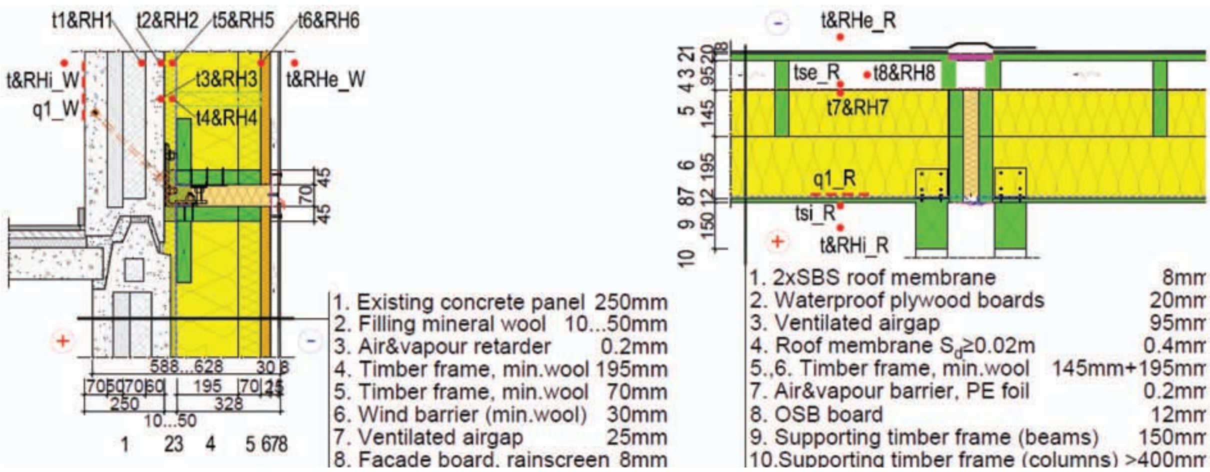

Figure 11. Designed solution of nZEB with analysed points. Installed prefabricated timber frame insulation elements on the wall type 1 (left) and on the roof type 1 (right).

The main elements of the complex analysis and quality commission were:

- **Before design:** 3D laser scanning of the building; collecting of hourly climate data
- **During the design:** adjustment of predesigned solutions
- **During the production of elements:** supervision of production
- **During the construction on site:** supervision of designed measures
- **After the construction:** control measurements of building envelope; repair works
- **After the opening of building for tenants:** survey and questionnaire for tenants

Results and discussion

Analysis and dynamic simulations were completed and calculation model calibrated with actual climate data. Results of the complex analysis, measurements and calculations are listed in Table 2.

Table 2. Comparison of designed and measured or calculated values of thermal transmittance (*U*), moisture content of concrete panel (*w*), airtightness of the building envelope (q_{50}), mould index (*M*) and temperature factor (f_{Rsi}) after the nZEB renovation

Description, unit	Required (designed) value		Measured (calculated) value	Remarks
U_{wall} [W/(m²·K)]	•	0.11	0.10 ... 0.12	1.
U_{roof} [W/(m²·K)]	•	0.10	0.08 ... 0.12	1.
$w_{concrete\ wall}$ [kg/m³]	•	<110	50 ... 80	2.
q_{50} [m³/(m²·h)] – 1st measurement	•	<2	>3	3.
q_{50} [m³/(m²·h)] – 2nd measurement	•	<2	1.7 ... 1.8	3.
M [-]	•	<1	0.1 ... 0.5	4.
f_{Rsi} [-] – external walls and roof	•	≥0.8	0.90 ... 0.95	5.

Remarks:

1. measured value of the wall 0.10 (and of the roof 0.08) was between the wooden frames; value of the wall 0.12 (and of the roof 0.12) near by the wooden frames;
2. value 50 is measured in dry weather conditions; value 80 in wet weather conditions, after the rainfall, from external concrete panel samples;
3. 1st measurement was done right after the construction works and some leaking spots were found; 2nd measurement was done after the repair of mentioned faults;
4. mould index M results in most critical points of noteworthy mould formation possibility (see pos.t4&RH4 and t5&RH5 in Figure 11, left);
5. temperature factor at the internal surface of external walls and roof was calculated on base of measured surface temperatures (θ_{si}, θ_{se}) and heat flux (*Q*) data.

Conclusions

With analysis and continual surveillance, it is possible to achieve good results and build sustainable solutions according to the up-to-date requirements of nZEB in cold and humid climate. The results of current project with timber frame insulation elements is giving a strong signal to real estate developers, producers, engineers and designers and inspires them to extend their design practices and quality assurance processes.

Acknowledgements

This research was supported by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant TK146, funded by the European Regional Development Fund, by the Estonian Research Council with institutional research funding grant IUT1-15, by the personal research funding grant PRG483, Moisture Safety of Interior Insulation, Constructional Moisture and Thermally Efficient Building Envelope, and by EU funded Horizon 2020 project "MORE-CONNECT".

Revitalization of wooden apartments as a tool to deal with shrinkage – case study from Valga

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Summary

Valga is a small shrinking town in South Estonia. The study focuses on the possibilities of solving the problems connected with apartment houses by using the disposition of apartments and improving energy efficiency to meet the contemporary standards of living space and getting buildings in public possession.

Keywords: shrinking cities, housing, urban brownfields, urban decline, post-soviet country, energy performance of buildings

Introduction

Valga is a small shrinking town in South Estonia on the border of Latvia, and more than 250 kilometres from the capital Tallinn. Valga has lost 33% of its population since 1981 and 28% of the town territory is underused or abandoned. There are 358 apartment buildings in Valga and 146 of them have wooden constructions. 22 wooden apartment buildings lie within the heritage conservation area. Typical wooden apartment buildings have small apartments without bathrooms and with shared toilets.

A negative demographic change is always accompanied by the same phenomenon – a decline in economic activity and the concomitant deterioration of the living environment. A large share of unused residential and business properties results in a fall in real estate prices. In 2017, the average price of a flat was less than 150 euros per square metre. A low price prevents owners from selling their properties, since renovation is not lucrative and new apartment buildings are not being built. The result is the domination of low-quality living premises, and in the case of wooden houses, the conditions can become critical. If the number of empty flats reaches a certain level in a building, the most of the inhabitants move out if possible. Only owners with the lowest income who cannot maintain the building remain put and continue to live in the building in a poor condition even after it has become uninhabitable. The study focuses on the possibilities to manage problem of deteriorating houses.

Methods

The study described hereby deals with a case study and focuses on wooden apartment buildings having the problems described above. In addition to being in a dangerous condition the buildings were also morally depreciated. The following measures were used and aspects calculated:

1. changes in room dispositions,
2. improving energy efficiency,
3. the ownerships constrains.

Results and discussion

The paper focuses on the revitalization of apartment building lying within the heritage conservation area of Valga town. It describes a way how to overcome ownership barriers and get buildings in public possession. Then the paper presents an architectural and technical solution for the building reconstruction. One of the buildings used to have 10 apartments (5 on the first floor) (Figure 1). The reconstruction project designs 8 apartments (4 on the first floor) (Figure 2). The cold toilets area has been demolished. The disposition of apartments has been redesigned to meet the contemporary standards of living space. Insulation has been added and most importantly – living environment is modernized. There is a comfortable private bathroom in every apartment.

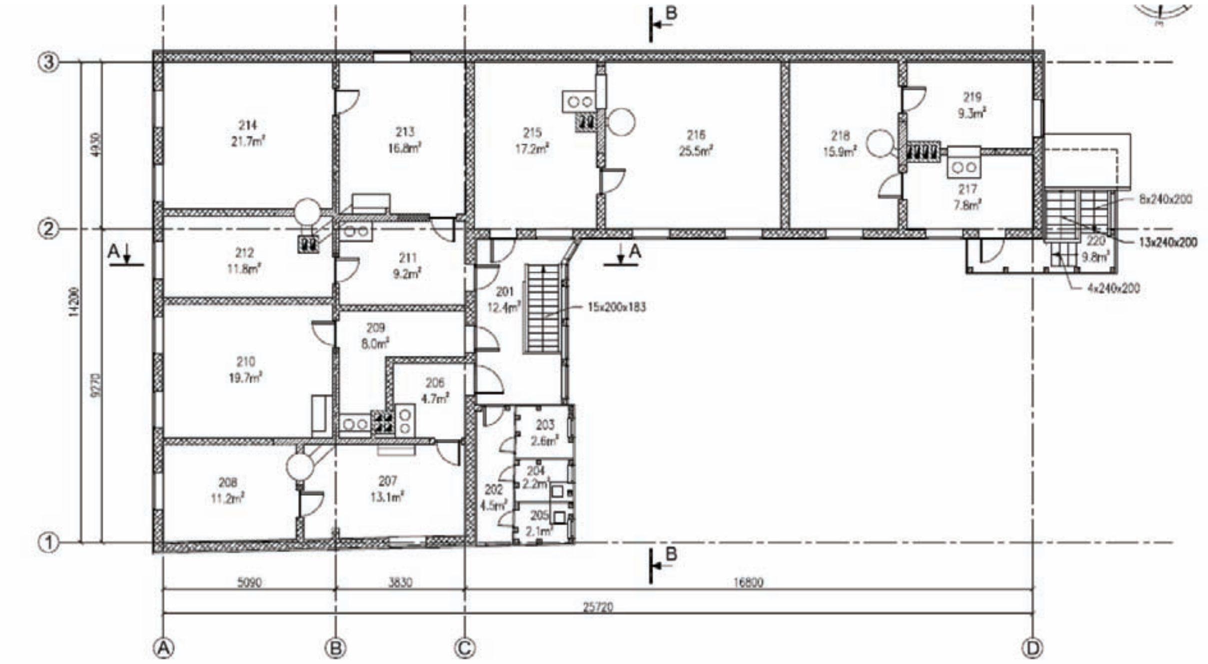

Figure 1. Plan with the initial planning of the first floor

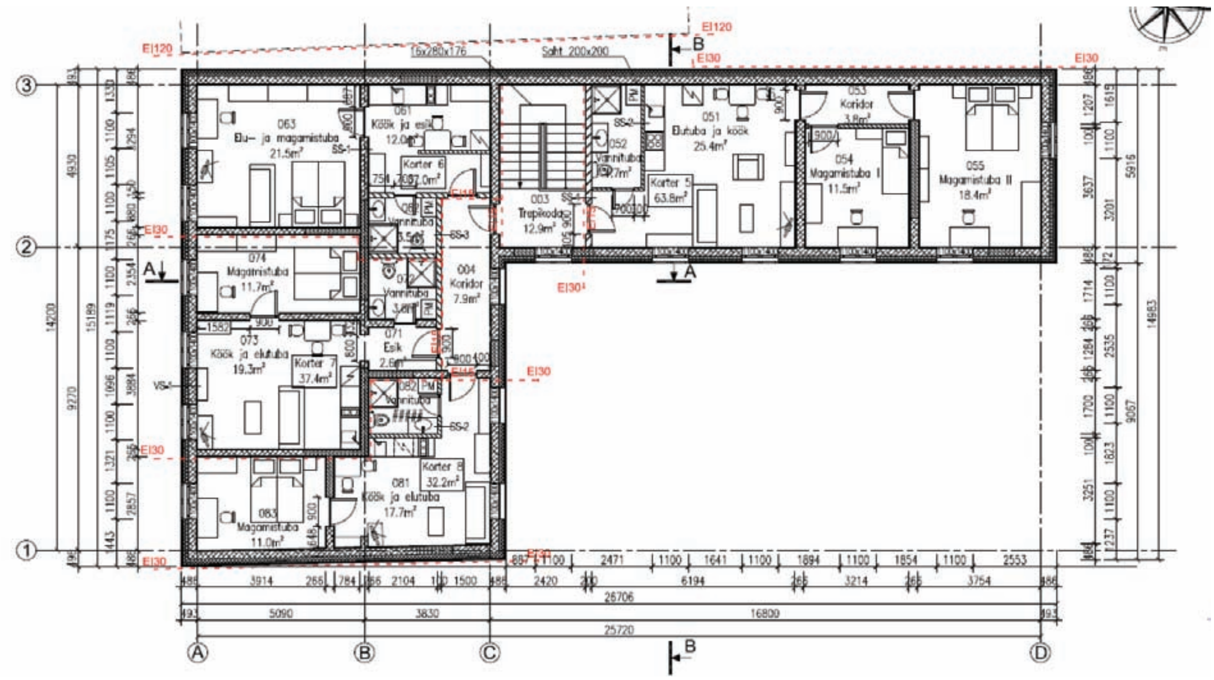

Figure 2. Plan of the first floor after redesign

Conclusions

Shrinking of population has several outcomes on urban areas. One of them is the prevalence of low quality and underfinanced maintenance of housing stock. This results in housing vacancy, and abandoned and underused apartment houses. The study shows that buildings can be quite easily revitalized. The main barrier of such revitalization is ownership constrains, not technical issues. Public investments in the revitalization of wooden apartment buildings and the creation of municipal apartment stock offers the citizens high quality living space helps to stabilize population of shrinking towns.

Acknowledgements

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FIRE RESISTANCE OF TIMBER STRUCTURES

An improved design model for fire ex-posed CLT floor elements

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Summary

New design models are proposed in this paper for fire exposed cross-laminated timber (CLT) to answer the future Eurocode 5 design concepts for (1) tabulated data and (2) simplified design model. In general, the design of CLT is as for solid timber, i.e. a two-step procedure calculating firstly (i) the residual (virgin) cross section and subsequently a (ii) effective cross section to account for heat losses in the residual cross section. To assess the performance of the adhesive, a test method is proposed. The zero-strength layer (ZSL) for is between 2 and 12 mm.

Keywords: fire, cross laminated timber, floor, design model, effective cross section method

Introduction

Economic design models are essential for the successful use of building products. In this study, new design models for the fire resistance design of cross-laminated timber (CLT) floor elements are presented. The models follow the general two-step procedure where (i) the reduction of the original cross-section is determined taking into account the adhesive used and (ii) the strength losses due to heating of the residual cross-section using the popular Effective (formerly Reduced) Cross Section Method (ECSM). With respect to the consideration of the strength losses in the residual cross-section, two models are proposed addressing different design concepts. I.e. (1) tabulated data for preferred layups and a more general (2) simplified model. Both models, (1) and (2), work with a so-called zero-strength layer (ZSL) to describe strength losses. The ZSL for CLT ranges between 2.0 mm and 12.0 mm, whereby the direction of the grain of the layers has to be considered. Besides the models, a method is proposed to determine the performance of the adhesive. It is proposed to use a standard fire resistance test (model or large scale), whereby the mass-loss (rate) of the product is related to solid timber that loses about 15 kg/(m^2·h).

