Competitive wood-based interior materials and systems for modern wood construction

WoodWisdom-Net

Wood2New

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Contents

WoodWisdom-Net

Wood2New

Introduction

Interior spaces and indoor air quality significantly affect our physical and mental well-being and comfort, especially in healthcare and living environments. The qualitative performance of buildings depends on several factors.

Temperature and moisture are central characteristics of interior spaces and research suggests that these can be affected by the choice of surface materials. Wood's propensity to interact with moisture can be put to good effect in helping to mediate the interior environment of buildings. As the humidity level rises, wood adsorbs moisture from the surrounding air and, when the humidity drops, the stored moisture is released back into the environment. Associated with adsorption there is a release of heat which can raise the surface temperature of wood; conversely heat is required during desorption. These processes combined with the other thermal properties of wood give rise to the concept of 'hygrothermal mass', which may have the potential to improve the energy efficiency of buildings. These attributes are gradually being recognized.

Interior air quality is affected by, for example, volatile organic compounds (VOC), formaldehyde, air-borne particles and microbes, as well as other factors. The sources of chemical compounds and particulates include human activity, structures, surfaces, furnishings, and the air itself. Reference values for various chemical compounds and particles are defined, and values lower than these usually result from normal use and do not pose a risk to human health. The amount of formaldehyde in wood products has been nationally regulated since 1980, and in 2004 the European Standard EN 13986 established formaldehyde classes E1 and E2 for use in construction. To further the development of indoor air quality regulations, it is now important to quantify the VOCs released from materials, including wood. The odor of wood is widely recognized and used in, for example, air fresheners. However, the amount and long-term development of VOCs released by wood material in a living environment have not yet been clearly identified.

The importance of interior comfort grows with increasingly energy-efficient building. From January 2021 onwards all new buildings within the European Union are to be built to nearly zero energy standards (nZEB). In various pilot projects, wood has so far been used sparingly, even if the characteristics of wood materials support the creation of a pleasant space. Empirical studies have shown that wood is perceived to be a pleasant, warm, breathing, and timeless material. Europe is also aging; future social sustainability requires accessibility and comfort in our living and care environments. Basic requirements concern design for all, good acoustics and good interior air quality. Wood also supports the feeling of a homely environment; it is a familiar material, and the warm surface increases comfort.

Materials and products with environmentally, socially and economically sound values should have an advantage if they can deliver competitive performance. The aim of Wood2New was to reinforce and improve the competitiveness of wood-based interior products and systems based on these values.

This report is a collaborative effort between project partners.

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Wood2New

The Wood2New project

The *Wood2New - Competitive Wood-Based Materials and Systems for Modern Wood Construction* - project was built around six Work Packages, in addition to project management and dissemination activities. These were WP1 Framework, WP2 Wooden Surfaces, WP3 Indoor Environment, WP4 Human Perception, WP5 Wooden Spaces and WP6 Commercialization and Business Models. The work was based on an iterative learning process incorporating theoretical approaches, laboratory tests, first-hand user experiences and demonstrations. The project partners included six research entities and nine industry partners from Finland, Austria, Belgium, Norway, Sweden, and the United Kingdom. The project was coordinated by Aalto University, Finland.

The objectives of the Wood2New project were to:

(1) Identify opportunities and limitations for the use of wood in interiors

(2) Assess and enhance the beneficial effects of wood on human well-being

(3) Develop, design and evaluate sustainable, value-added, multi-functional wood-based interior materials, products and systems for both new construction and the retrofitting of residential, care, educational and work environments

To reach these objectives the project identified, assessed and developed the following aspects of wood-based materials, products and systems for interior use:

- Opportunities for, and barriers to, wood in interior refurbishment and new construction
- Options to promote the beneficial effects of wood-based products on human well-being

Figure 1. Monitoring of moisture buffering effect of wood material at the Supermarket Kiwi Fjeldset at Elverum in Norway. Image Kristine Nore, Norsk Treteknisk Institutt.

- Material and surface properties in terms of improved durability and cleanability, energy efficiency, indoor air quality and human perception of wood-based products and systems
- Competitive and sustainable wood surfaces and coatings
- Design solutions that promote human well-being, restorative interiors and energy efficiency
- Design solutions to meet end user expectations in selected market segments
- Demonstrate, test and evaluate solutions in closed test spaces and real life test beds
- Propositions for effective product declarations of wood-based materials and systems
- A basis for market access, including business environment and services

Results

The main achievements of the Wood2New project include:

- An overview of European building regulations regarding the use of wood indoors and the key user requirements
- An established protocol for the long-term monitoring of indoor air quality
- Evaluated monitoring data of the indoor air quality in new built, occupied structures over a period of 12 months from 13 objects
- Laboratory tests confirming haptic properties, moisture buffering effect and the hygroscopic capacity of various wood species, as well as variations in VOC emissions due to changes in moisture content
- Methodology and laboratory test scheme for determining energy potential from hygrothermal mass for use in building design
- Energy assessments and operationalization of results for use in building applications
- Evaluation of potential of using innovative solid wood technology for construction of single family houses
- Focus group studies on the use of interior wood products, and the relation between desired product performance and wood properties
- Study of hospital patients and the potential impact of visual wood surfaces on well-being and health outcomes
- Four surveys on people´s perceptions on wood as an indoor material and in care environments
- A book of ideas on research results with 25 new designs using wood in wet spaces
- The identification of key success factors for market access, and also the internal processes for sustainable value creation in forest product companies
- Active dissemination throughout the project including a total of over 40 publications of which 20 scientific. The majority is available through the project website www.wood2new.org

The following sections present the results of the Wood2New project in more detail.

Framework

The aim of Work Package 1, led by the Building Research Establishment, BRE, was to gain an overview of the limitations and opportunities for using wood in the interiors (Figure 2) of refurbished residential homes, educational and care environments, driven by external factors such as codes and regulations, traditions and end-users.

In order to do so, a review of building regulations, space requirements, end-user requirements, requirements for sustainability assessment and fire safety has been undertaken for Europe, and more specifically for the participating countries of the Wood2New project: Austria, Finland, Norway, Sweden and the UK.

Figure 2. Wood in interiors

Building Regulations, EU and National

The T1.2 report provides an overview of current building regulations and requirements in Austria, Finland, Norway, Sweden and the UK, with regard to the use of solid wood and wood-based panels in building interiors. Fire, accessibility, acoustic and indoor air quality regulations and standards were reviewed. The report highlights the building regulations and requirements that are present across the EU for construction products and whole buildings, as well as deviations and additions to these standards at a national level within the Wood2New participating countries. Additionally, for legal requirements, the reports looks at products and whole building sustainability schemes and standards in place in the different countries, and highlights how these could potentially impact on the use of wood in interiors.

The harmonised EU building regulations are the key standards that need to be met in all Wood2New participating countries. Wood-based products are primarily classified according to performance based European Standards in terms of their intended end use. The harmonisation of the EU standards aims to remove technical barriers to trade in the field of construction and ensure the free movement of construction products across the EU. With the introduction of the Construction Products Regulation (CPR) in July 2013, CE marking of construction products covered by European Technical Standards has become mandatory and is therefore one of the key requirements that manufactures will need to meet in order to trade throughout Europe. There are however, still significant differences between some of the National and EU wide requirements for timber products, hence the importance of national regulations.

In summary, the structure and necessary implementation of the majority of building regulations in the participating countries have not been developed to include, or exclude, a product by the material used in its composition. But rather, regulations specify a number of requirements that a product needs to meet in order to be used in a certain application, such as fire, indoor air quality, accessibility and acoustic regulations. In terms of interior space requirements, there are limited regulations and standards that need to be met by manufacturers, instead the focus is on the subject of occupant wellbeing, and how buildings can affect people indirectly through psychological wellbeing (such as the impact of day lighting on mood). The research around this topic is discussed within the section relating to EU wide regulations and specific opportunities were identified (Table 1).

Table 1. Showing where advantage and thus maximum opportunity lies for interior wood

	Fire	Access	Acoustic	IAQ	Sustainability
Floors	++	++	+	~	++
Walls	+	.	+	~	++
Ceilings	+	.	+	~	++
Loose (e.g. furniture)	+	.	.	~	++

++ = advantage (e.g. anti-slip properties of flooring, lower impact EPD)

\+ = slight advantage (e.g. a technical solution that maintains sustainability credentials)

~ = not restrictive

. = not relevant

Various sustainability drivers across Europe encourage the use of materials with a low environmental impact. Sustainability credentials of wood are therefore an incentive for its increased use. Indoor air quality aspects are also dealt with in numerous environmental labels and schemes, with incentives to limit certain types of treatments and additives. A major requirement of the different schemes is also the responsible sourcing of timber products, which can currently be demonstrated by a number of existing chain of custody labels. Finally, concepts such as change of use and repurposing of buildings need to be taken into account when considering new construction products.

Space and End-user Requirements, Past and Future

The T1.1 report provides an overview of end-user and space related requirements in Austria, Finland, Norway, Sweden and the UK, with regard to the use of wood and wood-based materials in interiors. A short summary is presented in Table 2.

The task compiled an understanding of the traditional and future trends, the limitations and the requirements of wood use in interiors, and gathered a foundation of information in order to identify challenges, regional commonalities and a framework for further research focus. The report gives an overview of the situation in each country and enables identification of similarities and differences in order to provide recommendations for supporting the development of wood use in interiors. For each country, the following sections were addressed: cultural preferences and heritage, requirements and limitations, present and future trends in wood use and innovations.

The variety of geographical, historical and cultural contexts within the participating countries has revealed different traditions in the use of wood in construction. While being a prominent material in the built environment in some countries, it is still considered, in some cases, difficult to manage in

Table 2. Short summary of features in the Wood2New participating countries

Country	Forests culture in 2016	Forest coverage	Culture and heritage 200 years	Requirements and limitations	Key opportunity	Present use and future trends for wood use in interiors	Key innovations & technologies
Austria	Strong	47%	Flooring Furniture Fit-out Joinery	Maintenance Humidity Behaviour in an air conditioned environment	Indoor air quality	Flooring Furniture Fit-out Joinery	CLT Advanced education programmes for wood technologies
Finland	Strong	72%	Flooring Walls (vernacular log houses)	Humidity Acoustic Insulation Maintenance	Health & Wellbeing Environmental credentials	Flooring Fit-out Joinery Growing trend:Multi-storey housing	CLT Advanced education programmes for wood technologies
Norway	Strong	38%	Flooring Walling Fit-out Joinery Furniture	Humidity Maintenance	Health & Wellbeing Environmental credentials	Flooring Walling Joinery Furniture	CLT
Sweden	Strong	70%	Flooring Fit-out Joinery Furniture	Humidity Maintenance	Environmental credentials Need for more housing	Flooring Fit-out Joinery Furniture	Easy-to-assemble interior solutions
UK	Weak	14%	Flooring Furniture	Acoustics Durability Humidity Fire	Health & Wellbeing	Flooring, Staircases Interior joinery Furniture Fit-out	Accoya TMT hardwoods CLT Dowellam Glulam

others. Despite a number of differences related to these various experiences, some commonalities in the participating countries still emerge from the analysis. The advent of new building technologies in the 20th century have led to the decrease of timber use in buildings. However, a significant renewal of interest in using wood has been noted in the last few decades, both for environmental and aesthetical reasons and for its ease of use in offsite manufacturing techniques. The type of products employed has evolved, as the reconstituted wood products industry grew and enabled the wide-scale commercialisation of cheaper wooden products such as MDF and particleboard. The customer now also has high demands regarding environmental credentials of materials, and various labels are increasingly required to guarantee transparency in forest management. Additionally, there seems to be concern about the maintenance and surface cleaning of wood in specific applications, which will need to be considered in the further development of wood-based solutions.

Based on these findings, recommendations were established to support the growth of wood in interiors addressing education, political will, practical solutions, health and wellbeing, ecolabelling, regional hot spots, responsible sourcing, campaigns and further research.

Framework and Criteria for Multifunctional Interiors

The outcomes of these two tasks were then considered together to draw a picture of the background in each participating country in terms of building regulations, space requirements, end user requirements and sustainability drivers, enabling a systemised framework that constitutes a basis for work in Work Packages 2-6.