Residual cross-section and Falling-off of charring layers

The *stickability* of the charring layers is essential for the protection of the virgin wood behind this insulating layer, any failure of char counteracts this advantage of wood. The behaviour can be described by the term *debonding* or *falling-off* of charring layers. In general, it was observed that *falling-off* can be determined when 300 °C are reached in the bondline behind this layer. Then, an increased charring rate (about factor 2) is observed for the subsequent layer until an insulating layer (assumed to be 25 mm) is available again. In this case, or when the performance of the adhesive is not proven, the *stepped charring model* shall be used. However, until now, no test method was available to verify a temperature stabile bondline.

In a series of tests with CLT using different adhesives and providing different layer ar-rangements (number and thicknesses), ETH Zürich developed a method to compare the mass-loss of CLT with solid timber (decks). The authors of defined a maximum acceptable mass loss rate of 16.5 kg/(m^2·h) for CLT panels in standard fire resistance tests where the stickability of charring layers is confirmed and, thus, no falling-off of charring layers occurs. Further, in this case a burn-out in re-al fires is not counteracted by the adhesive. The test method is easy to combine with standard fire tests (loaded or un-loaded) and does not require any instrumentation inside the CLT, which is in general difficult to apply.

Effective Cross-Section method for CLT

The new Eurocode 5 (EN 1995-1-2:2022) will give (1) tabulated values for twelve preferred layups (examples are given in Table 1), and (2) simplified rules for a more general application by engineers. Industry partners evaluated several simplified models and concluded in agreement with the authors that the model "12 and 2", drafted in Figure 1, is favourable. Models are determined based on the well documented charring behaviour of CLT using a "stepped model" be linked strictly to the charring model for standard fire given in the new Eurocode 5 that is currently under revision.

Layup	30 min	60 min	90 min
20+20+20	2.0	7.0	n.a.
40+40+40	8.0	4.0	n.a.
20+20+20+20+20	3.0	10.0	5.0
30+20+30+20+30	5.0	3.0	11.0
40+20+20+20+40	6.0	5.0	8.0
40+40+40+40+40	5.0	5.0	2.0
n.a. … not applicable			

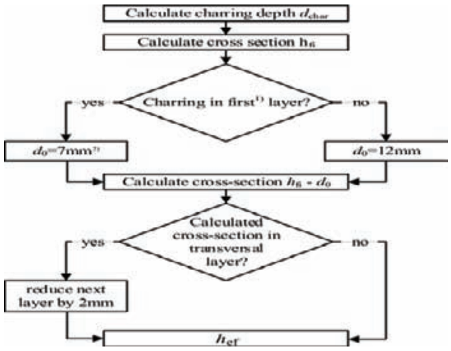

Figure 1. ZSL as (1) tabulated data (left) and simplified design (right).

Conclusion and future work

To verify the fire resistance of CLT, ZSL values for two design concepts for the new Eurocode are presented in this study. In the future, fire safety engineering for complex structures shall be applied to verify the overall fire safety including optional burn-out when required. For this, the stickability of charring layers is essential (see Section 3). The procedure presented here will be further developed and proposed for standardisation. Simplified models are currently not available to cover the fire dynamics of combustible compartments and are to be expected to be developed in the next years. Further work has to be done do determine a model for CLT walls where the buckling behaviour and thus the change of the overall CLT stiffness is essential for the verification of the fire resistance.

Acknowledgements

The autors would like to thank the lab team of ETH and RISE for their support conducting fire resistance tests of different scales. Further, the COST Action FP1404 for the basis of discussion and the involved industry partners, especially the CLT group of the Austrian Timber Association.

Fire resistance of punched metal plate connector joints in timber structures

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Summary

This paper presents fire resistance research results on punched metal connector plate joints. Some fire protection methods for these joints were tested for its fire resistance. Non-standard fire resistance oven was built for this research. Specimens were loaded with tension force during fire resistance test. Detection of the failure time, temperature measurements inside wood and analysis of charred cross section of timber were done. The fire resistance of unprotected punched metal plate connector joints was less than 5 min. Research results shows that the best fire protection can be achieved by encapsulation methods and the worst fire performance of punched metal plate connector joints can be for fire retardant treated wood.

Keywords: Fire resistance; wood constructions; punched metal plate connectors.

Introduction

Punched metal plate connector joints have increasing popularity in timber constructions due to its easy use and cost efficiency. These joints ensure good mechanical properties and permits fast and easy mounting of complicate timber structures. Punched metal plate connector joints are widely used in roof truss constructions. These type connections have been invented at Florida in 1952 and it revolutionized the wood truss industry. The mechanical performance of these connections is one of the most important points, which has been studied by several researchers. Not enough attention has been focused to the fire safety performance of punched metal plate connector joints.

The aim of this research was to investigate fire resistance performance of punched metal plate connectors and evaluate the efficiency of different protection methods.

Methods

Strength graded spruce wood construction timber with strength class C24 were selected for this research work. MiTek TOP W punched metal connector plates with 1.5 mm thickness and 84x150 mm dimensions were selected for fire resistance tests. Connections were made industrially by pressing method at company SIA „Woodcon". Ten specimens were prepared for mechanical testing to find tensile strength of these joints to determine load ratio for fire resistance test.

Five different fire protection methods of wood joints with punched metal plate connectors were prepared for investigation of fire resistance improvement possibilities. The special fire resistance testing equipment was built for this experiment. General description of equipment is shown in Fig. 1. Specimens were fixed to tensile loading equipment, where constant 10 kN static load were applied. The loading ratio was about 25 % of joint cold failure strength.

The evaluation of punched metal plate connector joints fire resistance performance was done by following criteria: 1) measurement of joint failure time; 2) measurements of temperature rise dynamics in joints exposed to fire; 3) analyses of charred wood element cross section.

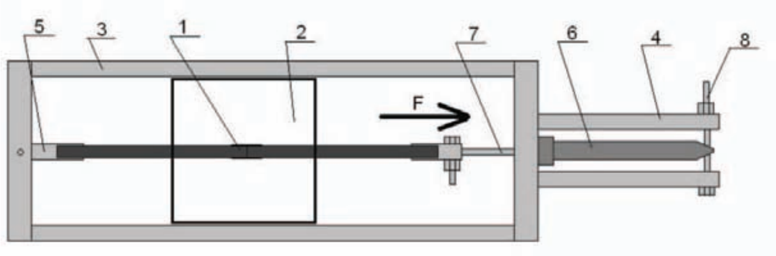

Figure 1. Fire resistance test under tension load:
1) punched metal plate connector joint;
2) fire chamber;
3) load frame;
4) hydraulic cylinder support frame;
5) fixed specimen support;
6) hydraulic cylinder;
7) moving support;
8) hydraulic cylinder knuckle joint.

Results and discussion

The joint failure characteristic of worst case and best case is shown in Fig. 2.Unprotected punched metal plate connector joint failed after 3.4 min form fire exposure moment. The most effective joint fire protection showed encapsulation methods by intumescent bandage and gypsum plasterboard. Undamaged wood were discovered at the joint under gypsum plasterboard, see Fig. 2 b) Failure of the joint happened after 16.8 min due to complete charred wood element outside encapsulated area. Failure of timber elements occurred when the load bearing wood cross section reduced to critical value for carrying 10 kN load. Average charring rate of the timber element in oven were 1.1 mm·min^{-1}, which is significantly higher compared to other researchers findings. Reasonably good protection was achieved also with 12 mm thickness solid wood boards. It was observed that joint encapsulation by wood showed the best protection from temperature rise point of view at the first minutest of test.

a) b)

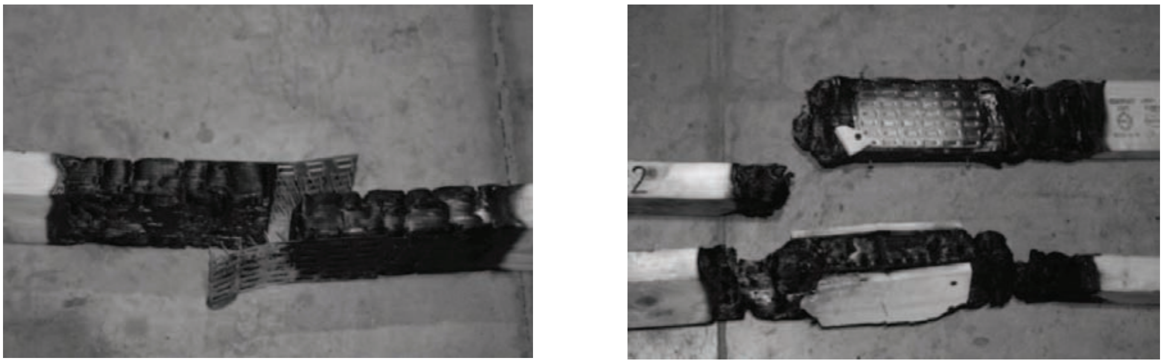

Figure 2. Failure characteristics of unprotected joint (a) and gypsum plasterboard encapsulated joint (b).

Conclusions

Punched metal plate connector joints can be cost effective solution on timber construction engineering but the fire safety of these constructions is the weakest point. These joints cannot ensure significant fire resistance without additional protection methods due to low metal teeth penetration depth. Fire resistance of these joints in real fire is less than 5 minutes which can be critical for building construction element collapse. The results of this research show the good fire protection possibilities of these joints by using any encapsulation methods. Single fire retardants usage can be more dangerous solution for these constructions due to chemically aggressive reaction with zinc coated steel elements.

Acknowledgements

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Fire design of initially protected CLT

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Summary

Cross Laminated Timber (CLT) can be used as the main structural material for high rise timber buildings. CLT structures should often be initially protected to achieve the required fire resistance. Charring scenario of CLT is dependent on the protection and on the behaviour of bondlines between lamellas. This study covers investigations made with CLT structures protected with gypsum plasterboards and plasters. Experimental and numerical investigations are analysed and the design procedure for protected CLT structures is proposed.

Keywords: Fire design; Timber structures; Gypsum plasterboards; Gypsum fibreboards; Start time of charring; Clay plaster; Fall-off times.

Charring of CLT

The charring rate of a timber member is different when occurring behind protection or after the fall-off of the protection. [1] The protection offered by protection materials is described by the start time of charring and the fall-off time of the protection. These times separate three distinct charring phases (see also Figure 1):

- Encapsulation phase (Phase 1) is the phase where no charring of the timber member occurs;
- Protection phase (Phase 2) is the phase where relatively slow charring occurs behind the protective cladding while the cladding is still in place;
- Post-protection phase (Phase 3) is the phase where the protective cladding has fallen off and charring is fast but may slow down if the timber member develops a 25 mm thick char layer.

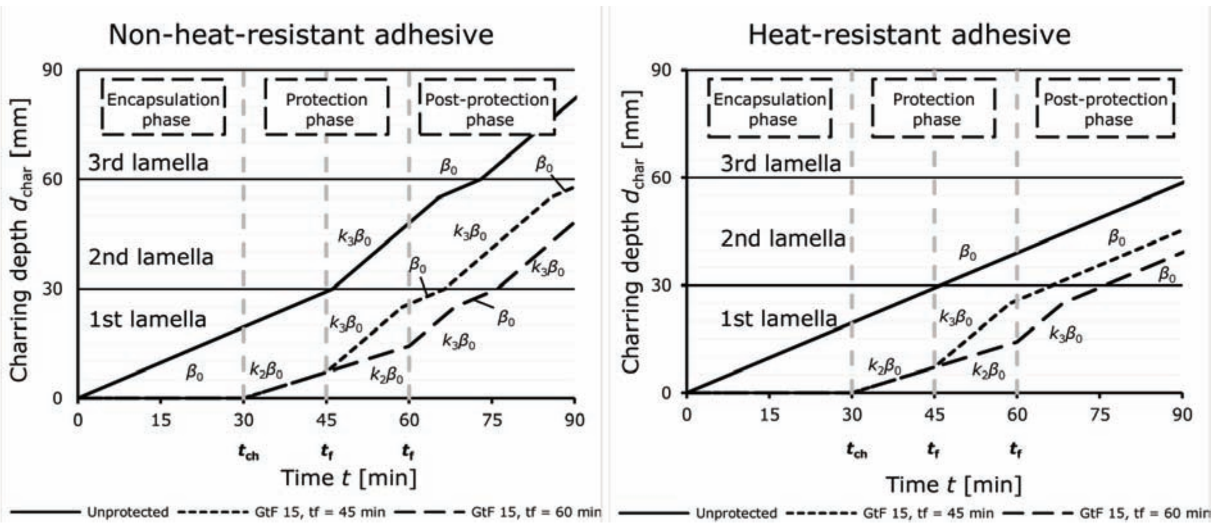

Figure 1. Charring scenarios for CLT with heat-resistant adhesive (right) and non-heat-resistant adhesive (left).

The start time of charring t_{ch} is defined by taking into account the thickness of the protection. It may be calculated using the Component Additive Method. The start time of charring has been investigated by thermal simulations and furnace fire tests.

Fall-off time tf is dependent on the board thickness, the spacing and length of fasteners and also by the backing material.

Fall-off times

Fall-off time is one of the most important parameters influencing the fire resistance of timber structures, especially concerning smaller timber members. In the present study, results from an analysis of a database and thermal simulations are presented. Design values for the fall-off times of gypsum claddings, Type F (fire rated), are proposed.

To investigate the fall-off times of gypsum plasterboards and gypsum fibreboards a database with data from 440 full-scale fire test reports was collected at RISE Research Institutes of Sweden (formerly SP). The first results based on minimum (100% guaranteed) values of the fall-off times were produced by Just et al. [2] and published in the „Fire Safety in Timber Buildings. Technical guideline for Europe" [3].

The present analysis is performed by determining 5% fractile values of fall-off times and is based on an increased number of test data. The analysis shows that the scatter of the fall-off times is considerable, especially considering the effect of different backing materials, showing a 35% difference in wall assemblies [4–5]. The temperature increase behind gypsum plasterboards backed by insulation is faster and the fall-off of the board occurs earlier. Hence, the fall-off from a CLT surface may be delayed due to decreased heat transfer and distance between fasteners.

Compositions with 15 mm thick gypsum plasterboards backed by stone wool or timber were investigated. Thermal degradation was supposed to occur within temperature range from 600 °C to 800 °C. Simulation results show that the time difference between the 2 tested compositions are 9 minutes at 600 °C and 12 minutes at 800 °C behind gypsum plasterboard. This is 25% of difference.

Clay plaster

The protective properties of clay plaster have been investigated experimentally [6] and numerically. The fall-off of time clay plaster depends on the fixation as well as the adhesion between clay and the fastening system. Fixation of clay plaster onto CLT can be excellent and, therefore, clay plaster offers good protection to the timber structure.

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Acknowledgements

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Fire design of timber frame assemblies – a proposal for the next revision of EN 1995-1-2

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Summary

At present, Eurocode 5 Part 1–2 provides a model for the fire design of the load-bearing function of timber frame assemblies with cavities that are completely filled with stone wool insulations. This model is limited to 60 minutes of fire resistance. An improved design approach which enables to evaluate timber frame assemblies for longer fire resistance times is proposed. Furthermore, this approach has the potential to consider the contribution, in terms of fire resistance, provided by any cavity insulation products. By means of this approach it is possible to predict the load-bearing capacity of timber frame assemblies under standard fire in bending and compression.

Keywords: Timber frame assemblies, Effective cross-section method, Fire resistance

Introduction

Structural behaviour of timber members under fire conditions is influenced by material properties, geometrical characteristics, protection and boundary conditions.

In order to predict the load-bearing capacity of timber member under fire conditions, it is not sufficient to evaluate the reduction of cross-section due to charring, but it is crucial to know possible loss of mechanical properties of the uncharred cross-section.

Evaluations of load-bearing capacity by means of advanced simulations are possible; however analytical design models are simple tools and can provide an adequate accuracy.

Current Eurocode 5 part 1–5 includes an analytical design model for timber frame assemblies exposed to standard fire, however it takes into account only the protection of stone wool products after that the cladding is fallen-off. Furthermore, this model is limited to 60 minutes of fire resistance.

Improved design approach for timber frame assemblies

An improved design approach for TFA has been proposed by Tiso and Just. This approach introduces the concept of protection levels (PL) of insulation materials. The protection level of an insulation material indicates its capability to protect timber against charring. The protection level is evaluated by means a standard test set-up. The improved approach includes also a design model for charring. This design model considers three different charring scenarios depending on the protection level of the cavity insulations. The protection level is evaluated by means of a specimen of floor to be tested in a model-scale furnace. The specimen consists of a wooden frame with a timber beam placed in the middle of the frame. The timber beam in the frame allows for two cavities which could be filled with a selected insulation. The specimen is exposed to 60 minutes of standard fire according to ISO 834. During the test, the charring at the depth of 100 mm on the interface wood-insulation (line 1 and 3 in Figure 1) is considered. A criterion to assign the protection level is based whether the charring exceeds or not the depth of 100 mm on the interface wood-insulation. Three different PL can be assigned to an insulation material, where PL3 indicated the weaker protection level and PL1 indicates the stronger protection level.

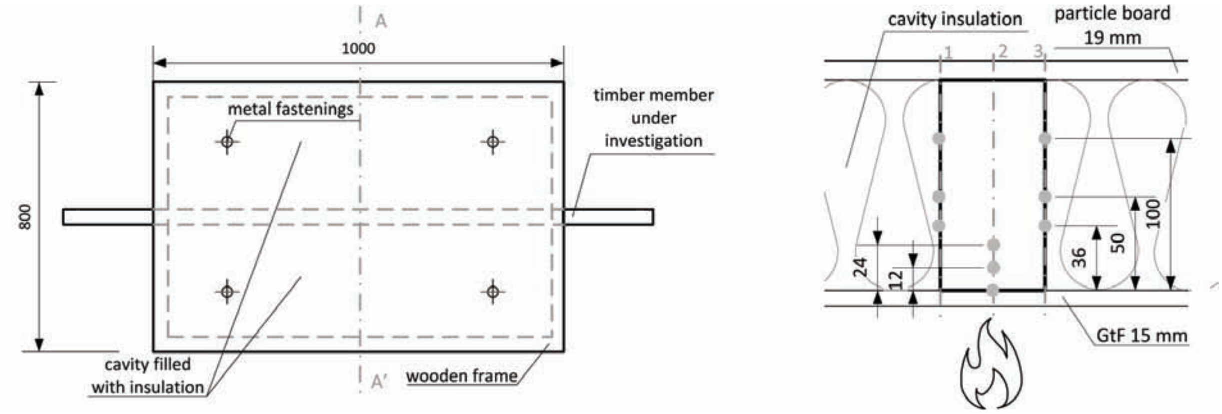

Figure 1. Test specimen for a mode-scale furnace: (left) overall plan; and (right) position of thermocouples on the timber beam cross section.

The improved design model for the load-bearing capacity of TFA follows the principle of the effective cross-section method (ECSM). In the ECSM, the decreases of strength and stiffness properties of the equivalent residual cross-section are compensated by using a so-called zero-strength layer while strength and stiffness properties at ambient temperature are used.

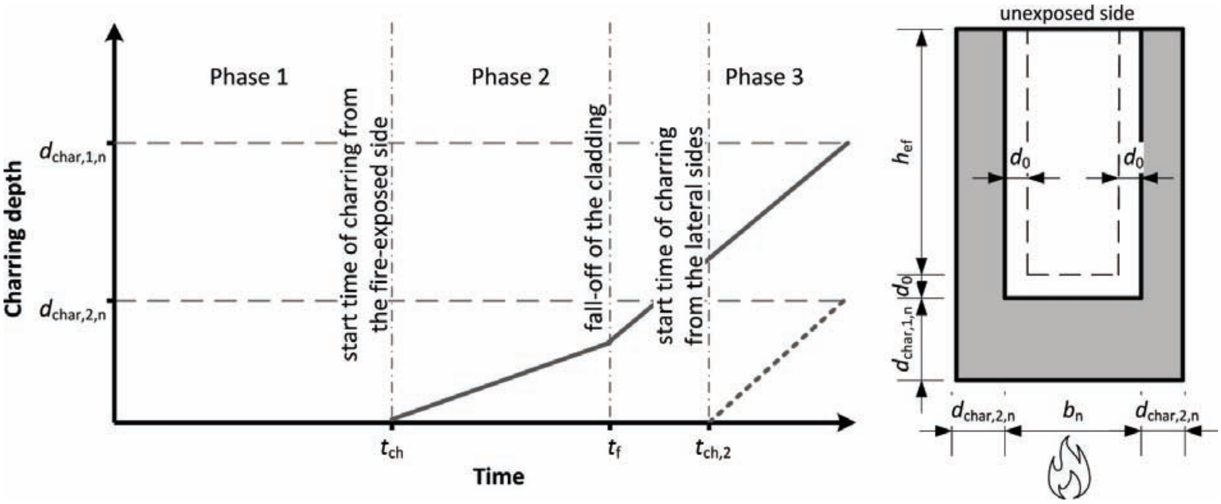

Figure 2. Different charring phases for the improved design model for TFA with PL 2 (left) and the concept of the improved design model for timber frame assemblies (right).

The design model proposed considers three different charring scenarios for TFA with cavities completely filled with insulation. If the cavities are completely filled with insulation materials qualified as PL1 the charring occurs mainly on the fire-exposed side of the member (charring depth indicated as $d_{char,1,n}$), while the lateral sides are protected by the insulation. If the cavities are completely filled with insulation materials qualified as PL2, the charring is regarded from one side during the protection phase and from three sides of the cross-section during the post-protection phase due to the degradation (recession) of the insulation material (charring depth from lateral sides indicated as $d_{char,2,n}$) (Figure 1, right). When the cavities are completely filled with insulation materials qualified as PL3, the charring is regarded from three sides of the cross-section already during the protection phases. Zero strength layers depend on load configuration, cross-section dimensions and cavity insulation. Simplified expressions to evaluate zero-strength layers for member in bending and compression are proposed.

Conclusions

A comprehensive methodology to evaluate the load-bearing capacity of TFA exposed to standard fire is proposed. The design model is verified by means of full-scale fire tests.

A Model for Pyrolysis and Oxidation of Two Common Structural Timbers

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Simo Hostikka, Associate professor
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Summary

The reduced cross section method for the calculation of timber structures' fire resistance is based on empirical and numerical assessment of charring propagation. The current work aims to construct a model for the pyrolysis and oxidation of spruce and pine woods to allow coupled simulations of cross section reduction and burning rate in fire models. A comparison of thermogravimetry and microscale combustion calorimetry results reveals that the classical reaction schemes may need to be supplemented by a reaction describing char devolatilization to satisfy both the experimental mass loss and heat release.

Keywords: Charring; Pine wood; Pyrolysis modelling; Spruce wood

Introduction

Performance-based design of the timber structures' fire resistance is often based on the reduced cross section, and thus relying on empirical and numerical assessment of charring propagation. Coupling the charring propagation with fire conditions requires the use of numerical fire simulations, for which the heat release rate (HRR) is the most important boundary condition (Östman et al., 2017). This coupling means that the fire development is not prescribed but rather predicted using a pyrolysis model that simultaneously predicts charring and production of flammable gases (Matala et al., 2008). However, validated pyrolysis models for the wood species of Nordic structural timber are not readily available.

The current work aims to address this by providing a model for pyrolysis and oxidation of Norway spruce and Scots pine, the two most common structural timbers in Finland. The model provides a chemical kinetics – based estimate of pyrolysis and oxidation rates of the wood primary components and oxidation rate of the resultant char. With known heats of combustion of produced volatiles and heats of oxidation for virgin wood and char, HRR is calculated from the reaction rate. The model is intended as a solid phase HRR boundary condition in computational fluid dynamics – based fire simulators, such as Fire Dynamics Simulator (FDS). Model validation by cone calorimetry is planned as a future work.

Methods

The experiments were performed on samples of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) woods with measured average dry densities of 408 kg/m^3 and 493 kg/m^3, respectively. Their chemical compositions are assumed as by Sjöström (1981).

The main experiments performed in this work were thermogravimetric analysis (TGA) and microscale combustion calorimetry (MCC) (Lyon et al., 2013). TGA runs were performed under an inert atmosphere (nitrogen) and in air to measure mass loss as a function of temperature. Four heating rates (2, 5, 10 and 20 K/min) were used and the runs were terminated at 600 °C (air) or at 800 °C (nitrogen). MCC experiments were similarly performed under nitrogen and air (ASTM D7309 Method A or Method B, respectively) to give heat release rate of milligram-scale wood samples as a function of temperature. MCC experiments were performed from 75 to 750 °C with heating rates of 20 and 60 K/min.

This work employs a scheme of parallel reactions, where each wood primary component (extractives, hemicellulose, cellulose and lignin) decompose independently following Arrhenian kinetics, producing char and gaseous products. The reaction model was fitted to experimental TGA data with the shuffled complex evolution (SCE) algorithm embedded in Gpyro 0.8186 (Lautenberger, 2014) to estimate the kinetic triplet and product yields.

Results and discussion

Figure 1 presents the model predictions for mass loss and HRR of pine in nitrogen and compares them to experimental TGA and MCC results, respectively. The figure includes TGA runs at 2 and 20 K/min and a MCC experiment at 20 K/min. The MCC device log revealed the actual heating rate to be 33.4 K/min. The results for spruce are similar.

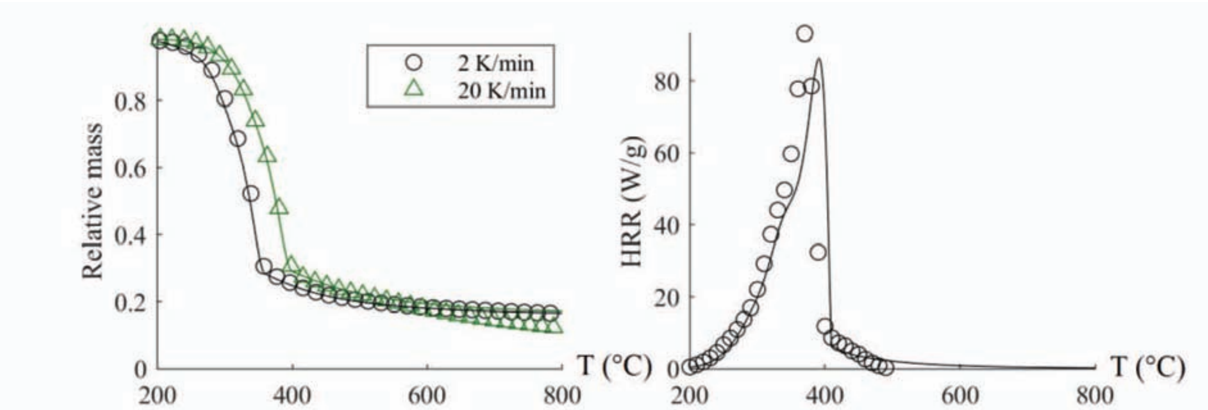

Figure 1. TGA at 2 and 20 K/min (left), MCC at 33.4 K/min (right) in hollow markers, and the corresponding model predictions in solid lines. All data is pine in nitrogen.

Figure 1 reveals that the current parallel reactions scheme agrees well with the mass loss data. Each wood component is assigned a heat of combustion to give optimal agreement between simulated and experimental MCC tests. The SCE algorithm allocates all high-temperature mass loss in TGA for lignin pyrolysis. Lignin pyrolysis products should realistically be assumed to have a nonzero heat of combustion, which would lead to slow heat release in high temperatures also in MCC tests. This however conflicts with the results in Figure 1 as any heat release terminates before 500 °C in the shown experiment.

Conclusions

The ability to predict the heat release by different components accurately is a necessary criterion for the model to be used as a HRR boundary condition in a fire model. Therefore, to counter the inconsistency between the measured mass loss and heat release, we propose a new reaction scheme that contains one further reaction describing high temperature (>500 °C) devolatilization of the char residue (Várhegyi et al., 2002). This additional reaction is to model mass loss without causing heat release. Estimating kinetic parameters for this scheme is currently a work in progress.

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Fire design method of timber frame elements with bio-based insulation

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Summary

Within the German research project "Standardising the fire safety performance of timber frame elements using bio-based building products" fire design methods for the separating and load bearing function of timber frame elements with bio-based insulation and lining materials were developed. This paper describes the conducted fire tests and results, the determination of thermal material properties and associated parametrical investigations by Finite Element Modelling with cellulose and wood fibre insulation and the validation of the derived design equations.

Keywords: fire resistance, timber frame elements, separation function, load-bearing function, wood fibre insulation, cellulose insulation

Introduction

Currently an increasing amount of bio-based insulation and lining materials are used in timber frame constructions for walls and floors. In order to verify the fire safety requirements with respect to the fire resistance of such elements and constructions not only national and European technical approvals or classification reports, based on test results exist. But also tabulated designs like in the German standard DIN 4102-4 can be used. However, only with the conservative assumption neglecting the contribution of the bio-based cavity insulation to the fire resistance of the element. The design method for timber structures in EN 1995-1-2 do not allow to determine the fire resistance for timber frame elements when bio-based insulation materials are used. All options currently available are time consuming, expensive and/or conservative and inhibit the use of bio-based insulation or lining materials. To overcome this limitation an integration of bio-based insulation materials and linings in a standardised European design method for the fire resistance of timber frame elements, which allows both the assessment of the separation- and load-bearing function, became necessary. This will help designers, authorities and producers to overcome existing constraints and limitations for bio-based insulation materials and enables the efficient application of these materials in buildings with requirements to fire resistance.