In Austria, Finland, Norway, Sweden and the UK, the following commonalities were observed:

- Increasing awareness of the environmental impacts of materials. Wood is often frequently seen as a solution to this issue due to its low embodied carbon
- Governments and private organisations are promoting the use of timber in construction, especially for its sustainability credentials
- Customers are asking about a healthy indoor environment, and are looking at both the emissions of materials and visual benefits with a view to improving occupant health and well-being

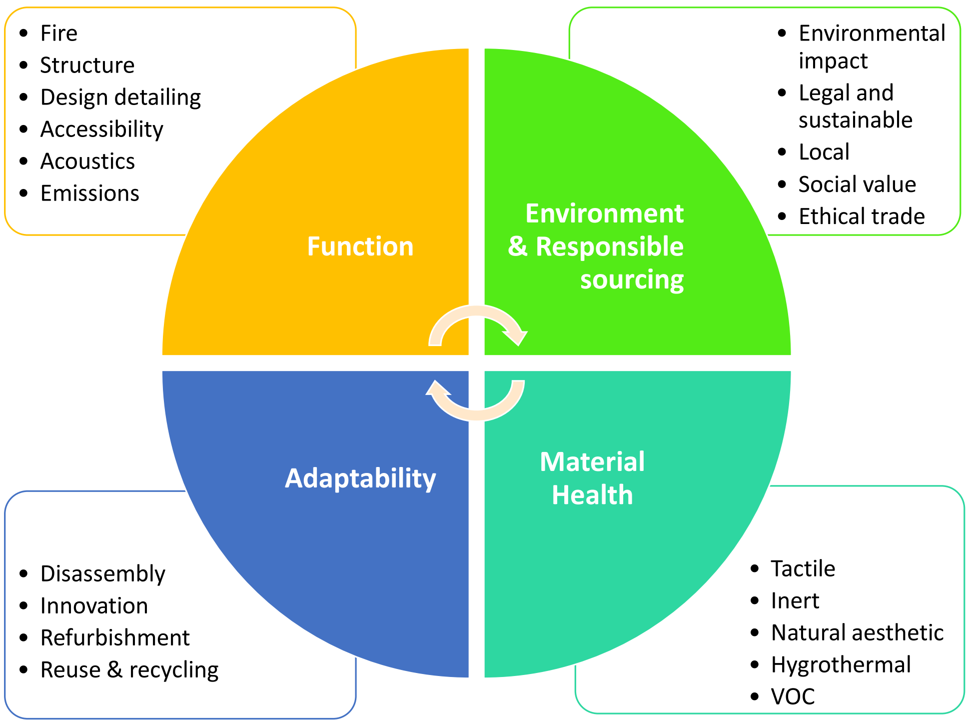

Figure 3. The criteria for a framework for multifunctional interiors

- Customers, the construction sector and sustainability, as well as assessment standards, require timber from responsibly managed forests (legal and sustainable) and there is an emerging trend to advance the use of local species both at the European and country level
- The main discussion point and area of concern about the use of wood indoors in interiors relates to maintenance and surface cleaning. This is especially so in healthcare environments, but also in domestic housing where low maintenance is 'valued' such as in the UK
- The European population is ageing and an important focus will be needed on health care buildings for elderly and the retrofitting of existing houses to improve accessibility

The framework for specifying multifunctional interiors needs to be constructed to address the above opportunities using four specific criteria and their supporting elements, as summarized in Figure 3.

These four criteria and the elements that support them are key to consider for the specification of the benefits of multifunctional interiors in future. From the research conducted in Wood2New it is clear there are benefits across all four criteria for wood, including but not exhaustively:

- Legal and sustainable timber from the European resource
- Flexibility as a multitude of interior products and adaptable in use
- Low specific VOC emissions
- Natural appearance creating a warm and nature-based interior
- Hygrothermal mass for moisture buffering
- Positive tactile properties create a warm impression

Material Properties of Wood

Work Package 2, led by Aalto University, focused on the material properties of wood. As a cellular material wood is a good thermal insulator and, being hydroscopic, it can also buffer the internal relative humidity of a room, with several studies suggesting that this could be used to reduce space heating requirements (Osayintola et al. 2006; Orosa and Oliveira, 2009). Moreover, during the phase transition from vapour in the air to bound water in the wood cell wall, an exothermic reaction occurs. This latent heat exchange has been shown to lead to a change in wood temperature (Kraniotis et al. 2016; Kortelainen, 2015) and this mechanism could contribute positively to the overall energy balance of a building. Both the moisture buffering and latent heat exchange possibilities have been investigated in this work package. As the emission of VOCs is strongly dependent on temperature and relative humidity, a change in climate conditions, as occurs during moisture buffering and the related latent heat exchange of wooden materials, is likely to influence the emission behaviour of these materials. This potential impact was investigated with uncoated and coated wood at the laboratory scale (in collaboration with Work Package 3).

Colour, surface structure and surface temperature are the main properties that impact human perception. It is, however, very difficult to capture this human sensation and to define physical parameters that can be measured and used to improve the design of products made of solid wood. Thus, a goal of the Wood2New project was to investigate the relationship between haptic sensations and the material properties of wood and other commonly used materials, to see whether wood is perceived in a positive light in comparison to other materials. Factors that influence the haptic properties of wood surfaces have been studied during the course of the project.

Sorption and energy efficiency

Moisture buffering

The moisture buffering ability of Silver birch (*Betula pendula* Roth.), European white elm (*Ulmus laevis* Pall.), common ash (*Fraxinus excelsior* L.), common oak (*Quercus robur* L.), black alder (*Alnus glutinosa*), Norway maple (*Acer platanoides* L.), Douglas fir (*Pseudotsuga*), Siberian larch (*Larix sibirica* Ledeb.), Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) was investigated using climate chambers situated at the Department of Forest Products Technology (now the Department of Bioproducts and Biosystems), Aalto University. The tests were carried out in accordance with the methods set out in the NORDTEST method (Rode et al. 2005). The test was modified where necessary to enable the effects of the wood structure on the moisture buffering ability to be studied. Buffering on the transverse surfaces of four species were studied: Scots pine, Norway spruce, silver birch and common oak. This resulted in data about the moisture buffering ability of the transverse, radial and tangential surfaces of wood to be obtained. The wood material has been categorized into moisture buffering value (MBV) classes according to the criteria presented in the NORDTEST method (Figure 4). Moisture buffering class describes the moisture buffering ability of wood better than a mere numerical value, since there is always some variation within the species depending on the material characteristics like density and the amount of extractives.

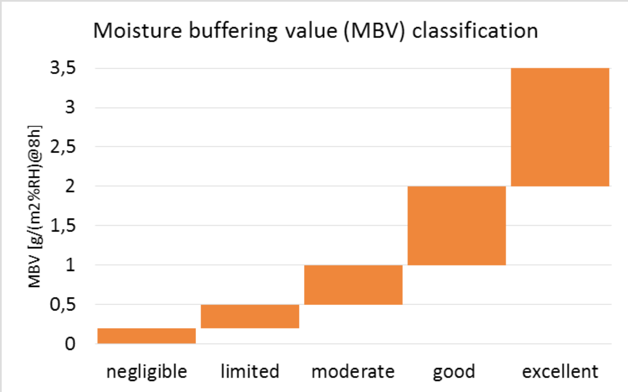

Figure 4. Moisture buffering value classes according to the NORDTEST method (5).

<u>Key findings:</u>

Effect of species

Two different sample sizes were used in the test. Firstly, boards with a thickness of 13 mm, width 80mm and length of 325mm (according to the NORDTEST method) and secondly, cubes with an edge length of approx. 25mm (non-standard). When the tangential or radial surfaces of the wood material were exposed to humidity variation, all species were classified as having either 'moderate' or 'good' moisture buffering values. There was no difference between the two sample sizes (boards/cubes), indicating that the MBV values of the latter were reliable.

Effect of orientation

In the test with the cubes, it was possible to have parallel sets of specimens either exposing the tangential/radial or the transverse surface to humidity variation. The transverse surfaces of all the species (Scots pine, Norway spruce, silver birch and common oak) tested had MBV that classified them as having 'excellent' moisture buffering ability. In some cases, the MBV of the transverse surface was fourfold that of the corresponding radial or tangential surfaces.

Latent heat exchange

Latent heat exchange was investigated as a means of increasing energy efficiency. A master's thesis was completed at Aalto University and work undertaken at Norsk Treteknisk Institutt has demonstrated the energy savings potential of accounting for the latent heat of sorption of wood.

Figure 5. Experimental arrangement to measure surface temperature rise

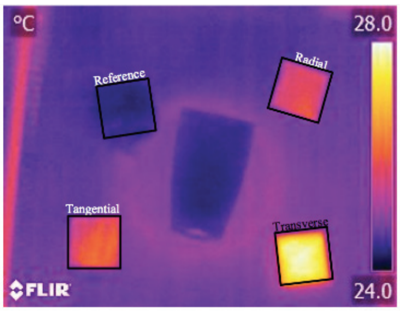

Figure 6. Pseudo colour image of the surface temperature on wood surfaces measured using thermal imaging

<u>Key findings:</u>

The surface temperature change arising from adsorption (wood conditioned at 33% RH and then subjected to 75% RH) and desorption (conditioned at 75% RH and then subjected to 33% RH) in silver birch, Scots pine sapwood, Scots pine heartwood and initially bone dry Scots pine heartwood was investigated using a FLIR E60 thermal imaging camera. The test set up is shown in Figure 5.

As indicated by the lighter colour (more yellow) in Figure 6, the surface temperature rise during adsorption was found to be greatest on the transverse surface. This is most probably a result of the much more rapid adsorption of moisture in this anatomical direction, as indicated by the moisture buffering values (MBVs) noted previously. The difference between the radial and tangential surfaces seems to be marginal and this is again a reflection of the smaller difference in moisture transport in these two anatomical directions.

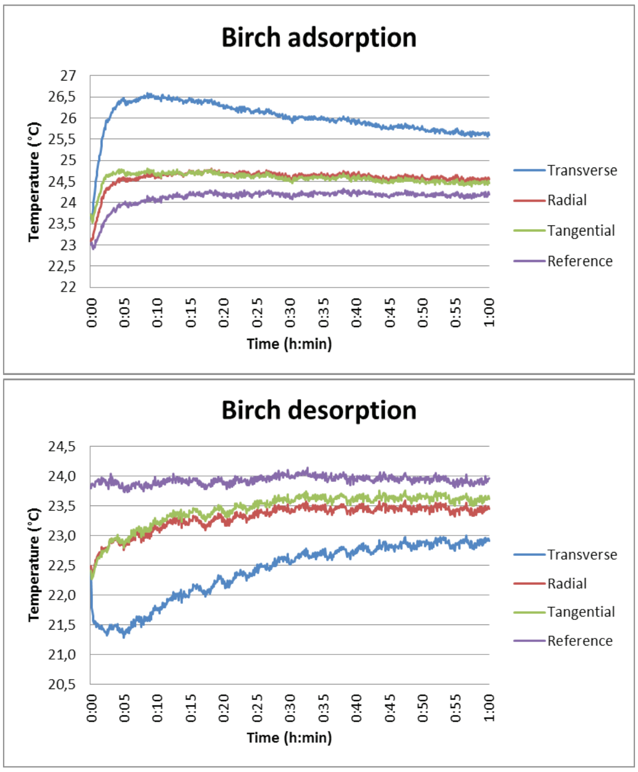

Figure 7. Surface temperature changes in birch wood during sorption

Figure 7 illustrates the differences in temperature arising from adsorption and desorption in birch wood. The greatest temperature rise of approximately 3 °C is observed on the transverse surface. The rise in temperature on the radial and tangential surfaces was rather similar. A drop in surface temperature was recorded during desorption.

Clear species effects were noted: silver birch exhibited greater temperature changes than Scots pine under the same conditions. Moreover, as might be expected, the lower the initial MC the greater the change in temperature. There was no clear difference between heartwood and sapwood.