Scientific concept

Based on experimental investigations and additional numerical simulations extensions for the fire design methods for separating and load-bearing function were developed. Accordingly, the research project comprised following steps:

- Compilation of timber frame element setups with bio-based insulation materials with practical relevance
- Analyses of temperature dependent material properties (density, conductivity and specific heat) based on test and numerical approaches
- Analysis of the material behaviour, with respect to temperature stability and shrinking under elevated temperature before flaming combustion
- Medium scale fire tests with wall and floor elements under standard fire exposure to get more information about the reaction to fire of bio-based insulation materials

- Calibration and further numerical analysis of influencing parameters and designs not assessed in fire tests
- Development of analytical design methods based on the conducted experimental and numerical investigations
- Validation of the design method based on collected full scale fire test results

Results and discussion

The research results provided new findings about the material properties and method in order to determine these values and system specific influencing factors for timber frame elements. At the same time the research project provided new knowledge about the behaviour of cellulose and wood fibre insulation at elevated temperatures before flaming combustion. The results have shown, that product specific additives in the insulation materials can influence the dimension stability in a negative way, however without leading to a shrinkage of the material already in a temperature range under 250 °C. At higher temperatures, resulting in flaming combustion conditions, the aspect of shrinkage becomes more dominant – especially for wood fibre insulation products, resulting in an opening of joints and recession of cavity insulation away from timber members. For cellulose fibre insulation the temperature dependent shrinking was less dominant. This temperature induced shrinking process and loss of dimension stability can lead not only to an earl opening of joints or falling-off of part of the cavity insulation itself, but also will influence the load bearing capacity of timber members when not sidewise protected from insulation material anymore. To investigate specific materials and system behaviour new assessment techniques and set-ups were established, allowing the time specific falling-off of protective layers and the transient evaluation of the protective capacity of the insulation materials in the protection and post protection phase of the lining. Based on the experimental and numerical investigations analytical design equations to be used in the component additive method (CAM) for flexible cellulose-, wood fibre insulation and insulating wood fibre boards were developed, in order to allow the assessment of the separation function in case of fire up to 90 minutes. It must pointed out, that for blown-in insulation materials and materials with a high shrinkage behaviour an increased risk of a falling-off of the insulation exists, and must considered by structural methods. Based on the full scale test results, an additional factor was introduced in the CAM, limiting the protection capacity of such insulation materials based on a potential early falling-off beside the protection capacity derived from the heat transfer. With regard to the assessment of the load-bearing capacity, the insulation materials examined were assessed based on the protection level (PL) concept. This concepts allows the assessment of the sidewise protective capacity of the insulation on loadbearing timber members, before and after falling-off of the protective linings. For the assessed cellulose insulation a protection level – PL 1 and for the flexible wood fibre a protection level – PL 2 can be reached, if an earl falling-off will not occur.

Conclusion

By using the new results, the consideration of the positive influence of bio-based insulation materials to the fire resistance of timber frame elements becomes possible on a standardised way. This was not possible until now. The derived results and analytical approaches for bio-based insulation materials will be made available to the standardisation committee within the current revision of EN 1995-1-2, to allow for further standardisation and application of timber constructions with bio-based insulation.

Acknowledgements

The authors would like to acknowledge the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) and the Federal Office for Building and Regional Planning (BBR) for funding this research project in the German research initiative "Zukunft Bau". Further the participating industrial partners "Verband Holzfaser Dämmstoffe e.V., Wuppertal" and ISOCELL GmbH, Neumarkt am Wallersee must be acknowledged, for the financial support and providing construction materials.

Fire protection provided by clay and lime plasters

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Summary

Today, plasters are not considered as fire protection materials for timber according to EN 1995-1-2. This study aims to assess the fire technical properties of selected plasters by determining the material thermal properties at high temperatures. Results are used to analyse previously conducted fire tests and as an input for heat transfer simulations. First outcome provides good agreement between simulations and experimental tests. Design parameters are recommended. Further research is needed to examine the fire performance of plaster and support systems such as reed mat on timber in furnace.

Keywords: Fire resistance of timber structures; Fire protection; Clay plaster; Lime plaster; High temperatures; Fire design

Introduction

Clay and lime plasters are traditional surface finish materials extensively used in historic timber buildings to cover walls and ceilings. Hardly any fire design parameters and thermal material properties are currently available for plasters. Today, the European fire design standard for timber structures (EN 1995-1-2) determines only some conventional building materials as fire protection materials, e. g. gypsum plasterboards. This hinders an adequate fire assessment of historic fabrics and limits their use in new buildings.

This study provides an overview about the fire protection performance of a selected range of clay and lime plasters. Comparison between the fire protection ability of clay and lime plasters is presented in small-scale. Previously conducted fire tests are further analysed based on new findings related to the assessment of plasters by thermogravimetric analysis (TGA) and transient plane heat source (TPS) /hot disc method. Results are used as input for first heat transfer simulations using SAFIR software.

Materials and methods

Materials

Different types of clay plasters and two lime plasters were selected based on previous research by some of the authors, see example Figure 1 (right). Undercoat plasters (density approx. 1800 kg/m³) with a grain size of 0–4 mm are tested, which allows to build up multiple plaster coats. Traditional clay plaster with different fibres such as straw, hemp and cattail are examined. One traditional and one lightweight lime plaster is tested. Plaster is applied on timber surfaces by using a support system a.k.a. substrate such as a traditional reed mat or lathwork.

Experimental investigations

Thermal material properties were determined by using TGA and TPS method. The temperature-dependant changes in plaster were assessed by TGA. Thermal conductivity and specific heat were determined by TPS method (ISO 22007-2). Test results were used as input parameters to carry out fire simulations with SAFIR software. Comparison of fire protection ability between different plasters was made using the cone heater of a cone calorimeter (ISO 5660).

Results and discussion

TGA results indicate a clear difference between clay and lime based plasters. Significant change in clay plasters take place after 600 °C is reached. Clay plaster with cattail fibre presents greater mass loss compared to other clay plasters with straw and hemp. Traditional lime plaster presents two distinct mass loss stages around 400 °C and thereafter at 700 °C. For reference, gypsum plasterboard undergoes mass loss (crystallised water) at 100 °C that is clearly detectable in fire tests as the temperature rise behind board is slowed down (see Fig.1, right).

TPS tests presented problems in achieving reliable measurements higher than 400 °C due to water evaporation from the test sample, thus matching well with the mass loss detected in TGA tests. TPS results need further analysis. Figure 1 (right) demonstrates the comparison between furnace tests and simulations under standard fire exposure for clay plaster with hemp. In legend, the _SIM refers to simulation results based on input parameters received from TPS tests.

Cone tests provided a basic comparison between all plasters and a reference to gypsum plasterboard. Lime plaster demonstrates better fire protection ability compared to clay plaster. This may be argued by the results gained from material tests that showed greater material changes (reactions) at high temperatures that restrain the heat transfer through material. Further studies are needed to test lime plaster on timber in furnace.

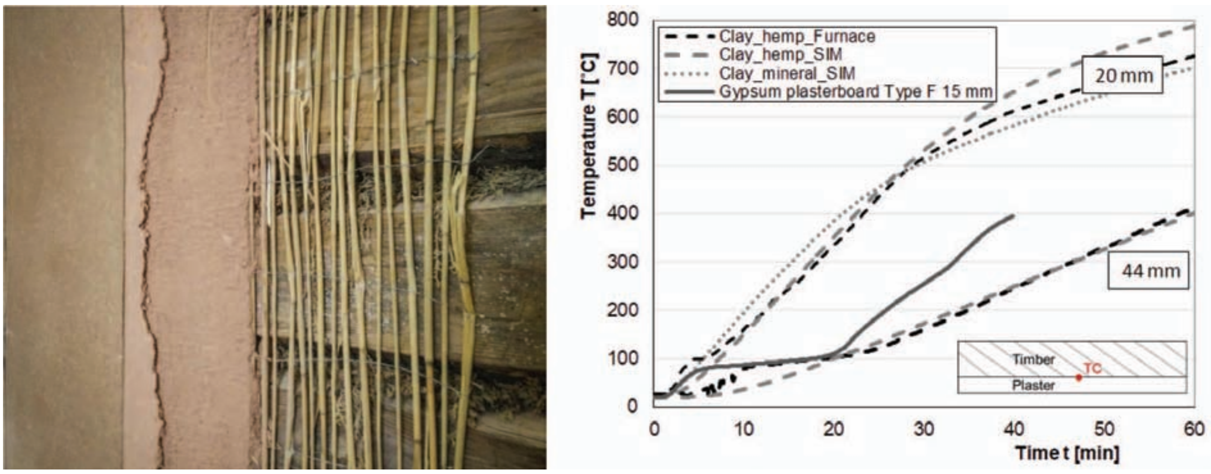

Figure 1. Plaster and reed mat on timber wall (left). Temperature measurements recorded behind plaster (TC) in furnace tests and simulation results (right).

Conclusions

Material test results provide useful insight to the temperature-dependant changes in plasters that support the observations made in previously conducted furnace tests, e. g. cracking. First numerical simulations provide encouraging potential to serve as a reliable investigation tool for various types of plasters. Thicker coats of plaster provide enhanced fire protection. The presented results may serve as a guideline to assess the fire performance of traditional and modern plasters. This work contributes to sustainable design of timber buildings with natural materials.

Acknowledgements

This work was supported by the Estonian Research Council under Grant PUT794 and TAR16012. The acknowledgements extend to Fraunhofer Wilhelm Klauditz Institut für Holzforschung, Bundesministerium für Wirtschaft und Energie within Zentrales Innovationsprogramm Mittelstand. Additionally, Dora Plus scholarship fund provided by the European Regional Development Fund and Estonian government is acknowledged. Special thanks are given to Saviukumaja, Claytec, Gräfix for materials and support.

NEW WOODEN STRUCTURES AND BUILDINGS

Prefabricated wooden frame multi-storey apartment buildings

Andrus Leppik; Kodumaja, Estonia

Abstract

Kodumaja AS consolidates the companies whose main area of activity is design and construction of prefabricated wooden frame buildings from modular sections. More than 7000 apartments are built in multi-storey apartment buildings in twenty years. More detailed data of five apartment building projects are brought out in this presentation, exclusively is included the world's tallest timber building Treet in Bergen, Norway. Those buildings were thoroughly planned, designed, built and tested. Focus is on advantages of that construction method and on achievement of purposeful architecture, acoustics, energy performance and fire resistance of buildings. Way of building

Keywords: (3–7 keywords are required, must fit on two lines)

Building from prefabricated modular sections (MS)

MS is spatial part of a building where the floor, walls and ceiling of MS are assembled at the factory. One MS may include several rooms. Since MS is a "closed" element, it is possible to complete a lot at the factory. For an example up to 95% of the interior finishing and furnishing of the rooms as well as to complete most of exterior finishing works.

Transportation dimensions of MS are within the following limits: width – 5,3 m, length – 14,5 m and height – 4,5 m. The typical weight of one MS is: 8–16 tons. Time for mounting one MS on a completed foundation is: 20–60 minutes. In case of multi-storey blocks of flats Kodumaja site team is able to mount: 15–30 MS a day.

Advantages of building from prefabricated MS:

- **Good working conditions** = high quality at lower costs,
- **Efficient construction method** = good possibility for shortening construction time,
- **Flexibility** = readiness for implementation of one-of-a-kind projects,
- **Compliance with applicable norms and standards** = high durability and healthy human environment at low maintenance costs.

Methods of measuring the achievement of targets of building the projects were:

- **Public feedback**, for an example from the competitions,
- **Calculations** based on analyses (fire, acoustic, energy, statics) made for projects,
- **Measurements** (acoustic, air tightness) carried out of the projects.

Examples of buildings

The world's tallest timber building Treet in Bergen, Norway

Treet (The Tree) was the world's tallest timber building in 2015. Treet was built on the idea of making impossible possible.

Treet ties up more than 2000 tons of CO_2.

This equates to emissions from 1400 cars in one year.

Figure 12. The world's tallest timber building, Bergen, Norway (2015).

The main characteristics:

- 52.8 m high, 14-storey apartment building,
- made of glulam truss system and integrated prefabricated modular sections, CLT panels are used in staircases, elevator shafts, balconies and some inner walls,
- the main load bearing structure is handled by glulam alone,
- highest compression force in glulam column is 4287 kN,
- max horizontal deflection of building on 14^{th} floor is 71 mm (required ≤90 mm),
- each modular section / apartment complies with Norwegian passive house standard NS 3700:2010,
- in total, net heating energy demand and heating of ventilation air is 7.5 kWh/(m^2·a), total delivered energy 71 kWh/(m^2·a),
- structure is capable of withstanding 90 minutes of fire,
- measured air change rate (n_{50}) inside the apartments is between 0.48-0.57 h^{-1},
- measured average airborne sound insulation index is 68 dB (required ≥ 55 mm),
- measured average impact sound insulation index is 49 dB (required ≤ 53 mm).

Conclusions

In addition to advantages, there are some specialities of building in prefabricated wooden frame modular buildings. Specialities are:

- Certain limitation in the architectural designs,
- It is important to make majority of significant decisions regarding the building before the start of the production and construction process,
- Special requirements for transport,
- Some customers are sceptical about timber-frame as a building's load bearing structure,
- Somewhat increased material consumption. Need to combine different materials in load bearing structures, sometimes.

Deeper analysis may show that seemingly disadvantageous specialities may actually provide certain benefits.

Acknowledgements

Thank you for Kodumaja team members, customers and their architects, cooperation partners of universities in Scandinavia and Estonia!

Helsinki's new Central Library

Timo Urva, project manager; Karel Koitla, designer;
Indrek Tiits, sales manager
Timbeco Woodhouse OÜ, Estonia

Summary

Helsinki Central Library is 17 000 m^2 building, which design and construction phase lasted for Timbeco Woodhouse OÜ over 2 years. Timbeco's delivery consisted of 8000 m^2 of wall and roof elements. Grand opening of the building was held in December 2018, on the eve of celebration of the 101st anniversary of independence of Finland. Timbeco part was to produce and install roof and facade elements in situation where elements needed to be curvy and/or twisted and where information flow from the site was main key to success.

Keywords: 3D model, wooden house elements, design and installation, complex building

Massive wooden elements on an uneven and unpredictable surface

Design phase

The basic information for the project came from BIM model, with the entire layout of the building, the supporting structure and communications. Timbeco Design Team used concrete and steel layers in the model as basis to which they designed all elements.

The challenge Design Team faced was constantly changing information. As the concrete and steel structures were being designed at the same time, the underlying information was in constant change during the whole project's life cycle – during engineering, production and installation phases.

Production phase

Because of building design, many roof and wall elements were curved or twisted and needed to be shaped around the steel structures and concrete facades. Normally all elements are produced in flat surface, so producing curved elements was quite interesting challenge and needed a lot non-standardized solutions. While production of roof elements, the challenge for Timbeco was processing and handling of massive LVL (laminated veneer lumber). The largest roof element was 4,3 m x 12 m in size. This element contained from 12 beams. One 12 m beam weight is 250 kg, so total mass of the element was 9 t (with skylight windows).

Figure 1. Element producing and lifting with the cranes (left). Helsinki Central Library concrete and metal frame (right)

Construction phase

The largest roof elements were up to 4.5 m wide, thereby transportation had to be arranged by customized oversize transportation. This demanded also careful planning and timing, because there wasn't any storage space in construction site. Elements were mounted directly from the truck to their exact position on the building.

3D scanning was used regularly, which lead to fewer errors and significantly accelerated installation work.

Management of large building projects

Cooperation is always the key to success in complex projects like this. The construction site has a lot of subcontractors and a lot of interfaces between their scope of work. Next contractor can start their work only when they receive their workfront from the previous contractor. There is constant need for information flow in the project with other parties.

In this case, the task for Timbeco project team was also to export the knowledge about the build-up and the progress status of the timber frame elements.

All puzzle pieces find their place

It was necessary for Timbeco to independently carry out different surveys throughout the project in order to be sure of starting the next construction phase on time.

One of the biggest benefit what Timbeco got from 3D scanning was on the wall of the western side. The timber frame elements were designed and built according to the 3D scanned point cloud. Thanks to 3D scanning, all the elements could be designed and produced to fit the actual structures. Without scanning, installation works would have been extremely difficult, if not impossible.

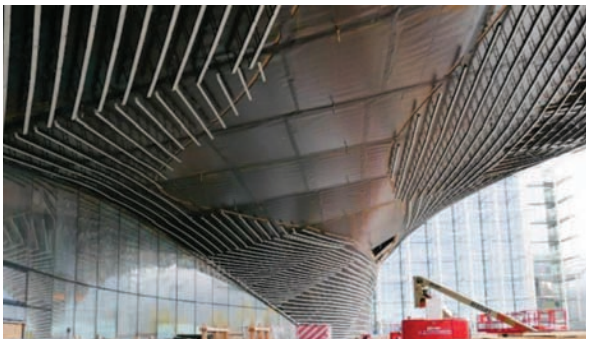

Figure 2. Helsinki Central Library western wall (left). Helsinki Central Library roof elements (right)

Conclusions

Helsinki Central Library was the biggest and so far, most challenging project in Timbeco's 25-year history. The internal teamwork and cooperation was put to a test but we are proud to acknowledge that the whole project was successful for Timbeco. Our knowledge has improved remarkably and gave us confidence to face more such complex projects in future.

A certain belief and suggestion for all companies from this project – to achieve good results in prefab hybrid constructions, using 3D laser scanning and point cloud (wisely) is a MUST.

Acknowledgements

Many thanks to Timbeco project team, and specially Timo Urva, who led the project from the start to end, Karel Koitla, who was the designer of the project and Verner Nõmmsalu, who was the site manager.

Smart housing and sustainable built environment based on glass and wood

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Summary

The Smart Housing Småland (SHS) initiative was granted funding in 2013 and is an accelerator and catalyst for R&D in the triple helix related to the regional strengths, wood and glass. The initiative provides opportunities for innovative collaboration in projects and networking in different ways on several kind of meeting places.

Key words: Innovation, research, development, cluster, industrial production, prefab, off-site production, planar glass, wooden construction

Introduction

The Vinnväxt Initiative Smart Housing Småland

In 2001, the Swedish innovation agency (Vinnova) started a programme called "Vinnväxt – Regional Growth through Dynamic Innovation Systems". The program has issued six calls for proposals since then and granted three new winners each time. Today, there is 16 Vinnväxt initiatives in Sweden.

"Innovations systems" refers to systems of organisations, individuals and rules and regulations under which the creation, dissemination and innovative exploitation of technology and other fields of knowledge takes place. The Vinnväxt initiatives aim to renew the traditional strengths of a region having international potential. The SHS initiative is shaped around the strength areas, wood and glass i.e. industrial production of wooden houses and building components with planar glass, in Småland that include the three regions Jönköping, Kalmar and Kronoberg. The focus is to encourage development and innovations relating to smart living and sustainable built environment.

Methods

SHS aims to reinforce the competitiveness and sustainable growth of the region by creating good partnerships among all community stakeholders at both a national and an international level. SHS work is led by Research Institutes of Sweden (RISE) in close cooperation with Träcentrum Nässjö, Linnaeus University and Jönköping University. To accelerate research, development and innovation in the triple helix i.e. enhance innovation collaboration between stakeholders in the community, businesses and academia different tools and activities are used e.g. pilot projects, seed money for funding application work, thematic groups, see also Figure 1.

Pilot projects are initiatives relating to an issue, within the SHS areas of strength, initiated by companies or by members of the academia. SHS provide funding for researchers to do R&D activities regards to the issue together with the companies. When a company has an idea SHS help to make contact with researchers from the institutes or the academies and amongst them finding a project leader. Higher priority is assigned to funding applications that are open with results (no secrecy), where several companies are involved and that have a high share of in-kind work from involved companies (demand of at least 50%) and and has a clear planned continuation. The hope is that completed projects will continue in further development of the results in products, processes or services or new research projects financed by major research programs and financiers. In this extended abstract we will focus on describing the pilot projects further.

Figure 1. SHS work objectives (left). Illustration of focus areas (right).

Pilot projects are initiatives relating to an issue, within the SHS areas of strength, initiated by companies or by members of the academia. SHS provide funding for researchers to do R&D activities regards to the issue together with the companies. When a company has an idea SHS help to make contact with researchers from the institutes or the academies and amongst them finding a project leader. Higher priority is assigned to funding applications that are open with results (no secrecy), where several companies are involved and that have a high share of in-kind work from involved companies (demand of at least 50%). The hope is that completed projects will continue in further development of the results in products, processes or services or new research projects financed by major research programs and financiers.

Results and discussion

Since the start of SHS over 50 pilot projects has been finished. Information of projects can be found on the SHS website www.smarthousing.nu. A good example of pilot project with a research continuation is the project "FE model of a box unit – stress and stability analysis" lead by Sigurdur Ormarsson from Linnaeus University and in collaboration with OBOS Sverige and RISE. It has continued in new applications and granted funding of approximately 700 000 EUR together with more companies involved than in the pilot study project. It has made it possible to create a research team and employ two post graduate students.The project result is an FE model for studying the deformation and rigidity of a typical box unit for multi-unit dwellings made of wood. (FE = Finite Element method – a numerical calculation method for solving partial differential equations). The model has been made to be as quick and flexible as possible, and can simulate all nailed, screwed and bolted joints in the unit. It proved to be possible to create a quick and effective model, which means that the conditions are favourable for simulating and analysing complete multi-unit dwellings with reasonable calculation times, which is very interesting for the industry partners.

Conclusions

The SHS initiative has made it possible for the stakeholders in the triple helix with focus on the SHS areas of interest to meet and collaborate in different ways seminars, projects etc on different kinds of meeting places such as thematic groups. The most important result is maybe not the direct ones, but the effects of networking and finding new contacts with which it is possible to create new projects and collaborations.

Acknowledgements

The work of the environment is supported mainly by the Swedish innovation agency and the three regions of Småland i.e. Jönköping, Kalmar and Kronoberg, together with the Jönköping, Kalmar and Kronoberg County Administrative Boards. Smart Housing thank in addition to these the organisations, companies and academic members for initiating and taking part in activities and projects and for sharing results and knowledge.

Acoustics comfort investigation in residential timber buildings in Sweden

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Summary

Due to regulations for building acoustics and developments in the construction industry, there is a demand for higher standards to be met in dwellings, especially for residential timber multi story buildings. Various regulations exist in several countries to assess sound insulation issues from noise inside or outside a building, but residents still report complaints about noise from neighbors, outside road traffic, indoor technical installations or other sources.

Keywords: acoustic comfort, timber buildings, self-report, measurements, association, evaluation, indicators.

Introduction

Acoustic comfort is a concept not completely described in the literature. It has been used in engineering typically to refer to conditions of low noise or annoyance and therefore lack of discomfort. At the same time, current standardized methods for airborne and impact sound reduction are used to assess acoustic comfort in dwellings. However, the measured sound pressure levels do not directly represent the acoustic comfort levels, since human perception of the sound environment is a critical parameter. Past research has shown that measurements and metrics that acousticians use in order to assess building acoustic conditions, may not always be representative of how residents perceive acoustics in their living environment. For example, tenants might have problems with impact noise types or vibration transmission from adjacent flats in the low frequency range that is partially omitted from measurement spectra. Due to regulations for building acoustics and developments in the construction industry, there is a demand for higher standards to be met in dwellings, especially for residential timber multi story buildings. Various regulations exist in several countries to assess sound insulation issues from noise inside or outside a building, but residents still report complaints about noise from neighbors, outside road traffic, indoor technical installations or other sources. An important issue is therefore how well the perception of residents corresponds to the results acquired by acoustic measurements and the regulated descriptors of sound insulation in buildings.

Methods

This study concerns the evaluation of acoustic comfort in typical residential family buildings. We approach acoustic comfort via the association of objective and subjective data in the field, combining acoustic measurements and self-reported responses. In this paper, there is a focus on timber multi story buildings in Sweden, their acoustic behaviour and the effect of noise annoyance within the living sound environment to the residents. A research design has been setup which includes 5 different timber frame constructions or actually 21 different building blocks. Following the measurement steps as developed by the European or ISO standards and the choices established in previous research studies, a certain measurement template was used. Standardized sound transmission measurements data from two typical adjacent rooms, one above another, preferably bedrooms or living rooms, was used for every different building type. The rooms were typical of the construction, as in most cases the same floorplan is repeated and the construction has the same specifications. The room above was used as the sending test room and the one below as the receiving test room, according to the ISO methods. The measured data included airborne sound measurements (sound source above, microphone positions below), impact sound measurements (standardized tapping machine or other impact sources above, microphone positions below) and reverberation time measurements (impulse response measurement with sound source and microphones in the same test room) for the receiving room. The same choices have been done in pre-existing studies, due to the fact that these are the spaces were people spend most of the time in their flats, the bedroom or the living room. Therefore, they are supposed to be representative of the everyday life in the flat and for the human perception as well, when it comes to self-reports and comparison. The self-reported data was collected with the development of a social survey, using questionnaires sent to the residents. The survey aimed to capture several concepts that we consider part of the overall acoustic comfort concept: disturbance from noise in apartments, the overall perception of the living sound environment as well as the emotional state of the inhabitants in their own flats. There was special focus on targeting certain noise types, capturing the noise perception of all typical cases possible, provoking the evaluation of the living environment and investigating the feeling aroused by the inhabitants' personal space and its sound qualities. The questionnaire survey was distributed using post mail (one copy for every flat), which is the accepted way in Sweden; there was a web link provided too so the users could have the choice to do it online, as a faster, economic and eco-friendly option. The response rate was approximately 28% (103 out of 370 persons replied). Finally, 35 men and 56 women took part in the survey (age span 18–85), who spent from 1 to 9 years living in their flat. Further statistical analysis was employed for the evaluation of collected responses as well as investigating the association between acoustic data and self-reported data.

Results and discussion

The results indicate that impact noise can be an issue in timber buildings. The most important noise types that generate annoyance are: machinery noise in the building (electric devices, water pipes, ventilation, etc.), neighbor's walking and activity from the floor above or below (steps, kids playing, people slamming doors), low frequency noise from outside (e.g. traffic, music, ventilation, etc.). Slight annoyance was also reported due to transmission of neighbors' low frequency music and conversations.

The above mentioned noise types were generally rated as slightly annoying by most of the residents, while few residents reported them as moderately disturbing, especially mechanical noise (less than 10%). Only about 5% of the total sample of residents were very or extremely disturbed. Therefore, those are the dominating noise types while the overall annoyance is still moderate. The same questions regarding noise annoyance were used in an additional module about noise annoyance while sleeping during the night. The overall responses indicated that the residents are also slightly disturbed by noise in general during night's sleep. Only in few cases there was some slight self-reported disturbance about machinery, neighbors' walking or activity and outdoor low frequency noise (as before), as well as walking sounds in shared spaces (staircase, etc.). Furthermore, the majority of occupants rated their sleep as very good or fairly good, while they reported no disturbance at all during their sleep.

- Additionally, the results show that for the other two parameters of acoustic comfort, besides noise, there is no important complications. The occupants self-reported that they slightly think of not disturbing their neighbors while they think that their neighbors are not at all or slightly bothered by noise sounds they produce from their own home.

Conclusions

Finally, most residents reported that they are very or fairly pleased by the sound environment in their home (approx. 80%). Less than 10% of the occupants self-reported to be very or fairly displeased.

Costs and procurement for CLT in mid-rise buildings

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Summary

The objective of this paper is to report and analyse strategies for cost reduction, design processes, and procurement models of one wooden nearly Zero Energy Building (nZEB) in Norway. This publication is part of the dissemination activities of the EU Horizon 2020 project NERO, whose scope is to demonstrate the feasibility of cost reduction of nZEBs built with wood in the Nordic Countries. Case buildings from Estonia, Finland, Norway, and Sweden are studied with respect to their technological solutions, energy use, and construction cost. The Norwegian building investigated in this paper is the Moholt Allmenning, a newly-built student accommodation located in Moholt, Trondheim. Interviews with the building's owner and the contractor were carried out to obtain information on the decision-making process during the procurement phase, the planning phase, and the execution phase. The results show that the environmental goal and the criteria set for the use of wood in the tender announcement were a critical driving force for choosing cross laminated timber (CLT) in the final design. The results also show that the cost of using CLT in buildings is competitive against using concrete and steel. Given the requirement of little greenhouse gas (GHG) emissions from materials production in nZEBs, the use of CLT is however a better choice.