Norsk Treteknisk Institutt studied Norway spruce. A climate chamber was used to simulate different indoor environments, and thermographic techniques were used to measure the surface temperature of the exposed spruce surface. A covered spruce sample was used as a reference. The moisture adsorption in the material samples was measured using load cells. The results show that the surface temperature of spruce increased by 2.1 °C as a result of moisture adsorption, while the surface temperature of the reference sample only increased by 0.9 °C. This finding has direct implications for energy use in indoor environments with exposed wood surfaces, and is expected to have a major impact on how the timber's properties can be used in indoor environment. Industry partners have started using these findings in engineering and energy planning in several construction projects.

The effect of coatings on the moisture buffering and emission of VOCs

Key findings:

The MBV of coated wood samples was found to be significantly less than that of the uncoated reference material (Table 3), though it should be noted that the addition of coatings did create problems with the test protocol, with the coated samples not always meeting the criteria that there should be "less than 5% mass change between the cycles". Two coating types were investigated, a permeable (diffusion-open) coating and an impermeable (diffusion-closed) coating. For the diffusion-open variant the coating was diluted with 10 % water and applied by spraying with an application rate of 55 +/- 5 g /m². For the closed version the coating was applied undiluted with an application rate of 110 +/-10 g /m². In each case, two replicate samples were tested. In the case of the permeable coating one sample met the criteria set out in the NORDTEST protocol and had a MBV value of 0.31, another, which did not meet the criteria, had a MBV of 0.30. In the case of the impermeable coatings neither sample met the criteria, but one of the two was close to the 5% mass change (actual values were 6.8% and 12.4%). Nevertheless, the values were thought to be realistic and the differences between the samples and in the calculated MBV values were small (0.189 and 0.186).

Results:

Table 3. MBV of coated and uncoated wooden surfaces

Surface	MBV class
Uncoated reference	moderate
Permeable coating	limited
Impermeable coating	negligible

The effect of cyclic humidity loading on the emission of VOCs from coated and uncoated pine wood

In collaboration with Work Package 3, the effect of cyclic humidity changes as experienced during the moisture buffering test according to the NORDTEST method, on the emission of VOCs was investigated. The freshly sawn Scots pine was provided by the South-Eastern Finland University of Applied Sciences – Xamk in Mikkeli. The wood material was cut into boards and dried at Xamk after which it was transported to Aalto University without delay. At Aalto University the boards were planed, heartwood and sapwood separated and specimens cut to the defined specimen size (length 50mm, thickness 25mm and width varying around 50mm) for five parallel emission tests. The specimens were frozen immediately after arriving at Holzforschung Austria, which was within less than two weeks from planing and cutting at Aalto. Before emissions testing, some of the specimens were coated with a water-based system. The coating was applied by spraying. By applying the same coating at different thicknesses diffusion-open and diffusion-closed layers were created. Table 4 shows the variation in specimens.

Table 4. Specimen specification for the material emission testing.

Wood species	Cut	Treatment
Scots pine sapwood	Trans-cut	Untreated
Scots pine sapwood	Cross-cut	Untreated
Scots pine heartwood	Trans-cut	Untreated
Scots pine sapwood	Trans-cut	Coated, diffusion-open
Scots pine sapwood	Trans-cut	Coated, diffusion-closed

Methods:

Each specimen variation was divided into two specimen sets, prepared according to the

NORDTEST method (Rode et al., 2005) and installed into emission chambers. During the investigation period of 28 days, one specimen set was exposed at fluctuating humidity conditions (several cycles of 8h at 75% RH - followed by 16h at 33% RH), while the second set was kept in a fixed climate of 23°C and 50% RH.

Results:

Moisture fluctuations including temporary elevated humidity of 75% RH, did affect the emission behaviour of the untreated pine wood specimen. Not all compound groups were affected equally, but no clear trend, based on substance specific properties like, for instance, polarity, could be found. In general, the untreated pine specimen showed lower emission levels after 28 days of exposure to changing humidity cycles compared to constant climate conditions. This matches the findings of Kraniotis et al. (2015), who tested variations of VOC emissions from untreated pine wood due to air humidity fluctuations and found increased emissions after periods of flushing wooden samples with a dry air stream and decreased emissions after the surface had been subjected to air of a higher humidity.

The emission profiles of the coated specimen were not affected significantly by varying humidity cycles, no matter if the coating was diffusion-open or diffusion-closed. In this study the characteristics diffusion-open and diffusion-closed were gained by applying the same water-based coating in different layer thicknesses. Other coating types (e.g. oil-based products) shall

Statement report WP2– Surface sensation and surface properties

Holzforschung Austria ran a study in which blindfolded persons judged the haptic perception of different wood and non-wood materials at temperatures of 18°C, 23°C and 28°C. Using a bare hand, they judged the perception of temperature, general comfort and sweating as well as judging whether the material in question was wood or not. With bare feet, the participants in the study judged the perception of temperature only.

Table 5 shows the sample set used for the study. To perform the study, 6 replicates of each variation were used (judging was conducted with hands and feet at the three different temperatures). The materials were stored in climate chambers at 18°C and 23°C and 28°C prior to testing. The assessment of the materials was performed at a room temperature of 23°C and 50 % relative humidity.

Figure 8 shows an example of the results to assess the perception of temperature with bare hands and feet. The range for a comfortable temperature was between 2 (comfortable warm) and 3 (comfortable cold). Values BVELOW 2 indicate an uncomfortably warm perception and values above 3 indicated uncomfortably cold perceptions. No test person at any material temperature perceived the material to be uncomfortably warm. The most uncomfortably cold judgements were made at a material temperature of 18°C where the person's feet were slightly more sensitive than their hands. At a material temperature of 18°C, only 10 to 25 %

Table 5. Overview samples for test person study about haptic perception with bar hand and bar feet

Name	Material	Surface Treatment	Substrate
T	Tile	None	-
C	Concret	Coated	-
SynchO	synchronized laminate	None	-
V	Vinyl	None	-
L	Linoleum	None	-
OUS	Oak	Uncoated	Sanded
OOS	Oak	Oil	Sanded
OOC	Oak	Oil	Chopped
OUVS	Oak	UV sealer	Sanded
LUS	Larch	Uncoated	Sanded
LOS	Larch	Oil	Sanded
LOB	Larch	Oil	Brushed
LUVS	Larch	UV sealer	Sanded
AaUS	Aspen thermo	Uncoated	Sanded
AsOS	Aspen thermo	Oil	Sanded
AaUVS	Aspen thermo	Coated	Sanded

Larch and Oak UV Sealer: Industrial UV-curing floor coating system; Aspen Coated: 1K water born spray coating system of people perceived epoxy resin coated concrete (C) and tile (T) and 40 to 60 % vinyl (V) to be at a comfortable temperature. The laminate (SynchO), coated larch (LUVS) and oak samples were perceived to be less comfortable in temperature than oiled or uncoated larch and all the thermally modified aspen samples. From the non-wood samples, the temperature of linoleum (L), with a very rough surface profile, was perceived, in most cases, to be in the comfortable range.

The perceptions of the test persons was also measurable with IR-temperature imaging as shown in Figure 9, in which it can be seen that the temperature of the human hand cooled down more significantly by touching a tile than by touching a thermally modified aspen surface or Polystyrol. To compare the temperature sensation of the test persons with the material properties, a test procedure with dollies and IR-imaging was developed. The tests were performed in a climate

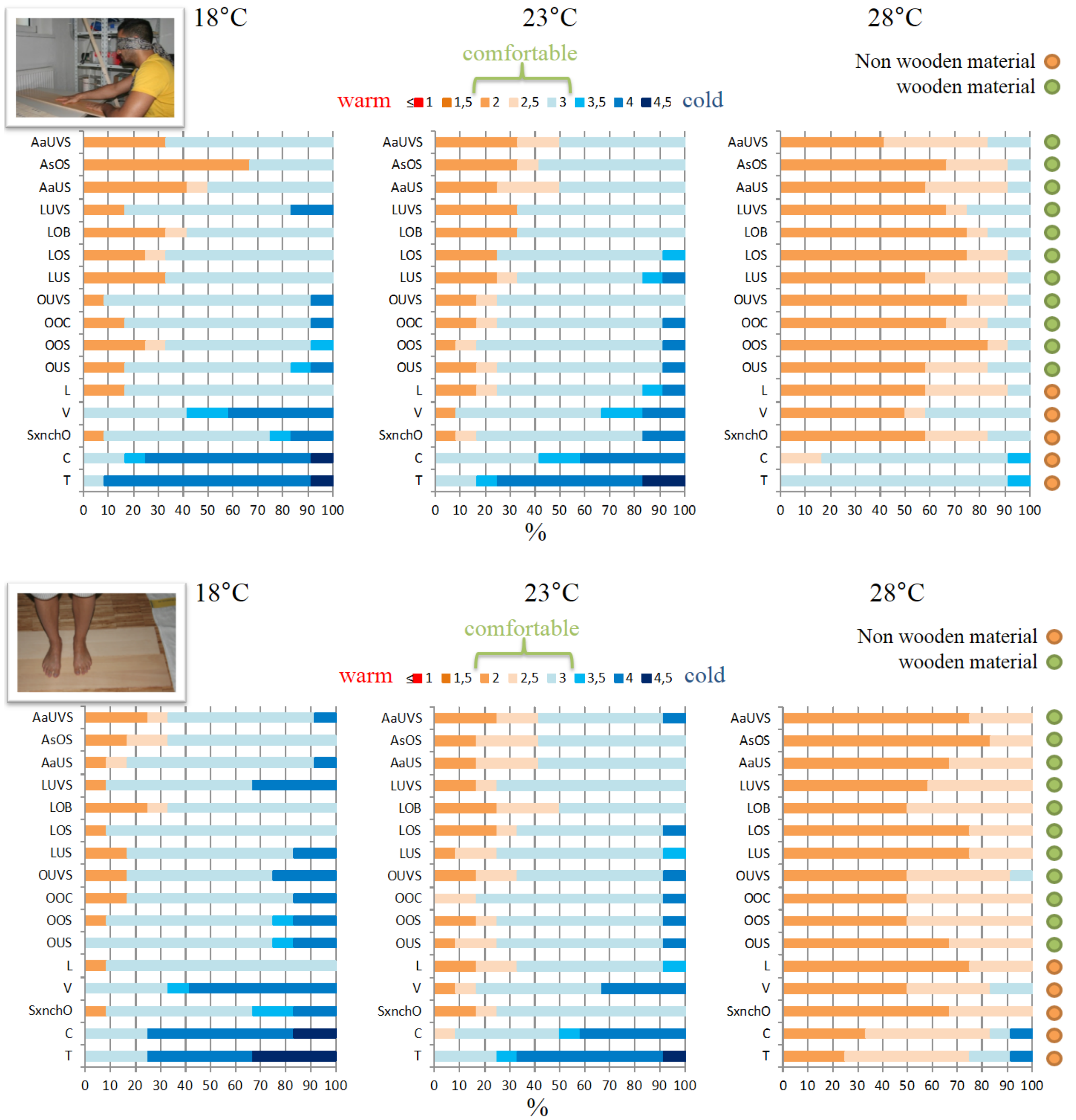

Figure 8. Temperature sensation with bar hand (top) and with bar feet (bottom) at material temperatures of 18°C, 23°C and 28°C

room at 18°C. An IR-camera recorded a video from above the dollies and sample. Dollies with a 0.5 mm thick silicon skin, filled with gel were heated up to 37°C. The dollies were positioned on the sample for 20 seconds and then twisted upside down after these 20 seconds to measure the temperature of the contact area the dollies had with the sample. The cooling down of the side of the dolly in touch with the sample gave a value which was in line with the temperature sensation of the test persons. The cooling down quotient of dollies showed a correlation with the lamda value for thermal conductivity taken from the literature as shown in Figure 10. Polystyrol showed nearly no cooling, followed by larch and thermally modified aspen, oak, laminate, concrete, tile and steel.