Keywords: CLT, massive wood, nZEB, procurement, GHG emissions, Architecture competition

Introduction

The Moholt Allmenning was commissioned by Sit (Studentsamskipnaden i Gjøvik, Ålesund and Trondheim) in 2013 through a design competition named Moholt 50/50. Sit is a student welfare organization that plan, build and run student accommodations. The Moholt Allmenning (www.arkitektur.no/moholt-5050) is an extension of the old Moholt student residence complex in Trondheim. The new construction consists of five towers of 9 floors each. Each floor accommodates 15 resident units for a total of 632 units. The towers are built with CLT as load bearing systems, and inside the wood surfaces are exposed and clearly visible in the student apartments. The building energy efficiency solutions were designed to comply with the Norwegian Passive House standard NS 3031/3037.

Method

Structured interviews were set with the stakeholders of the Moholt Allmenning, specifically the project leader, the contractor, and the owner of the building. The interview was based on a guideline developed in the WP4 of the NERO Project and aimed at answering the following main question: "What is the relationship between the objectives of the project, the use of CLT, the procurement process, costs and the degree of innovation?". The questions asked to the interviewees were structures under four themes (procurement process, use of CLT, innovation, and cost) and they were as such:

- Introduction
- The procurement process and implementation model
- Use of CLT
- Innovation
- Cost

Results and discussion

The main phases in which the building process was carried out, followed the timeframe: 2012–2013 Planning- and design phase with architecture competition in the spring of 2013–2015 Procurement- and cooperation phase. 2015–2016 Construction phase

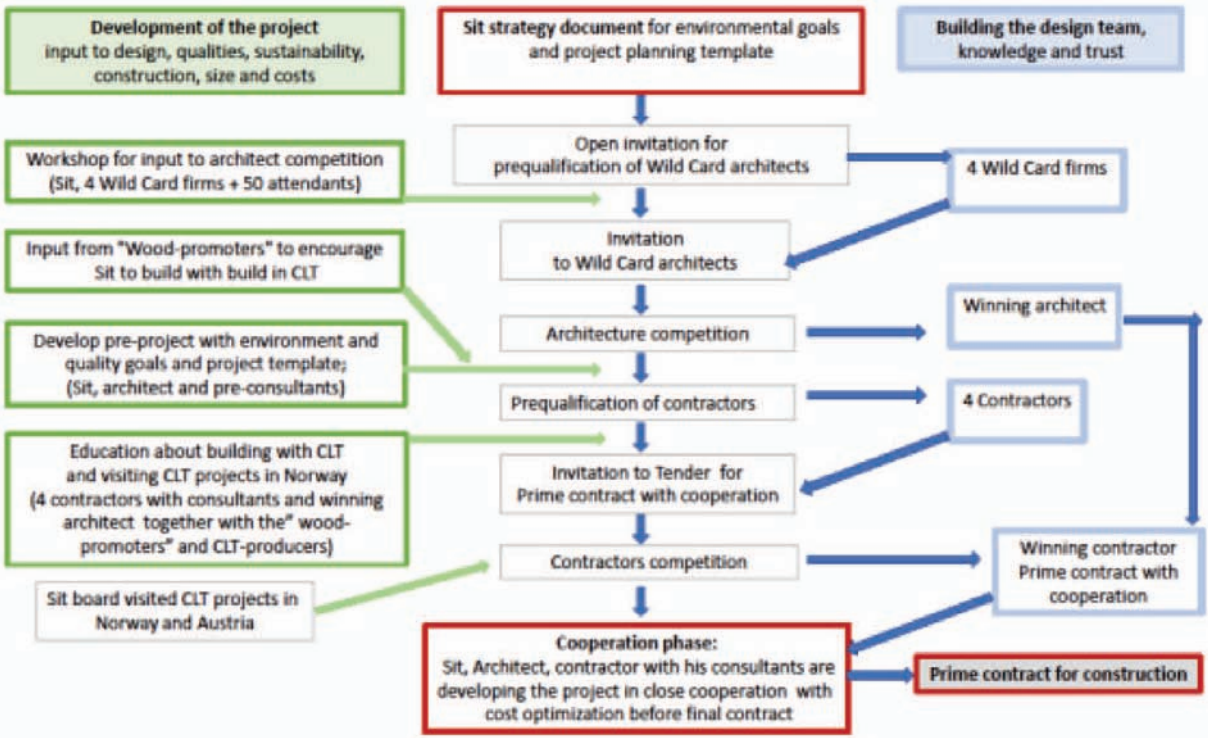

Figure 2. Mapping the developing the project and building the design team.

The complexity of the procurement route is due to the owner, Sit, taking an active part in developing the project and in building a knowledgeable design team. A large part of the definition work is done in the early planning phase in cooperation between the owner, the architect, the contractor and the consultants. In the figure all important stages of the procurement route are mapped to show the connections between all actions. Trust between all parties are important for good results in the end. A common understanding is that the procurement process can be used to secure both the good team work in all stages and good qualities for the final product.

Conclusions

The results show that the purchaser's knowledge and experience, the environmental goal and request for use of wood in the tender announcement was a critical driving forces for using CLT for Moholt Allmenning. The results also show that the construction costs of CLT buildings are competitive against similar buildings built with concrete and steel. For nZEBs with restriction on greenhouse gas emissions from materials production, the use of CLT is however a better choice than the use of steel and concrete.

How costs may develop for CLT buildings when more experience is achieved is not easy to predict. More experience will however always result in increased efficiency. A growing demand for low GHG solutions will most likely result in demand from public building developers for CLT buildings. This is what the building market need to achieve the experience needed to develop competitive cost-effective solutions.

Acknowledgements

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Effect of structural frame materials on lifecycle impacts of buildings

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Summary

In this study the lifecycle primary energy and greenhouse gas (GHG) implications of five multi-storey building versions with different construction systems are analysed considering flows from the production, operation and end-of-life phases and the full natural resources chains. The analysed building versions include conventional and modern construction systems with light-frame timber, reinforced concrete-frame, massive timber frame, beam-and-column timber frame or modular timber frame structural systems and are designed to the energy efficiency level of the passive house criteria. The results show that the lifecycle primary energy use and GHG emissions for the reinforced concrete building system are higher than those for the timber-based building systems. The findings emphasize the importance of frame material choice and lifecycle perspective in reducing energy use and GHG emissions in the built environment.

Keywords: Building frame material; concrete timber; lifecycle analysis; passive house; primary energy use; greenhouse gas emissions.

Introduction

Buildings account for a large share of the global primary energy use and offer significant opportunity to reduce fossil fuels use and thereby mitigate climate change. A variety of measures may be deployed to improve energy performance of buildings, including improved thermal envelope insulation, high performance windows, efficient energy supply systems, and use of less energy-intensive building materials. Lifecycle analysis considering the entire energy and material chains can play an important role in identifying options to reduce energy use and climate impacts of buildings. Most reported lifecycle studies of buildings are based on conventional building systems and few studies have explored modern building systems. Fewer analyses have compared the lifecycle primary energy use and greenhouse gases (GHGs) emission of conventional and modern building construction systems with different materials, considering all lifecycle activities.

In this study we investigate lifecycle primary energy use and GHGs emission of five multi-storey buildings with different building construction systems for Norwegian conditions, considering flows from the production, operation and end-of-life phases. The present study explores conventional and modern building systems designed to the passive house criteria with reinforced concrete or timber structural frame materials.

Methods

In this study a consequential-based approach with system perspective is used to analyse the lifecycle primary energy and GHG implications of conventional or modern multi-storey building system versions. The analysed buildings encompass conventional reinforced concrete-frame and light timber-frame buildings as well as modern timber-frame buildings with massive timber, timber beam and column and modular structural elements. All the five building systems are designed to be functionally equivalent with different structural frame materials to the Norwegian passive house criteria. The analysis considered the entire energy chains from the extraction of fuels to the delivered end-use energy and the system boundary is defined to include flows linked to the production, operation and end-of-life of the buildings. The functional unit of the analysis is defined at the complete building level and the total primary energy use and GHG emissions of the complete buildings are expressed in terms of the heated building floor areas.

Results and discussion

Figure 1 shows the primary energy and GHG emission for production, space heating and ventilation during 50 years, and end-of-life for the buildings when heated with district heating. The operation phase dominates the lifecycle primary energy use of the building system versions. Material production accounts for a large share of the lifecycle GHG emission for the buildings as heat supply is based on biomass-based district heating. The primary energy for building production is 4–18% lower for the analysed timber-based building systems compared to the reinforced concrete building alternative. Correspondingly, the timber-based building systems give 39–51% lower GHG emissions for building production in contrast to the reinforced concrete building alternative. Overall, the timber-based building systems have negative net GHG balances over their complete lifecycle due to the benefits of recovery of production biomass residues for use as fuel and the recovery as well as recycling of the end-of-life materials. The massive timber building gives the lowest lifecycle primary energy use and GHG emission while the reinforced concrete building results in the greatest lifecycle impacts among the analysed building system versions.

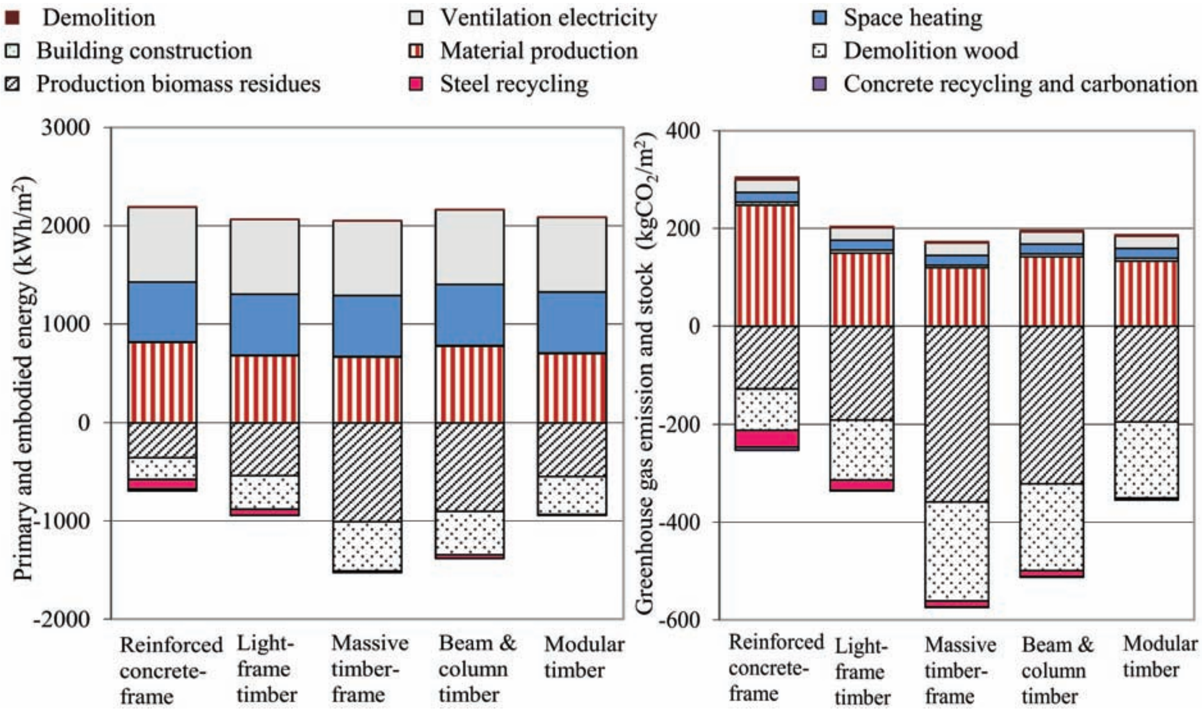

Figure 1. Primary energy use and GHG emissions for the lifecycle phases of district heated buildings for a 50-year period. The district heating is cogenerated with biomass.

Conclusions

Overall, the net lifecycle primary energy and GHG emission balances, including production, operation and end-of-life flows, are lower for the timber-based building systems than for the reinforced concrete building system, due primarily to the lower production primary energy use and greater amount of biomass residues when using timber frame materials. These advantages more than outweigh the energy saving benefits of thermal mass of concrete structure. The massive timber building system gives the lowest lifecycle primary energy and GHG balances. Except for the modular timber frame building system, the modern building systems outperform the conventional alternative systems in terms of lifecycle primary energy use and GHG emissions. The modern building system of modular timber-frame results in higher primary energy use and GHG emissions than the conventional light timber-frame building. In summary, timber-frame buildings and efficient heat supply are of great importance for a low energy building and should be key part of the efforts to create a low carbon society.

Slotted-in steel plate connections with self-perforating dowels in CLT

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Summary

The purpose of this paper is to provide a better understanding of the behaviour of self-perforating dowels in CLT. The strength and stiffness of the connection is experimentally investigated and discussed. Parameters influencing the results are also determinate. The results show the influence of the rope effect and drill tip on the load-carrying capacity of the connection with threaded dowels.

Keywords: Self-perforating dowel; Slotted-in steel plate; Embedment strength in CLT

Introduction

The use of slotted-in steel plates with pre-drilled dowels is a standard solution in glulam structures: it allows the transfer of loads along the element axis and makes the connection efficient. In CLT shear walls, mostly nailed angle brackets are used, which are easy to install but due to the deformation of the bracket itself and due to the eccentric load transfer the efficiency of the whole connection decreases. Slotted-in steel plates with pre-drilled dowels require precise components and installation. In contrast, self-perforating dowels allow rapid installation without pre-bored holes. This research focuses on the strength and stiffness of slotted-in steel plate connections with self-perforating dowels in CLT.

Methods

Within the study, a 6 mm thick slotted-in steel plate (S235) was connected in CLT (100mm: layers 5x20 mm) with pre-drilled dowels SBD 7.5x95 (Rothoblaas, 2017) and loaded parallel and perpendicular to the grain of the outer layers. Different setups with 1 and 4 dowels in one row (two columns) were tested, and for validation purposes, additional tests with longer dowels SBD 7.5x175 and WS-7x193 (SFS-Intec, 2013) were carried out. The latter tests aim to identify the influence of the rope effect and yield moment of the fastener. An additional measure to explain the behaviour of the connection was the determination of the embedment strength in CLT (see Figure 1), yield moment of fastener and fasteners tensile strength fu.