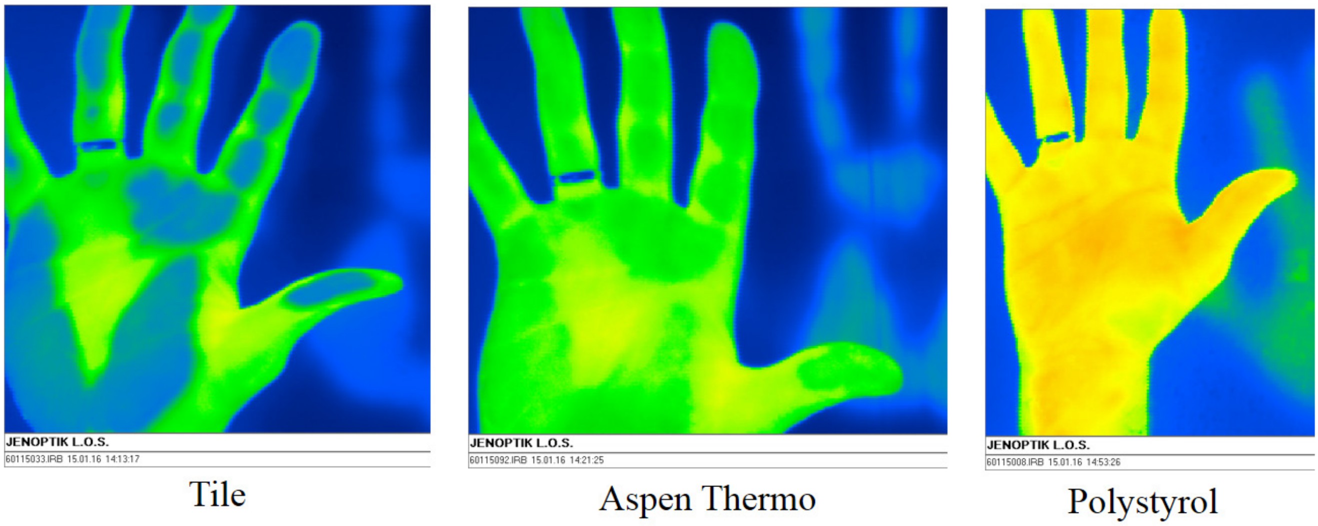

Figure 9. IR-temperature image of a human hand having touched for 10 seconds a tile, a thermally modified aspen board and a polystyrol board for 10 seconds at 23°C room temperature

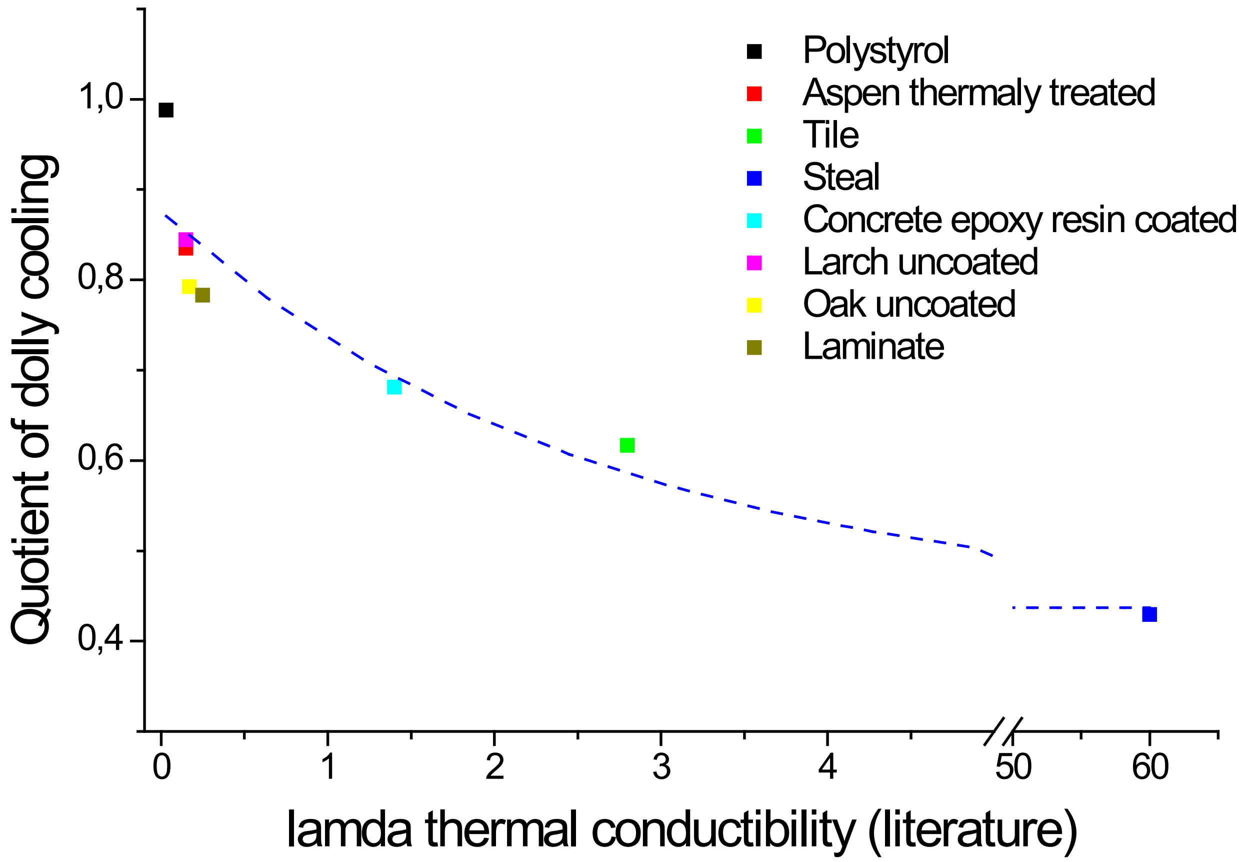

Figure 10. Quotient of dolly cooling after having touched different materials for 20 seconds

The results for the perception of sweating by touching the samples showed that significant sweating was quite seldom, but slight sweating was perceived by up to 50 % of the test persons on epoxy resin coated concrete (C) and up to 30 % on tile (T). The oiled thermally modified aspen (AsOS) was an outlier, because the oil formed a sticky surface. On wooden surfaces sweating was perceived more often on coated surfaces than on oiled or uncoated surfaces.

By asking the test persons about the general comfort of uncoated or oiled wood samples (except oiled thermally modified aspen, because of its sticky surface), they were perceived to be comfortable more often than coated surfaces and non-wood materials. The oak samples were perceived to be a little less often comfortable than the larch samples and the uncoated thermally modified aspen.

Figure 11 shows the variation in the topography of the surfaces used in the test person study about haptic perception. The uncoated wooden surfaces of oak, larch and thermally modified aspen differ from each other, and the characteristic cell structure of each wood species forms the surface topography. Oil treatments changed the topography slightly, depending on the oil used for the application. Coatings which form a layer on top of the wooden surface change the topography significantly. Additionally, the topography of wooden surfaces was influenced by the surface preparation technique, such as sanding, brushing (larch) or chopping (oak) which was perceived to be a little less comfortable than sanded and oiled oak or larch.

By touching the samples with the bare hand and blindfolded, most of the test persons were able to identify the wooden samples whether they were uncoated or oiled. Particularly at cold material temperatures, the coated wooden samples (UV-sealer and spray coating) were more often identified as being non-wood materials than the oiled or uncoated wooden samples. Nearly half of test persons perceived linoleum (L), vinyl (V) and laminate (SynchO) to be wood materials. Tile and concrete were very often perceived to be non-wood materials because of the temperature perception.

With an additional set of samples (Figure 12) the test persons were asked whether they were able to differentiate between wood and wooden imitation by viewing from different distances and at least by viewing and touching the sample.

Figure 13 shows the ability of the test persons to distinguish between wooden surfaces and wooden imitations. At a viewing distance of 1.5 m, the test persons were hardly able to differentiate between wood and imitation; nearly half of the imitations surfaces were seen as wooden materials. At a closer viewing distance, and especially by touching the samples, the people were more readily able to identify the imitations.

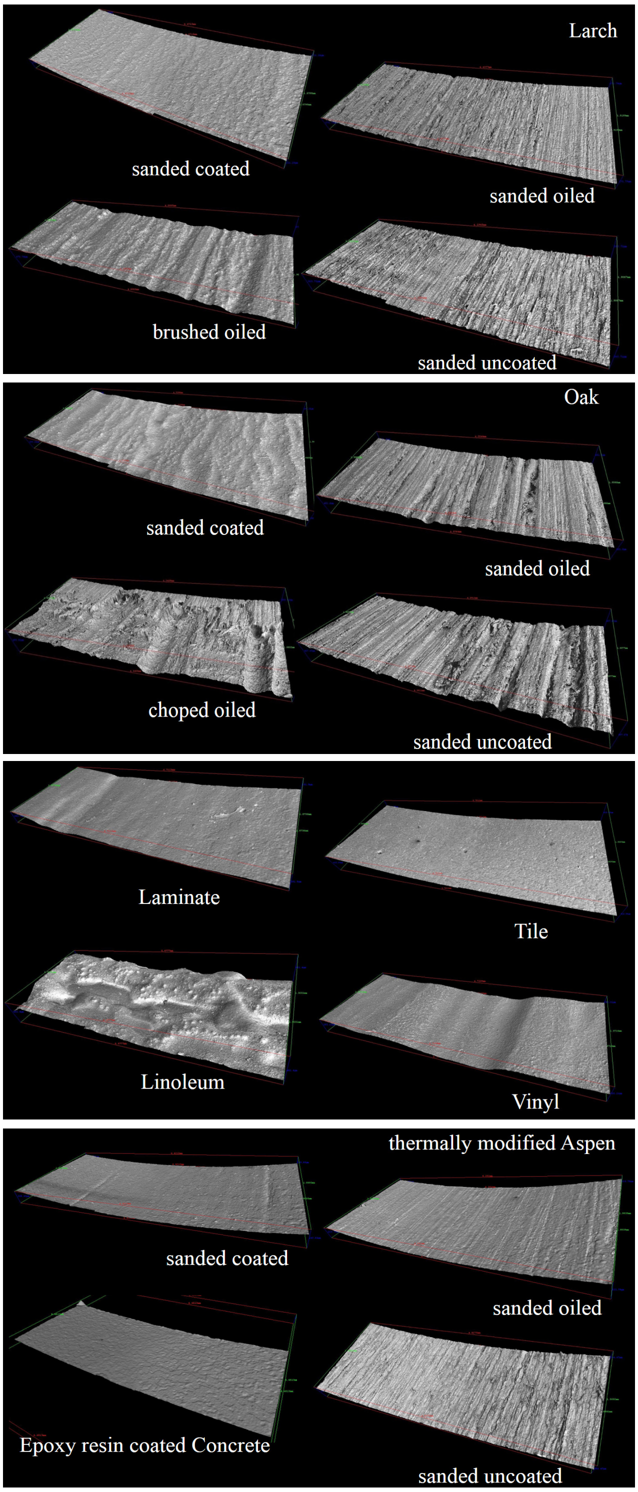

Figure 11. Microscopic surface images of samples used in test person study about haptic perception (sample size approximately 5 mm x 2 mm)

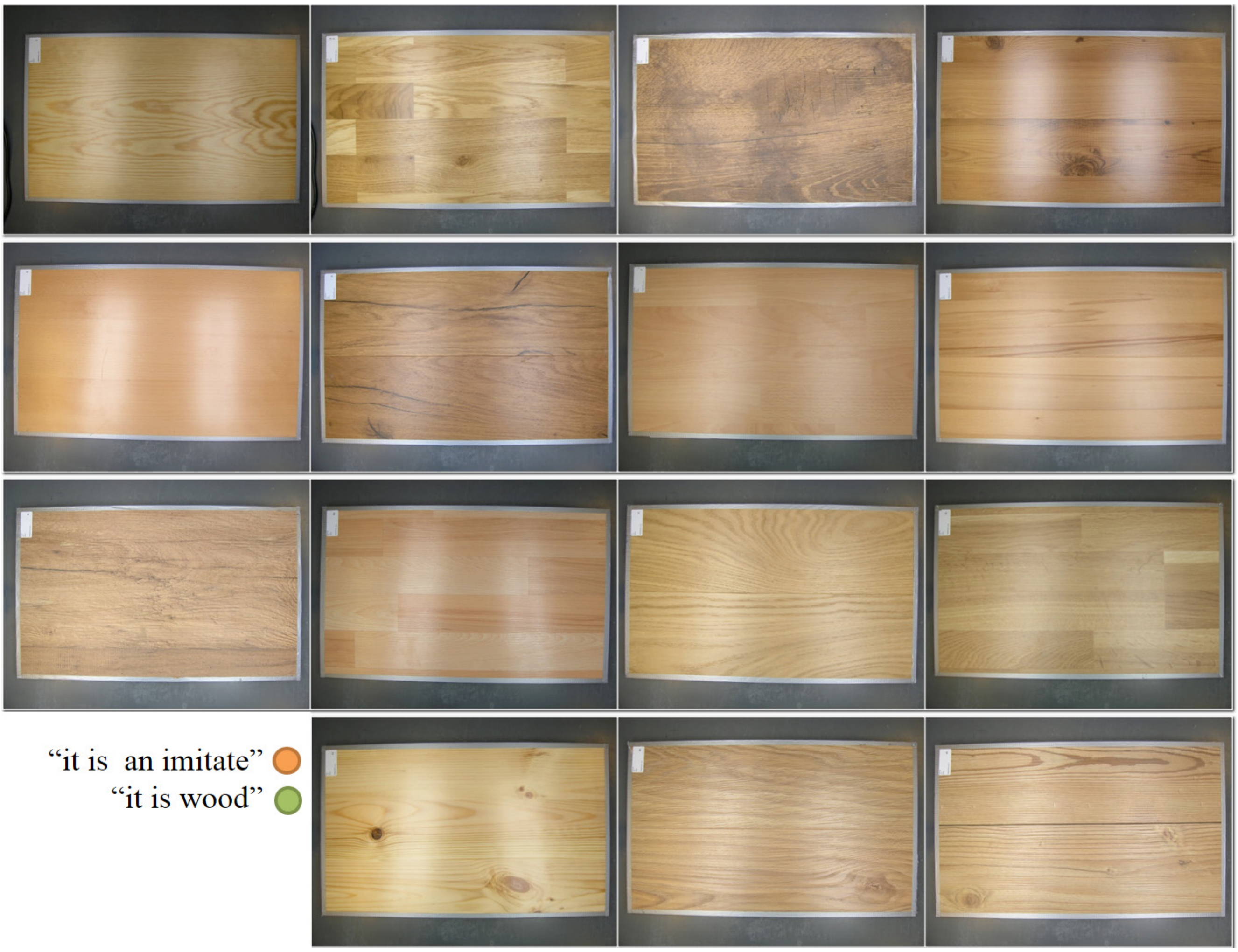

Figure 12. Samples for study about distinguish between wood and wooden imitate

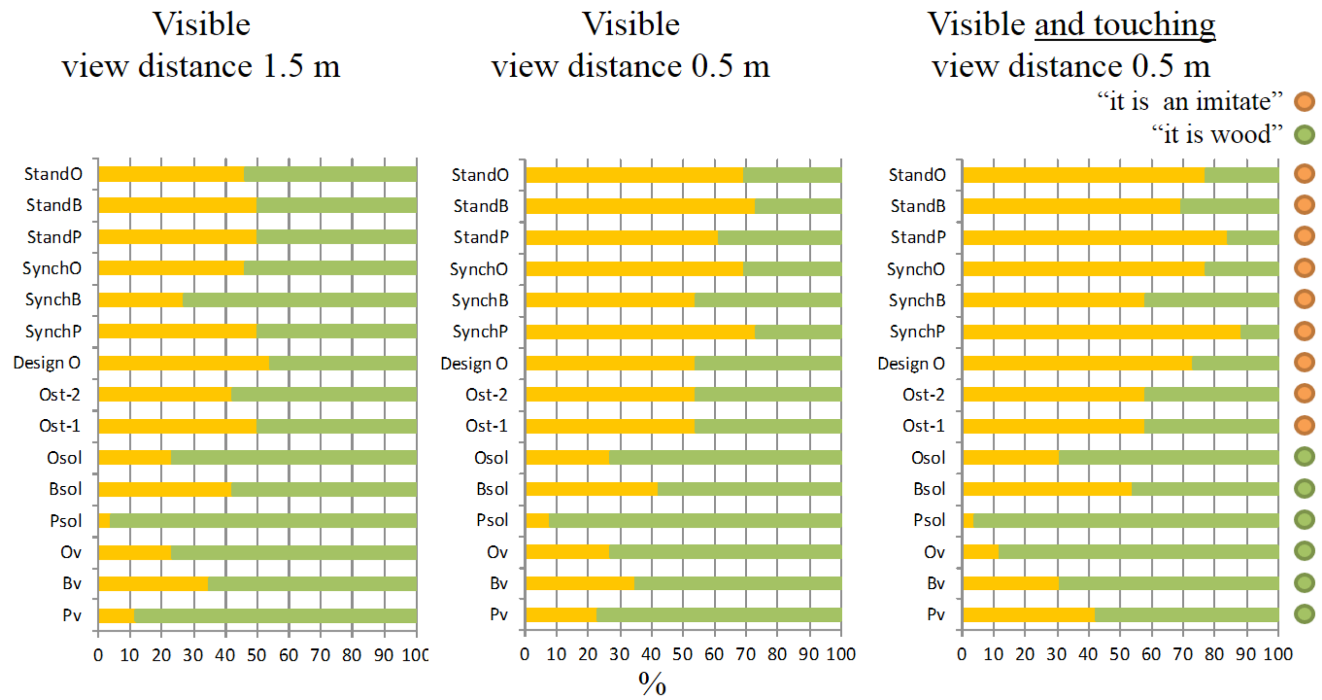

Figure 13. Ability to distinguish between wooden surfaces (indicated with green dot) and wooden imitate (indicated with orange dot)

Conclusions

Haptics and tactile properties influence decisions by choosing products and materials consciously and unconsciously. The touch of uncoated (if not too rough) wood was often felt to be comfortable and coatings significantly influence the sensation of wooden materials. With oil surface treatments, the haptic character of the wood was retained very well, because usually it forms no layer on the surface. Humans can judge very well a material type by touching a surface, where the temperature sensation is an important factor, without touching, however, it is often very difficult to differentiate between wood and imitation especially when viewed from a distance.

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Indoor Air quality and Wood

Holzforschung Austria collected indoor air data and specific health related parameters in 13 newly built occupied prefabricated timber houses on a long-term basis. Various construction and ventilation types were considered. The observed indoor air parameters included the emission of volatile organic compounds (VOCs) and formaldehyde, airborne microorganisms such as yeast and mould, particulate matter and climate data. Medical data included blood pressure and pulse, pulmonary function and the blinking rate of the eyes. The experimental measurements were completed with a medical survey focussed on parameters like quality of sleep, dermatological reactions, pain perception, mental pressure, quality of life and general well-being.

Materials and methods

The testing sites were chosen randomly, dependent on their availability. The 13 houses investigated included six solid wood constructions, six timber frame constructions and one concrete building, representing a non-wooden reference. Nine houses were equipped with mechanical ventilation systems, four were vented manually by window ventilation only. 11 testing sites had wooden flooring, the majority of which were coated with the use of natural oils. Table 6 shows the testing site conditions in detail.

Table 6. Overview of testing site conditions

site no.	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
solid wood	x	x		x		x			x				x	6
timber frame construction			x		x		x			x	x	x		6
concrete								x						1
ventilation system	x	x	x	x	NO	NO	x	NO	x	x	NO	x	x	9
wooden flooring	x		x	x	x	x	x	x	x	x		x	x	11
non wooden flooring		x									x			2

Table 7. Austrian orienting values for total VOCs in indoor air (BMLFUW, 2005), remarks by the German Committee on Indoor Guide Values (Ad-hoc Arbeitsgruppe der IRKA/GLMB, 2007)

Concentration [mg/m³]	Rating	Comments	Remarks by German Committee on Indoor Guide Values
< 0,25	low	achievable when using suitable materials	
0,25 – 0,5	average		
0,5 – 1	slightly elevated	VOC sources are likely, to be expected after construction work with solvent-free materials	
1 – 3	distinctly elevated	VOC sources present	inhabitation up to 12 months tolerable
> 3	strongly elevated	to be expected after construction work with solvent-based materials	3-10 mg/m³: inhabitation up to 1 month tolerable

Sample taking was always performed in the sleeping rooms of the houses. The first sampling took place at the construction site and served as a reference measurement for building product emissions. Subsequent samplings were carried out around the time of move-in and from then on at regular (monthly) intervals until a total 6 to 8 samplings had been conducted.

Sampling included the analysis of VOCs and formaldehyde, airborne microorganisms, particulate matter and the collection of medical data. In addition, medical questionnaires were filled out by the test persons.

All data was assessed with regard to indoor air quality. The quantitative assessment of the VOC concentrations detected referred to the guideline for the assessment of indoor air quality (BMLFUW 2005, see Table 7). A toxicological evaluation was included. Medical data and questionnaires were evaluated by experts in the field of environmental medicine.

Results

Indoor Air Quality

Figure 14 shows the development of the sum of all VOCs detected, also termed the TVOC1, in a comparison of the construction types investigated. The error bars represent the standard deviation of the underlying single values. Mostly, the emission curves reached their maximum around the date of moving-in, which shows the significant influence of both new flooring and furniture.

No significant difference was found between the solid wood and timber frame ($p = 0.225$) construction types. Compared to the concrete reference, the wooden constructions showed higher TVOC emissions at the construction sites and at the beginning of the utilization phase of the buildings. Emissions decreased significantly with time ($p = <0.001$) and about seven months after occupation the wooden constructions reached an emission level in the range of the concrete site.

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1 Definition TVOC: sum of all gas-chromatographically detected single-substances with a concentration exceeding 5 µg/m³, eluting within the retention-range of C_6 (n-hexane) and C_{16} (n-hexadecane) while using a non-polar column.