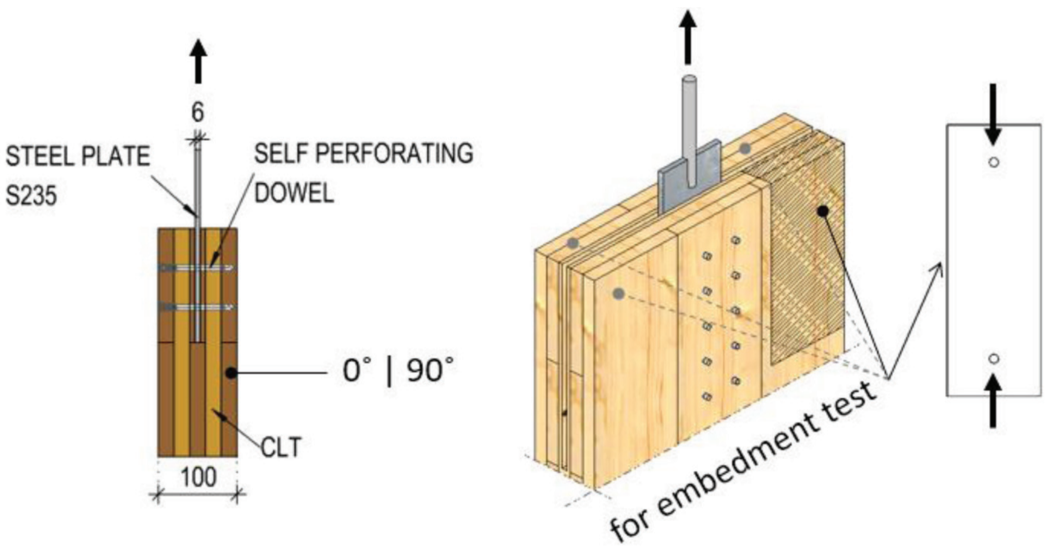

Figure 1. Load angle to the outer layer direction and cut-out for embedment test

Results and discussion

The results accord well with a theory proposed by (Johansen, 1949). The tests revealed that the rope effect caused by threaded parts on both ends of the dowel has an influence on the load-carrying capacity, drill tip will lead to the earlier failure of the connection. The SBD dowel is made of high-strength steel, and therefore visible cracks occur on the tensile side of the bent dowel. Despite the fact, there was sufficient plastic deformation without braking for bending angles of 50° for dowels.

Embedment strength values of the dowel in CLT confirms the locking effect and densification described in (Tuhkanen, Mölder and Schickhofer, 2018), but the analytical formula proposed by (Blaß and Uibel, 2007) shows significantly higher results than the tests reveal. Possible causes are also discussed more thoroughly in (Tuhkanen, Mölder and Schickhofer, 2018).

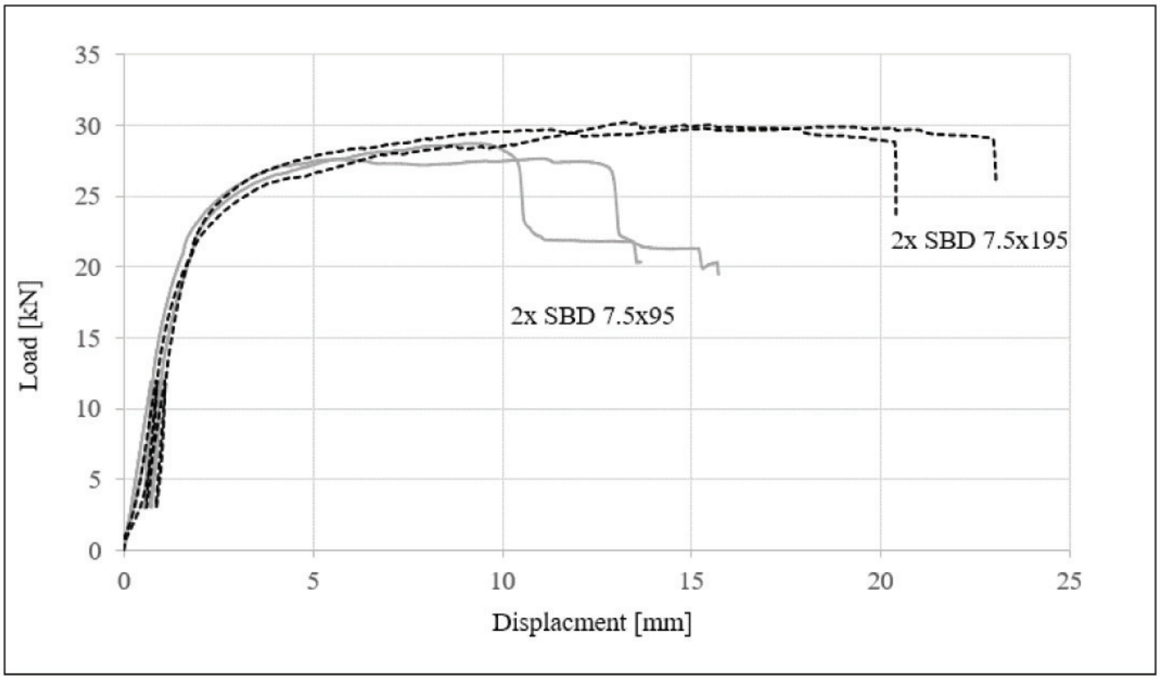

Figure 2. Load-displacement diagram of the short and long dowel

Conclusions

Self-perforating dowels have clear potential for fast and efficient connections. However, the importance of the input parameters and the impact on computational results must be emphasized.

Acknowledgements

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HiTimber project – to increase competence in timber construction

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Summary

Estonian Woodhouse Association (EWA) in co-operation with Tallinn University of Applied Sciences participate in an international program "Sustainable High-Rise Buildings Designed and Constructed in Timber (HiTimber)" that promotes timber construction education. The goal of the HiTimber project is to share best practices of different countries and start processes in universities of wider knowledge in designing, managing construction works and maintaining real-estate.

Keywords: Educational project; Timber construction; Timber high-rise buildings; study module

Introduction

Project background

The United Nations (UN) projects the world population to be 9.8 billion by 2050 and 68% of them will be urban – that's about 2.5 billion new people in cities. These people need homes and we can't just make cities bigger – we need to go higher. The race for timber high-rise buildings has started as more thought is put into how to do it sustainably. Wood is renewable, absorbs carbon dioxide (CO_2), has excellent insulation properties, light weight and is well processable. Wood is constantly more and more used in construction industry yet education regarding building high-rise buildings of wood is still moderate. The goal of the three-year co-operation project is to work out a new study module to help teach timber construction in universities.

HiTimber project was written by VIA University College (Denmark) in co-operation with several partners in order to fulfil future needs for higher education considering innovation, sustainability, international and cross-university approaches.

Outputs and project activities

Each Partner will contribute to all intellectual outputs: international study; new study module; book; assignment books; academic publications.

During the project participants will visit leading sustainable construction sector companies from architects to woodhouse manufacturies in Denmark, Lithuania, Portugal, United Kingdom and Estonia and will learn from the experiences of professionals to get the know-how. This will lead to new innovative skills not only for students but for teachers as well. Also, the project will give the students the possibility to take part in short practical placements in relevant regional and national timber construction companies.

The project was opened by the partners' meeting in Tallinn at the end of 2017. Next meeting of the project team took place in Denmark at the beginning of 2018 where an intensive project for students was discussed. Workshop for students of universities that participate in the program was held in Great Britain in April 2018. First two-week study period gathered 30 students from Portugal, Lithuania, Denmark, Great Britain and Estonia to Southampton. The students were introduced to specifics of designing timber structures, divided into international groups and were given an teamwork task to re-design an existing reinforced concrete building into a timber-structure building in a manner that would follow all existing construction requirements. In addition to the task, the students participated in lectures about timber structures, the architecture of wooden high-risand were guided in specific questions during their teamwork process.

Results of the project

Sharing of innovative ideas, regional and professional experiences and development of a new innovative trans-disciplinary, transnational course (module) will lead to a higher quality of teaching and cooperation within EU.

The basis of the project and the development of the new course or elective element will be formed around the education methodology "project based learning" and "learning by doing". That is a new concept for the participating universities that needs to be developed. This will lead to the transfer innovative education trans-national practices, where creativity, critical thinking, problem solving, innovation, communication and flexibility skills will be obtained.

- Built and strengthened partnerships, collaboration among the participating institutions;
- Increased awareness, knowledge and skills of all target groups (students, teachers, enterprises) in design, construction and management of sustainable high-rise timber buildings;
- International study on best practices and knowledge gaps for construction of sustainable high-rise timber buildings;
- Innovative teaching competences and improved quality of studies;
  - New BSc/BA trans-disciplinary study module "Sustainable High-Rise Buildings Designed and Constructed in Timber";
  - Book "Sustainable High-Rise Buildings Designed and Constructed in Timber";
  - Assignment books for project-based learning;
- Innovative knowledge and increased employment opportunities of graduates;
- Increased public awareness about sustainable high-rise buildings designed and constructed in timber

Project partners

Other partners of the project include: Southampton Solent University, Tallinn University of Applied Sciences, Vilnius Gediminas Technical University, Universidade de Lisboa, Charted Institute of Architectural Technologies (CIAT), Charted Institute of Builders (CAOB), Denmark Constructor Union (KF union), TISEM, LDA (TISEM), serQ – Centro de Inovação e Competências da Floresta – Associação, Sonae Group and Amorim Group, Lithuanian Association of Timber Houses Producers, Lithuanian Builders Association and Lithuanian Real Estate Development Association, Study and Consulting Center (SCC).

Opening indoor hygiene SME's exports to Middle East construction markets

Lauri Kivil, Managing Director, Estonian Woodhouse Association, Estonia

Summary

IHMEC-project combines offerings to tailored indoor hygiene (IH) solutions and export them to the Saudi-Arabia market. The ME climate forces people to remain indoors and hence, large crowds meeting daily at e.g. shopping malls, airports, schools, and hospitals are at risk of catching infections. IHMEC project connects actors in planning, designing, building, and furnishing IH spaces to form IH solutions. Project helps the companies to test and tailor the IH solutions to the Saudi-Arabia market. During the project a Living Lab (100 m^2 timber frame modular house) will be built and different type of test will be made in the Living Lab.

More than 5,200 construction projects are currently ongoing in Saudi Arabia at a value of US$819 billion, according to a report from BNC Network. These projects account for approximately 35% of the total value of active projects across the Gulf Cooperation Council (GCC).

Despite recent challenges faced by the sector attributed to low oil prices and a reported shortage of qualified workers, construction is recording a 4.1% increase this year in Saudi Arabia. Recent data from BMI research forecasts the sector's annualised average growth at 6.1% from 2018 to 2022.

Saudi Arabia's Vision 2030, along with significant investment in housing and infrastructure development promoted across the country by local authorities, are revitalising the construction industry and generating interest in a growing number of international players. The urban construction sector is the largest contributor to the construction sector's expansion with 3,727 active projects valued US$386.4 billion, BNC Network's report indicates. The utilities sector is the second largest with 733 projects worth US$95.6 billion, followed by transportation, with 500 projects valued at US$156.2 billion. (https://www.khl.com/international-construction/saudi-arabia-construction-sector-to-increase-4/135454.article).

Methods

EWHC role is to bring in the experience of Estonian wooden module and element house producers' in improving indoor hygiene of buildings, and to provide development activities with a dimension of conceptual module based comprehensive solution that enables to move from testing sole components and accessories to readymade solutions for buildings with good indoor hygiene.

IHMEC starts and increases exports of CB area SMEs into new Middle-East building markets using innovative and integrated turn-key solutions that solve indoor hygiene problems; these are the two competitive edges of the offering. Current means of preventing harmful infections global spreading are insufficient. Construction related indoor hygiene solutions offer innovative ways to tackle the problem. Today, the construction process value network of building industry (starting from need specification to interior design) lacks both guidelines on how to improve indoor hygiene and easy-to-buy and ready-made IH solutions. Instead, each producer offers their own products that form only a part of the solution needed. Currently, buyers need to solve numerous questions of e.g. setting the IH level, finding the products and services to fit the level and compiling it all together.

The project consists in:

- Scientific tests to convince the potential customers and relevant stakeholders will be made – Testing the products in lab in Kungliga Tekniska Högskolan in Sweden & in living lab at the market;
- Market study information for partners and PESTL analysis;
- Plans on how to best enter the market, executes the agreed actions with the companies, plans how the companies could best co-create and share value;
- Living Lab building to KSA and tests of the solutions;
- Showroom for potential customers to see a functioning IH solutions.

Results and discussion

Indoor hygiene (IH) solutions consist of:

A) Novel knowledge on how to build IH spaces:

- IHMEC offers IH guidelines – first in the world;
- The guidelines cover planning, building, and maintenance of IH spaces on four IH levels.

B) IH solutions that will be tailored to fit to the KSA markets:

- The solutions consist of products related to water, air, surfaces, buildings;
- IHMEC tests IH products and solutions in the real market conditions;
- IHMEC provides scientific proof that the solutions break the infection chain (i.e. they deliver the promised IH level);
- Indoor hygiene solutions are usable everywhere where a lot of people gather together and also if people have low immune systems – schools, hospitals, medical cities, airport, shopping malls, mosks, care homes for elderly people, etc.
- Infection prevention with building design and indoor environment design:
  - Building – zones, furnitures, surfaces, equipment;
  - Technical systems – ventilation, heating/cooling, potable water supply;
  - Use of the building – movement of the people, cleaning, waste management;

C) (Wooden) Model space as a comprehensive indoor hygiene solution:

- In a healthcare setting in KSA;
- Living Lab – to proof that the wood solutions work in KSA conditions as well.

Conclusions

IHMEC project helps the partner companies:

- To reduce the risks of entering Estonian companies to new markets with innovative IH products;
- To know the Saudi-Arabia market, their main players, regulations, customs, potential customers, way of doing business etc;
- To choose the most potential building segments;
- To build personal relationships needed to reach the potential buyers;
- To agree on the business (revenue) model needed to sell tailored IH solutions consisting of know-how and products of a network of partner companies;
- To start Estonian wooden houses export to Kingdom of Saudi Arabia.

The future of construction will be offsite and wood will play an important part in the change

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Welement, Estonia

Summary

There is a growing demand to use timber and more specifically mass timber on large scale construction projects. When talking about the future of construction should the focus be on changing materials (concrete to timber) or the overall arrangement of processes in the value chain? Timber has many positive aspects, but the gains are easily nullified when the management principles fail to look at the supply chain as a whole. The real focus of the industry should be on raising the productivity of construction and not on changing single materials. Productivity is in correlation with construction costs which affects the affordability of housing, the lack of which is a growing problem within the urbanization megatrend.

Keywords: Supply chain management, Offsite Construction, Lean, Timber frame elements, Modularity, Building systems, System thinking, DfMA.

Buildings are becoming machines

Like every other product in our lives, so have buildings become increasingly more complicated. Especially the complexity of building technical systems and the energy that is required to make the different parts work harmoniously. The cost of technical systems is now approaching 50 percent of a building's overall cost (Kieran & Timberlake 2005) and we are adding new systems every year. But who should take the lead among the biggest influencers in the building value chain – the client, the architect or the contractor? But the solution could also be that nobody actually takes the lead, but the different alignment of processes in the form of offsite construction will itself form the foundation for these goals.