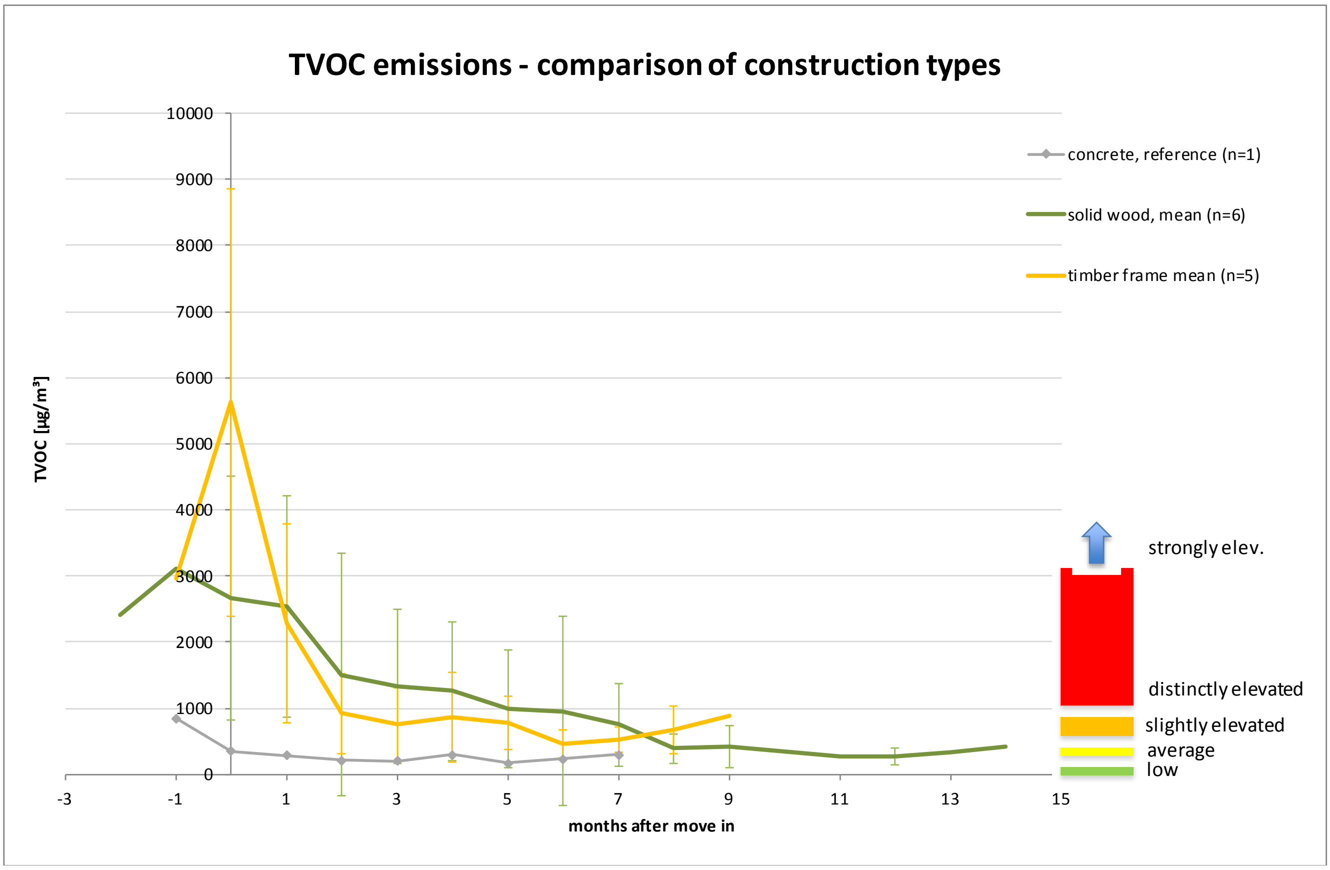


Figure 14. TVOC emissions – comparison of construction sites

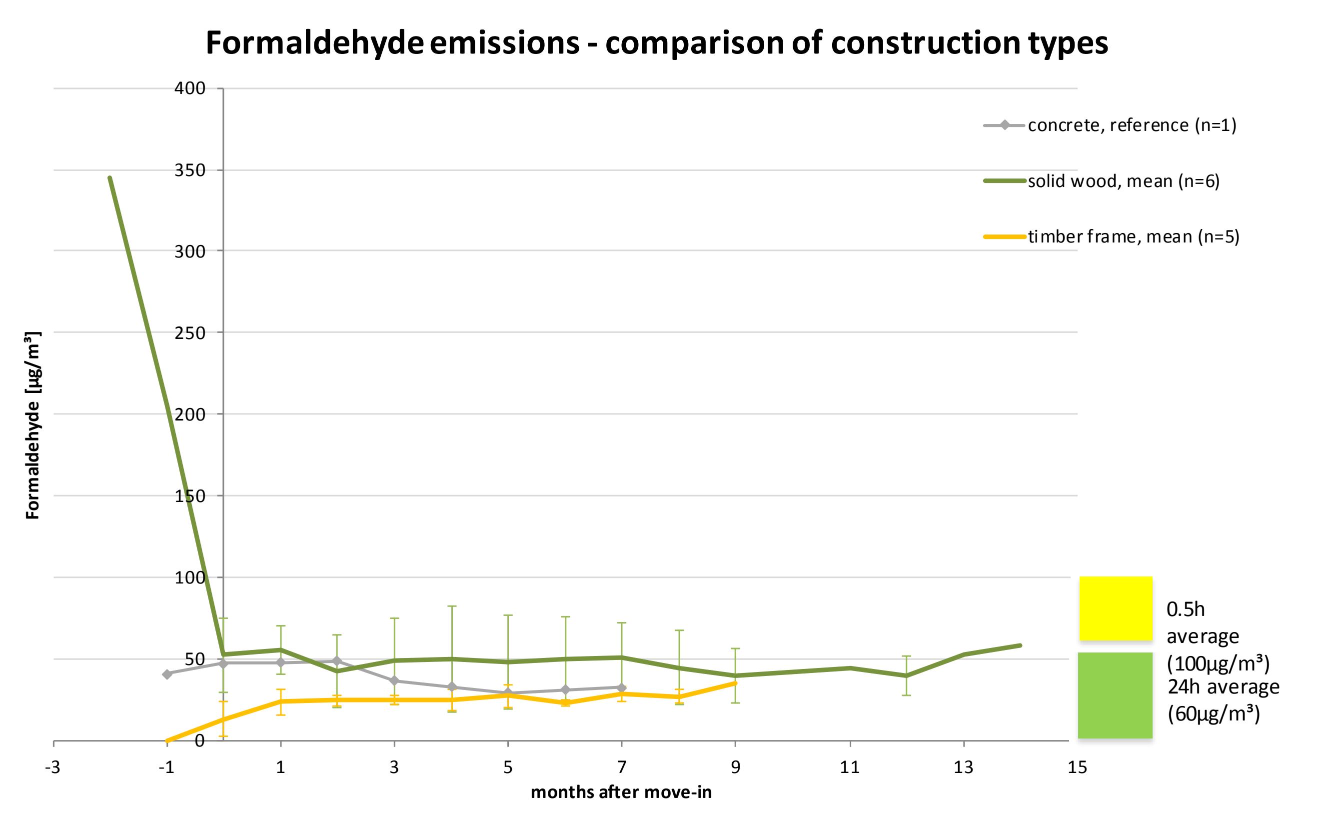


Figure 15. Formaldehyde emissions – comparison of construction sites

Figure 15 shows the development of formaldehyde emissions in the testing sites investigated. Comparing the solid wood and timber frame construction types, the formaldehyde emissions were found to be significantly higher in the solid wood houses (p= 0.022). When comparing the wooden construction types to the concrete site no obvious difference was found, meaning that formaldehyde emissions were within the same range, regardless the type of construction.

One solid wood site showed elevated formaldehyde release at the construction site, otherwise the formaldehyde emissions continuously remained at an approximately constant level, undercutting the 24h average value of the WHO quality guidelines for Europe (WHO, 2000).

Figure 16 compares the development of the TVOC (16a) and formaldehyde (16b) in testing sites equipped with controlled ventilation systems to the emission development in manually vented buildings. The figures clearly show that the use of controlled ventilation systems results in lower VOC concentrations and thus in higher indoor air quality.

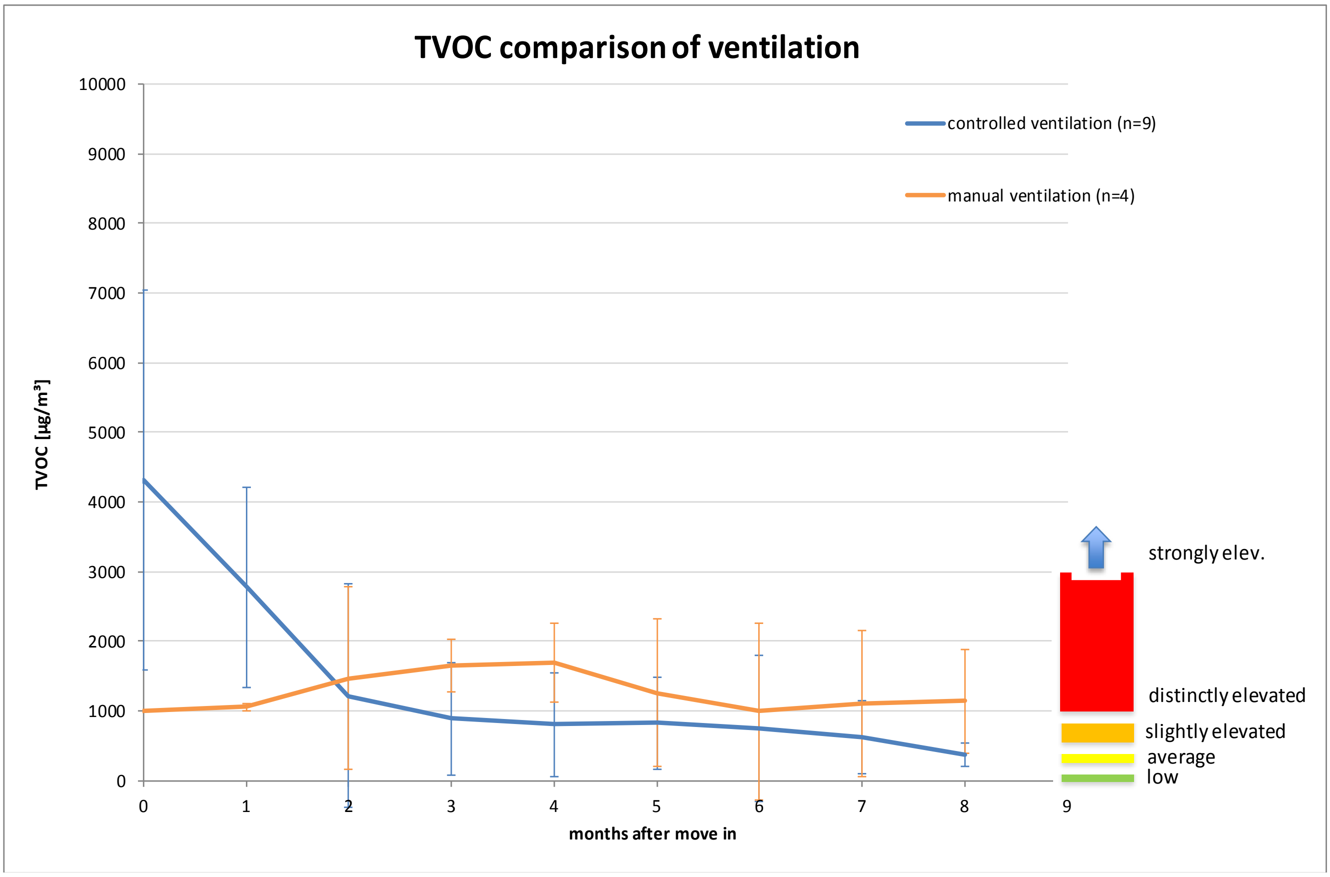
In a qualitative sense, the spectra of the emissions detected shifted significantly during the observation period. While initial emissions could be directly related to the construction products, flooring and new furniture, emissions at a later stage were harder to assign as they became more and more dependent on the behaviour of the occupants.

Analysis showed that there was no conspicuous presence of airborne microorganisms or particulate matter. Seasonal fluctuations of indoor climate were observed in all testing sites regardless of the ventilation type.

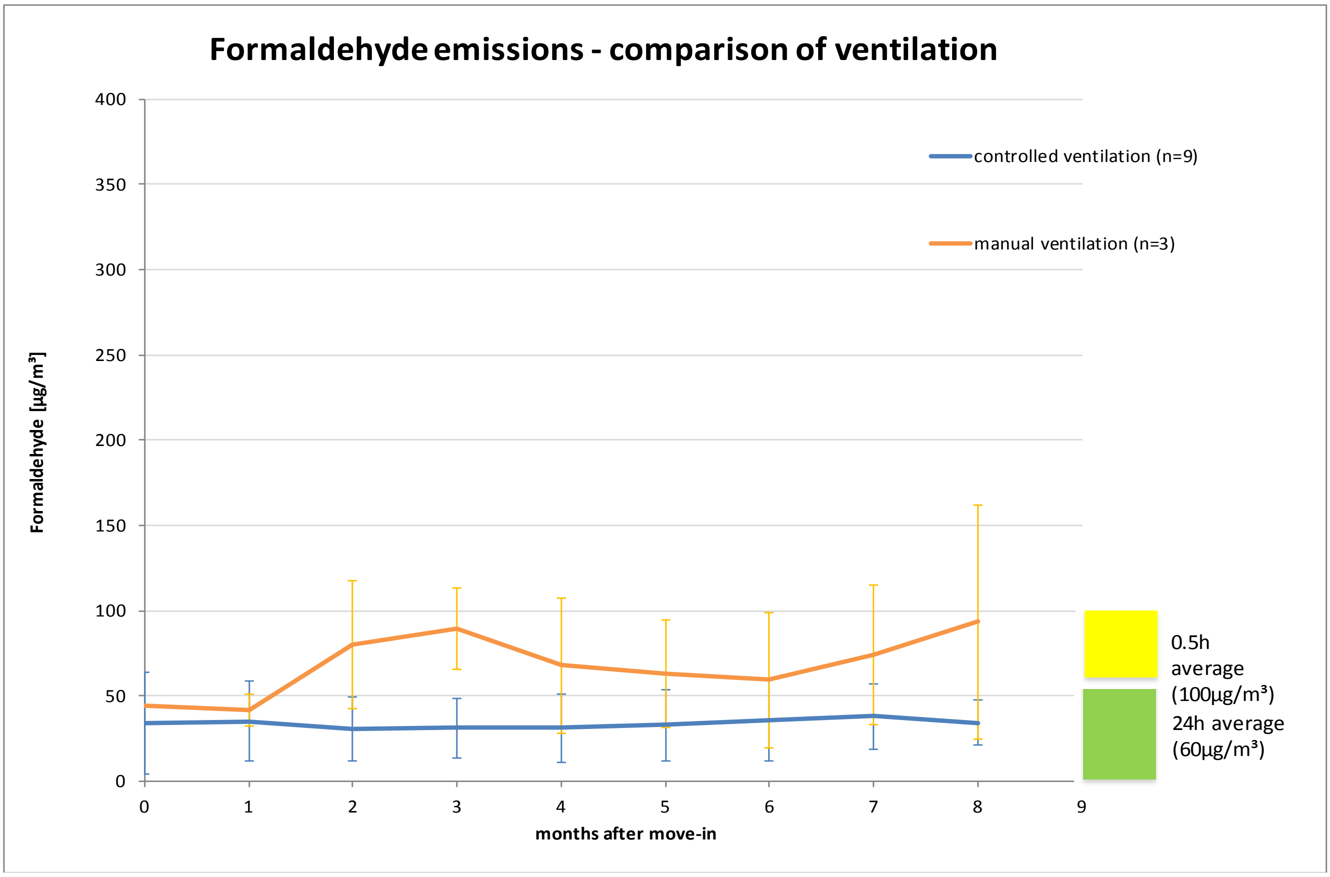
Seven houses showed good or very good indoor air quality, while in four houses indoor air quality was referred to as satisfactory. In two cases the toxicological assessment showed peculiarities, which are probably related to either specific building materials (particleboard) or user behaviour (smoking, air freshener). This resulted in poor air quality that should be counteracted by identifying the (temporary) sources and increasing ventilation.

Medical evaluation

The scope of the medical evaluation was to find a possible connection between health-related effects and wood-specific emissions. Therefore, the main focus was on irritant reactions regarding mucous membranes, in particular the eyes and the respiratory tract.



(a)



(b)

Figure 16. TVOC (a) and formaldehyde (b) emissions, mean values, comparison of controlled ventilation and manual venting

None of the test persons reported relevant symptoms in the questionnaires. Even at elevated VOC concentrations, as sometimes detected shortly after the occupants moved in (new flooring, new furniture), no physical complaints were recorded. Neither were there indications of acute or chronic respiratory symptoms nor negative effects on the quality of sleep.

The evaluation of the eye blinking rate showed no anomalies.

The health and well-being related self-assessment of the participants was generally at a very high level ("excellent", "outstanding", "very good") over the whole period of the investigation. The test persons were throughout very satisfied with their health and quality of life.

These subjective perceptions were confirmed by medical examinations, which had an orienting character only. The examinations that were conducted focussed on the respiratory (measurement of the pulmonary function) and the cardiovascular system (measurement of blood pressure and pulse) and gave no indications of physical impairment.

Summary and conclusions

VOC emissions in newly built and occupied timber houses were initially elevated regardless of construction and ventilation type. However, after a period of 6 to 8 months, emissions decreased mostly down to an average or slightly elevated level. Comparing the TVOC-development of the construction types investigated, no significant differences could be found between solid wood and timber frame, even though the solid wood constructions resulted in a distinctly higher release of terpenes. Formaldehyde emissions of the timber constructions were consistently in the range of those of the concrete construction.

The use of controlled ventilation systems resulted in lower VOC concentrations and thus in higher indoor air quality compared to window ventilation only.

The qualitative evaluation of the observed VOC-emissions showed that the impact of construction products, flooring and furniture is significant at the beginning of the observation period. At a later stage the emissions detected could be related mainly to the behaviour of the occupants.

From a toxicological point of view the major part of the houses investigated were unobtrusive and indoor air quality was considered as high or satisfactory. Two cases showed peculiarities resulting in poor indoor air quality. As remedial action, increased ventilation and / or removal of possible sources is recommended.

As an outcome of the medical evaluation the very positive health and well-being related self-assessment of the study participants can be emphasized. The test persons were very satisfied with their health and quality of life throughout. This perception was confirmed by the accompanying medical examinations of an orienting character, giving no indication of physical impairments in the field of the respiratory and cardiovascular system.

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Emission model

An algorithm for the prediction of long-term emissions based on previous simple models was developed and refined. It is based on a twofold exponential function with 5 constants, which not only considers emission processes and the absorption/desorption of VOC on surfaces in the room (which can serve as sinks), but can also include elimination by ventilation etc. The basal emission of the building (i.e. not disturbed by user behaviour or intermediate new sources) can be predicted by only four measurements at the beginning of the emission. This may be sufficient to predict the long-term emission behaviour of the materials for the lifetime of the building. However, further research is needed to confirm the general validity of these promising results.

Prediction of emissions

The underlying principle of the model is a system of compartments in the total emission situation (Figure. 17). The source is the material. The emission is determined by various material parameters like, density, porosity and chemical identity, as well as geometry factors like thickness and surfaces exposed to the air. Substances which have been emitted can also be absorbed by the material itself and by other surfaces in the room. So there are also sinks for the emissions. These sinks again can serve as sources, so after a certain time a steady state equilibrium establishes. However it is influenced by the elimination of the substance in the air (e.g. by chemical decay or ventilation).

One problem with the prediction of emissions is the emitting behaviour of the material. If the material is porous but has a very tight surface the diffusion in the material is fast, but the emission is slow. When the material is dense and the surface is open, then the diffusion in the material is slow, but the emission is fast. The course of air concentrations in both cases is different. Moreover the total amount in a material is constant for primary emissions and cannot be emitted indefinitely. The consequence is that depending on material parameters every emission has a maximum and then decreases (Figure. 18). The time of the maximum and the course of the curve can vary considerably. With high reservoirs of the substance in the material and slow emission, the maximum can become almost invisible and the air concentration seems to be constant.

Such processes can be described by differential equations (depicted in Figure. 17). The solution of the equation system is the room concentration at any time, which can be used for the prediction of long-term behaviour. The strategy in the current project was to develop and refine the model, to test its prediction with the first measurements and the compare the predictions with later measurements. It is clear, that unforeseen emissions (e.g. by user behaviour) cannot be described by any model. However, if emission behaviour is “normal” i.e. there are no disturbances, then a good model should be able to predict long-term behaviour of the emissions.

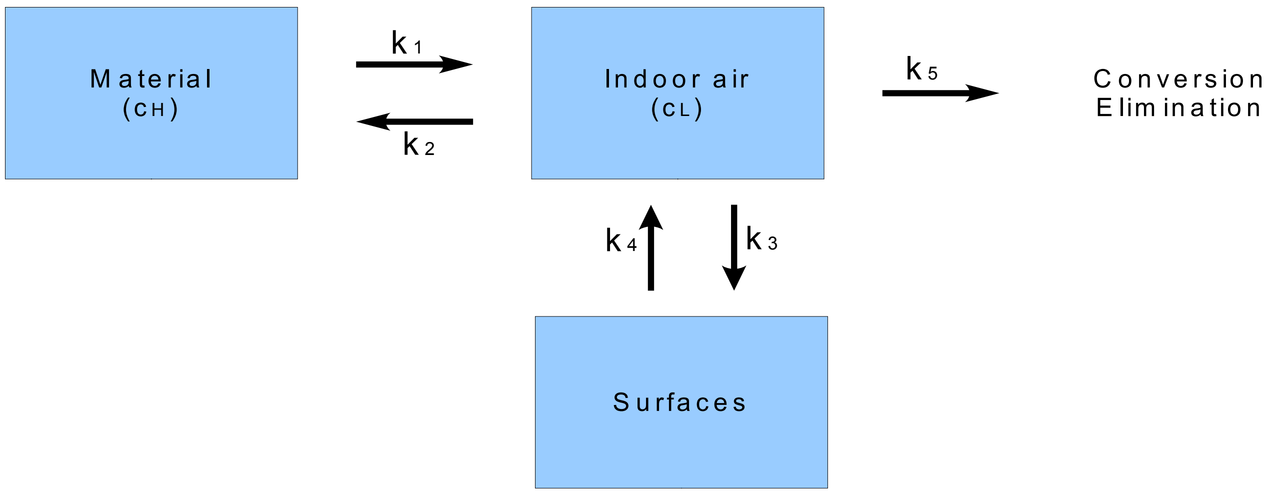

Figure 17. Principles of the model

The current model results in a twofold exponential function of the form:

$$Conc_{air}(t) = A + B*exp(C*t) + D*exp(E*t)$$

Theoretically the parameter A should be equal to zero but in reality, as described earlier, some materials can emit so slowly that their emission seem to be constant. Since in a whole building there could be more than one source of the same substance this parameter had to be included in the model. On the other hand for the emissions of single building materials the model works without parameter A.

With undisturbed emissions the current model can predict long-term behaviour with only the first four measurements, even if there is a local maximum in the emission curve (Figures. 19 and 20). However this model was tested for the first time in this project, with relatively few buildings. So further research is needed to evaluate the reliability of the model.

The model (red line) was used to calculate the long-term behaviour from the first four measurements (first four blue dots). The remaining three measurements almost lie on the predicted curve.