System thinking in construction and architecture

The new client desires choice, expression, individuality and the ability to change our minds at the last minute. Most commercial product industries already answer to this client mandate. By breaking down the product into smaller parts and by using supply chain management and information technology, they can tailor the product to the customers' choice with reasonable time and reasonable cost (Kieran 2014). With similar principles of modularity and standardized interfaces, almost every product around us today, is in some form, mass customized based on personal or regional choices. A mass-customized building system should abide by the following supply chain rules:

- All possible solutions and components are within a "platform of possibilities" creating a specific system of solutions or a concept.
- If the concept platform does not contain a solution or component, it must be developed taking into consideration all the necessary constraints from the effected down-and upstream supply chain members.
- The new solution or component must be modular, meaning that the interfaces (not necessarily the shape) must be standardized based on the network of solutions within the concept.
- If the new solution cannot connect with a critical number of existing solutions within the concept catalog it is either left out or it forms itself another catalog of solutions.

The benefits and limits of mass customization and its related supply chain operations must be understandable to all members in the construction value chain. Raw materials and labour costs will not get cheaper, so the only aspect we can actually control and improve, is lead time. In order to achieve this and the increased efficiency we should first fix as many of the variables as possible and more often than not the interfaces, not the general dimensions, of the modular components are the key to the puzzle.

From Project to Supply Chain Management

Construction projects are volatile, but whereas some industries have moved into agile methods, for some reason construction management methods are still based on the traditional waterfall method. The most effective way for managing risk could be the emergence of powerful offsite construction companies who incorporate architects, designers and procurement specialist in the creation process of building solutions so that the design can take into consideration how to assemble the buildings more efficiently and how to manufacture and transport with all the best practices already part of the initial conceptual design. Whereas a building is location based, the components don't have to be. In the future buildings will be built in factories and only assembled on site. The size and complexity of the components will be limited by the distance from the offsite factory to the site. The question from the beginning should already not be if offsite methods should be used, but how large is the degree of prefabrication (DOP) on specific projects. The DOP level of a component or module depends on many parameters within the supply chain: architecture, available time and information, transportation distances, manufacturing and logistical constraints etc. This is why timber is an excellent material for offsite construction. It is lightweight, widely used, easily accessible and therefore the price is controllable. Timber is also quite robust and handles logistics very well. When something is wrong with a prefabricated unit it is easy and fast to make alterations, so that assembly can continue. Like any other material, timber has pros as well as cons. Moisture, Sound and Fire are the top three. Fire and sound are mostly manageable in the design phase. Moisture on the other hand becomes a problem mostly when project management and risk analysis techniques are inadequate. This problem can actually have a positive effect because it instinctively forces the project team to tackle this risk by planning ahead and act as fast as possible.

Wood is also a great material for automated production of modules and elements. The industry providing machinery for prefabricated timber panels is well-developed and embraces innovation.

Summary

In the near future the construction industry has to start improving productivity to provide buildings more quickly and in mass quantity with acceptable quality. This all starts with a shift in the mindset and in practice the most foreseeable and efficient improvement is to figure out how to take the construction activities that traditionally occur on site to a factory. At the moment the construction industry is at a developmental point where is should not be hoping to get all the answers right and solutions solved but instead understanding what the right questions are. How to approach architecture of affordable housing and how to rearrange the processes in the construction value chain are just some of the immediate ones.

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Thermal properties of insulation boards made of tree bark & hemp residues

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Summary

Two dissimilar waste materials were mixed to identify the likelihood of constructing insulation boards. Tree bark and Hemp residues were combined in altered proportions and with different types of glue. The thermal conductivity (λ) for all boards was measured. Diverse methods of processing the final boards demonstrated altered thermal properties based also on the different density (low and medium). The results have validated the possibility of exploiting local waste materials to produce an eco-friendly, low priced insulation product with competitive (λ) compared to the market products. All materials were collected within a small range to the laboratory (< 100 km). The energy requirements and the carbon footprint of these boards were kept low compared to traditional chemical insulation materials.

Keywords: Thermal insulation properties, waste to energy, wood by-products, tree bark.

Introduction

The most commercial insulation products today are based on oil. Switching to more environmentally friendly materials to insulate the dwelling's shell has to be everybody's primary target. The tree bark comprises approximately ten per cent of any given tree. In Greece, the tree bark is considered as a waste by-product with no actual use. Hemp (Cannabis) fibres are also treated as agricultural residues with an additional cost for the producer to dispose of them. The goal of constructing trial composites was to identify the possibility of making insulation boards from waste natural materials originating from a short distance with regards to the manufacturing site. Both are carbon-negative materials.

There is a gap in knowledge in terms of understanding the consistency of the two materials, especially with different glues and how a relative stiff yet light or medium weight final composite insulation board maybe resulted.

Methods

The three test boards differed in the percentage of the two basic ingredients, the glue type as well as the bonding procedure. Board "A" (Figure 1) consisted of 80% bark – 20% cannabis with a medium-density of 500 Kg/m^3 with a urea-formaldehyde glue. A hot press was used to format this insulation board keeping it pressed for 15 min. For the low-density boards of 250 Kg/m^3 "B" and "C" (Figure 2), a non-toxic methyl cellulose glue was used. The boards consisted of 70% bark – 30% cannabis and 60% bark – 40% cannabis respectively. These boards were formatted without the use of a press, remaining within the cast for 24 h. The "box method" was used to measure the thermal conductivity value of all three insulation boards keeping them under the same conditions for 24 h each.

Results and discussion

The connectivity of two different materials with unlike proportions and the consistency of the final mixed boards with a relative respectable thermal conductivity value was the result of this research. After taking readings for each board (Figure 3), the following thermal conductivity values were derived (Table 1).

Table 3. Thermal conductivity (λ) values of the two insulation boards.

Insulation Board	Thermal conductivity value (λ) (W/m*K)
Board A (80%**TB**–20%**CF**)	0,077
Board B (70%**TB**–30%**CF**)	0,078
Board C (60%**TB**–40%**CF**)	0,079

TB: Tree Bark, CF: Cannabis Fibres

The use of a board with a urea-formaldehyde glue (board "A") has been tried before, however, mixing those two materials together was a novel approach. Nonetheless, the actual challenge was to combine the tree bark together with the cannabis fibres with a methyl cellulose glue as this had not been undertaken previously. This led to interesting results with regards to the percentage of the glue solution (for boards "B" & "C"). The 4% (glue solution), was the lower limit where the boards could stand alone with such stiffness to allow them to be positioned within a wooden masonry without breaking into small parts. Thus, the light weight of the two boards ("B" & "C" approximately 250 Kg/ m^3) together with the medium weight of the first board, have a satisfactory value for future new insulation products.

Conclusions

The use of such waste materials is expected to prove the energy-efficiency for masonry use and also to become economically beneficial to the producers of these products. The impact of using such resources apart from reducing the carbon footprint of the final composite product, plays also a significant role to the LCA (Life Cycle Assessment) due to the nature of the materials and the relative small distance from the source to the final manufacturing place. A feasibility study to exploit commercially the final product is the next step of this study expecting to identify the board's behaviour to fire.

The energy requirements for constructing those boards were kept low due to the minimum energy input during the whole procedure. This results a more advantageous carbon footprint compared to typical chemical insulation materials.

Acknowledgements

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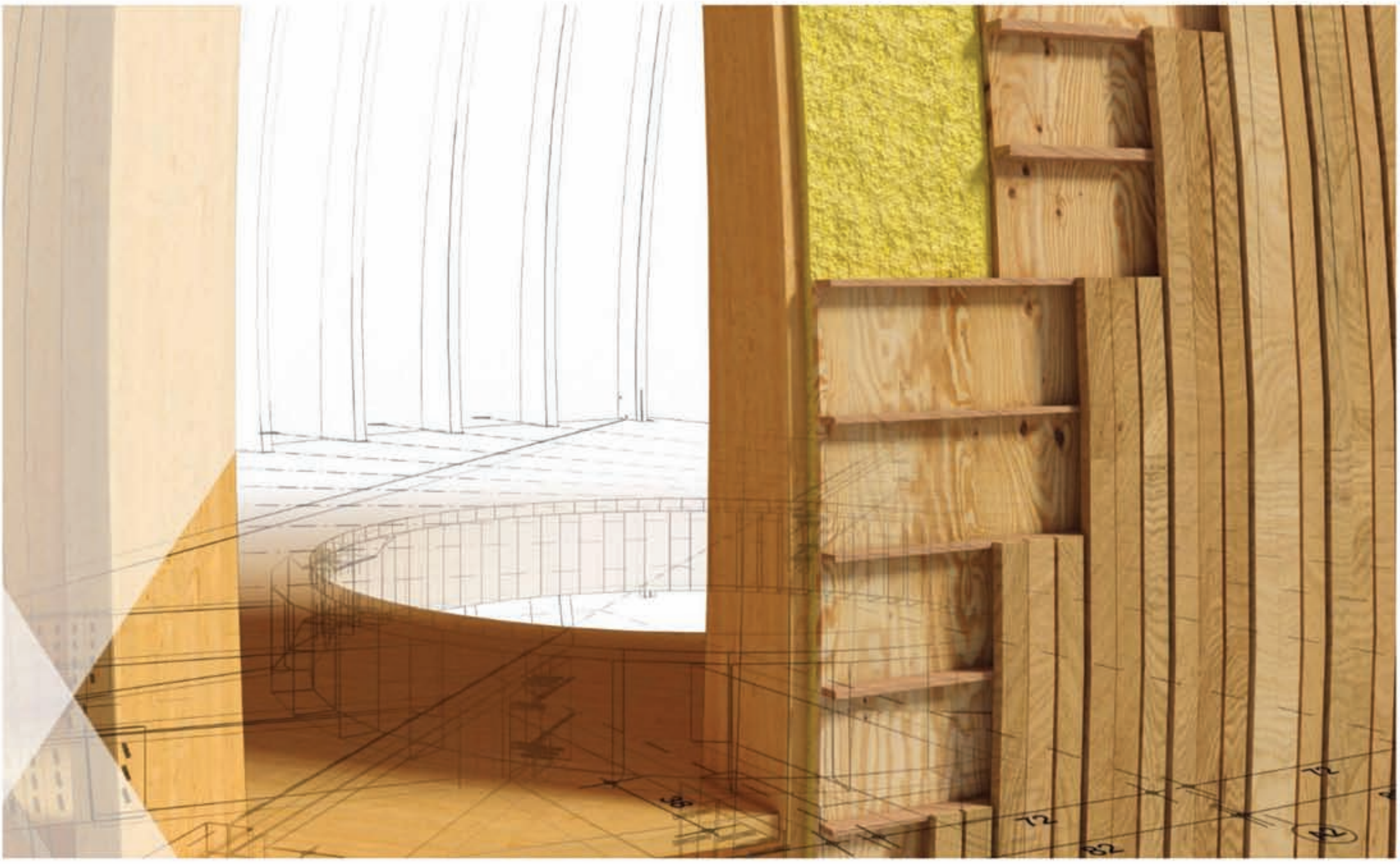

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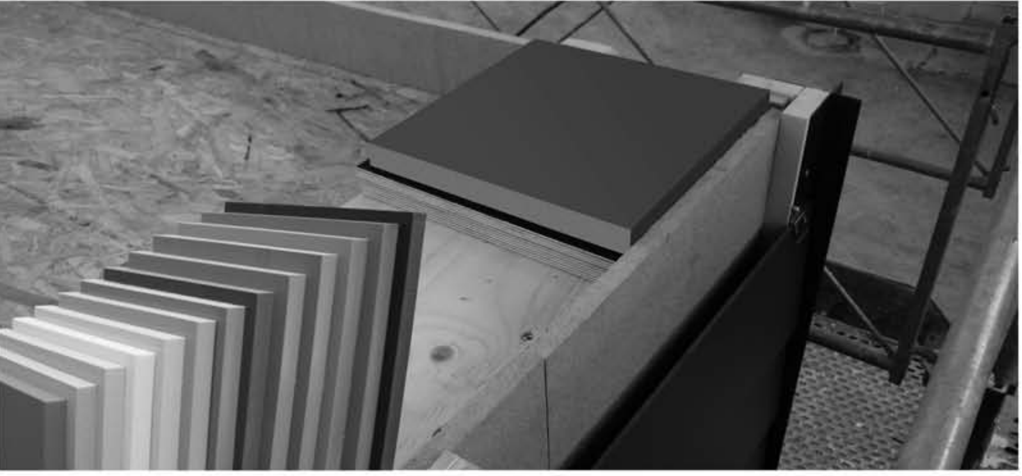

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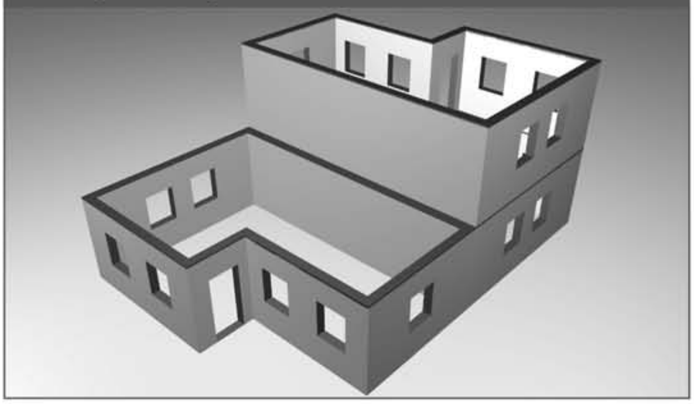
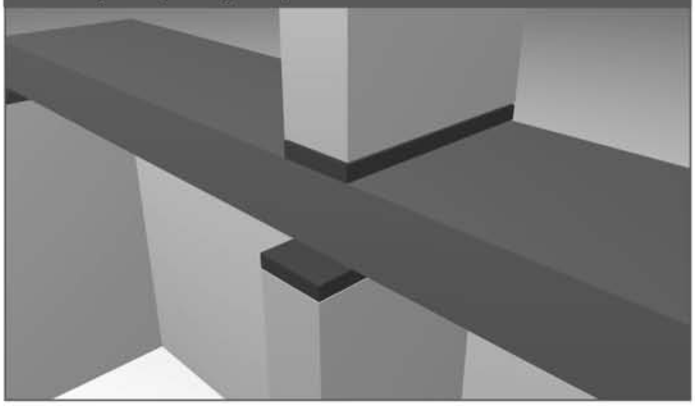


Mounting of adjoining components



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However, the physical properties of timber, in particular its capability to transmit sound, necessitate suitable measures to minimise the transmission of vibrations and sound.

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