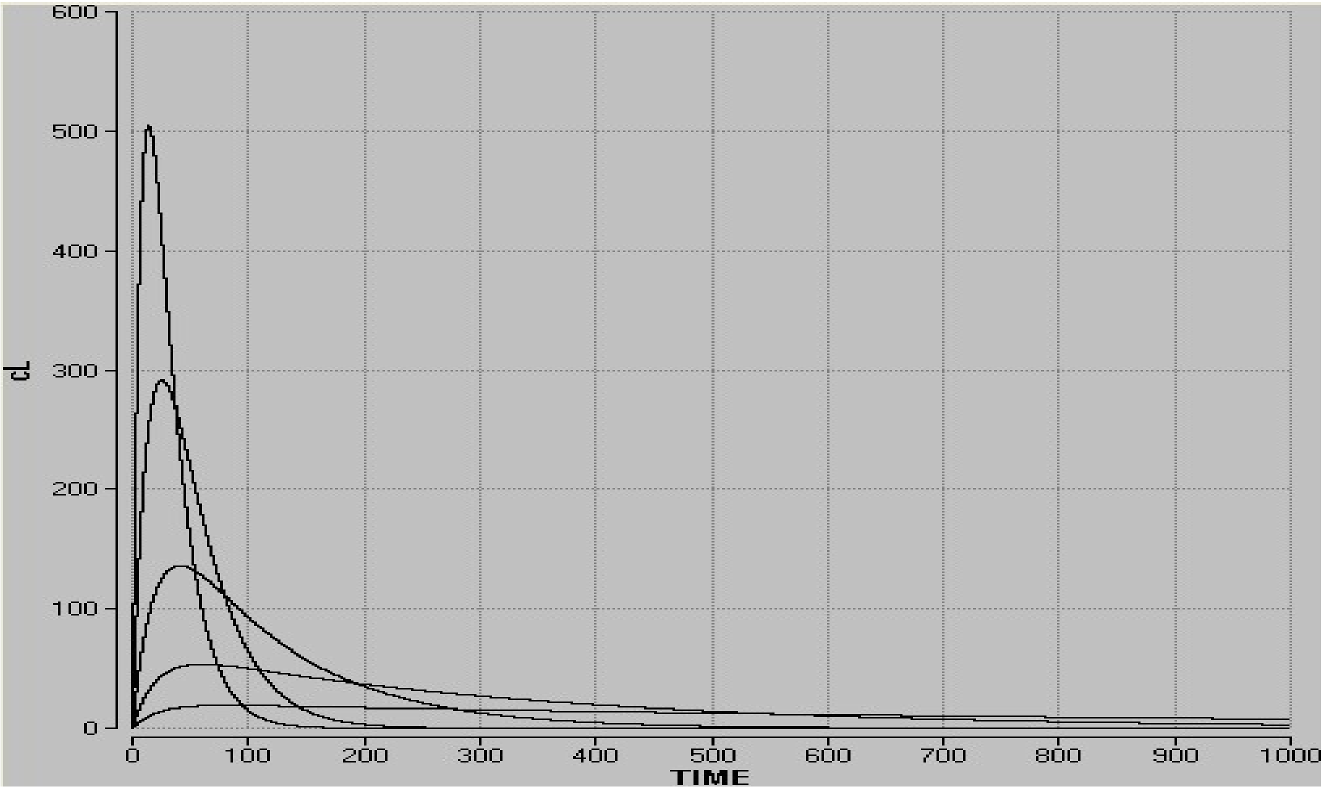

Figure 18. Material emissions behaviour

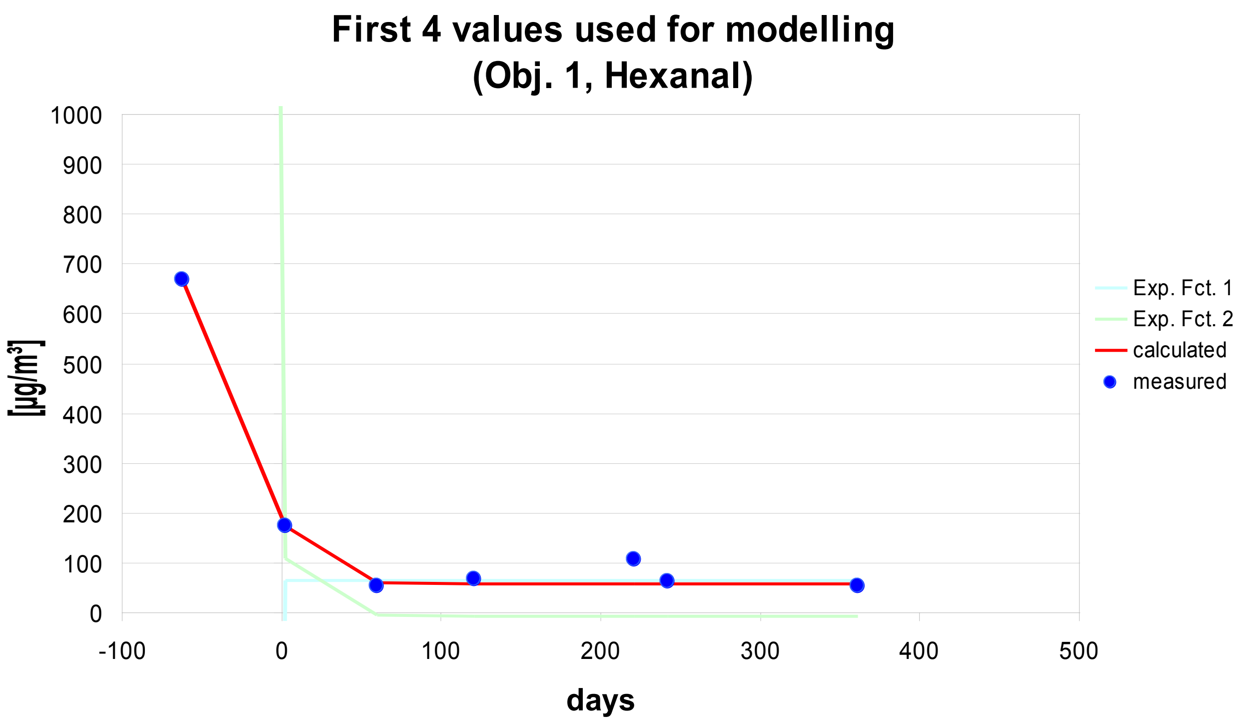

Figure 19. Modelled and experimental hexanal values

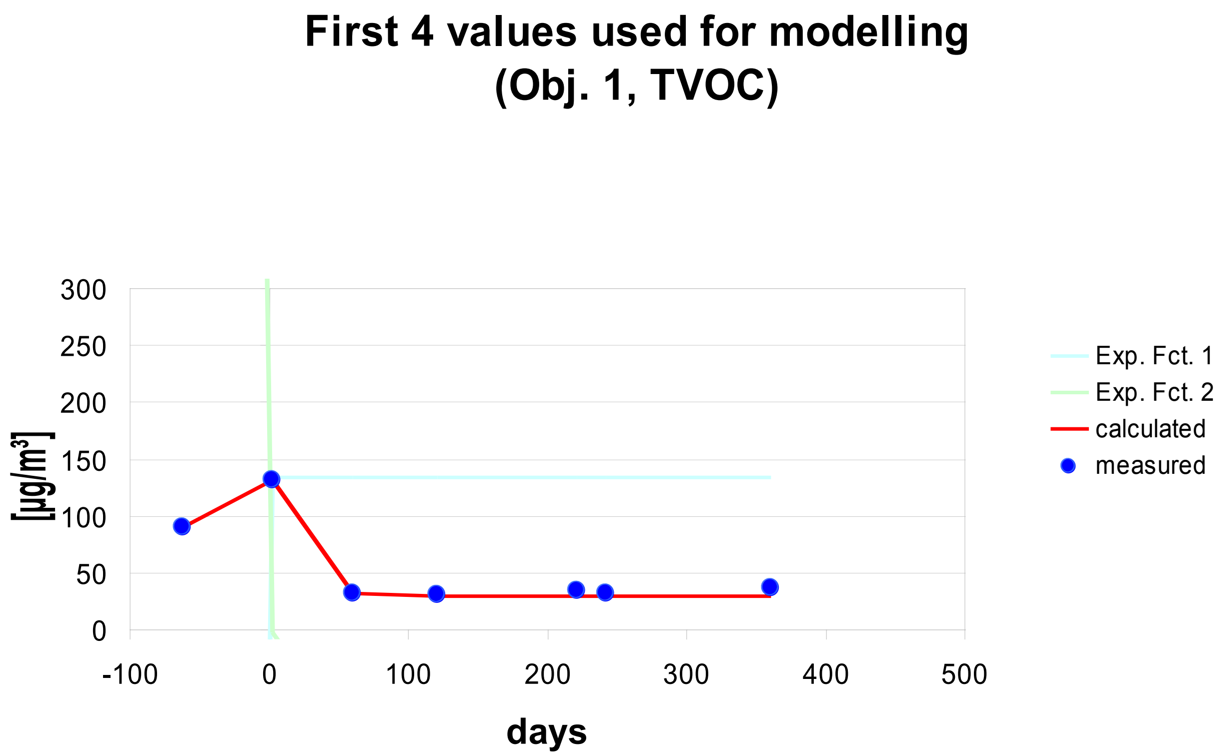

Figure 20. Modelled and experimental TVOC values

The same procedure was used as with Figure. 19. Even if there is a local maximum and the total emissions are considered, the model can predict the real emission behaviour.

Human Perception and Psychological Aspects to Interior Wood Use

Four studies on end-user perceptions and the psychological effects of wood on human well-being indoors were finalized within the Wood2New project. Work Package 4 undertook a focus group study on user perceptions of wood in four countries and an experiment on patients´ satisfaction at St. Olavs Hospital in Trondheim, Norway. Work Package 5 surveyed the end-user perceptions of four generic office spaces and occupant opinions on the use of wood in four day care centers and one care home for the elderly. Work Package 4 was led by Norsk Treteknisk Institutt, and Work Package 5 by Aalto University. The main results of each study are presented below.

User perception of wood as a building material – a focus group study

Focus groups were conducted in Austria, France, Finland, Norway and Sweden in order to understand how people, both professionals and laymen, perceive the connection between building materials and well-being in indoor environments. In the focus groups the participants discussed their opinions and experiences related to seven main topics: materials, naturalness, natural building materials, well-being in indoor environments, wood, washability and ethics and the environment. There is a correlation between the participants' opinions about indoor materials, and physical properties of wood: density / hardness, year-ring and knot patterns, thermal conductivity, moisture content, chemical composition, color and origin. The results of the discussion suggests that some properties are closely linked to the perception of wood as a natural building material. This means that by changing or influencing the properties, or by choosing the right real quality, consumer preference for wood products used in the indoor environment can be affected. The results are very relevant for product development and the marketing of wood products. The industrial partners in the project currently use this knowledge in their marketing.

Wood use in hospital buildings

An experiment was conducted at St. Olavs Hospital in Trondheim, Norway, to investigate the association between patients' satisfaction and the presence of natural elements in patient rooms. Patients were randomly assigned rooms when arriving at an orthopedic hospital ward. There were rooms with three different interiors: a *Wood room* with exposed wood surfaces, a *Landscape room* with a large landscape photograph and an *Art room* with a work of art. All patient rooms on the ward were for single patients. Patients filled out questionnaires during their stay, and a total of 210 patients participated in the study. The majority of patients had undergone surgery for knee or hip replacement. The results show that patients' pain, and to some extent stress, decreases faster in the wood room than for the other types of rooms. The results indicate that there is a connection between architecture, materials and health. There is indicative evidence that wood used in hospital rooms can result in improving healing processes and health outcomes, such as shorter duration of hospital stays.

Wood use in office spaces

The survey included three office spaces, one of which had a wood covered wall. The spaces were carefully documented and interior comfort factors measured separately at each visit in every space. Human perceptions were surveyed with a quick questionnaire identifying the initial impressions of the participants. Various spatial qualities were evaluated on a five-level Likert-type scale. Survey participants were selected randomly and the distribution between male and female respondents was fairly equal. They represented students of architecture and engineering, researchers, professors and other professionals.

The results did not show any big differences in perceptions between the spaces even if the amount of visible wooden surfaces varied from almost none to 17% of the total wall area. However, the presence of wood on wall, floors and ceilings got the best average score in the only space with a wood panelled wall. The room did not excel in any of the other qualitative aspects. The largest space, regardless of furniture which was partly changed halfway through the study period, was the one perceived as most comfortable, calm, clean, inspiring, colourful, fun and pleasant. The results do support earlier indications of the effect of a natural view from windows. A park view over a longer distance was perceived the best, as was the orientation and amount of windows in the same space.

The results of this survey indicate that furniture has the biggest effect on the perception of the space as such, when general comfort factors are otherwise satisfactory and equal.

Wood use in care environments

This study focused on human perception and experiences of wood in care buildings. Five buildings were included, four of which are day care facilities and one represents care homes for elderly. One building is a log construction whereas the others are timber-framed. Four out of five cases have extensive amounts of exposed wood indoors and all have timber-based cladding on the outside.

The buildings and user experiences were evaluated using qualitative study methods including questionnaires, interviews and observations on site. Stakeholders and end-users were approached separately. Young children or elderly residents using the premises were excluded from the user study. The young age of the children or cognitive disability of the elderly would have required other study methods.

The stakeholder survey revealed that even though the architect makes the final decisions and plans, different stakeholders of the design and building process affect the choice of materials. The results also indicate that the most highly valued outcomes as built were not primary criteria in the planning phase. For example, acoustics and the indoor air quality of the final building exceeded the expectations of the professionals. This is significant as the number of end-users in one of the buildings was 30% higher than the planned capacity.

The results of the end-user survey highlight the importance of context. In addition to safety, the quality of space, lighting, acoustics, materials and indoor air are important for the vulnerable user groups of care environments. For example, the appearance and level of lighting was slightly less appreciated in the care home for elderly than on average. Because of age related changes in vision, the level of luminosity should be high.

Interior materials influence both the visual and sensory environment. These aspects were generally appreciated by the users of the presented cases. The use of wood was generally perceived positively; ninety percent of the end-users would recommend wood material for interior spaces in care environments. User experiences of the log building were slightly better than on average concerning all features, except the indoor air temperature. It was also perceived as the most logical.

Design with Wood

The results of the Wood2New project confirm the beneficial effects of wood on interior air quality, moisture balance and its hygrothermal capacity. The haptic properties of wood are accepted well. The results of the research additionally support earlier findings on the use of wood and natural elements in interiors, their relationship with positive human perception and reduced stress. New findings include unexpected outcomes on the design and choices of materials such as the perceived positive effects on acoustics and indoor air quality. Wooden surfaces also seem to give the user an impression of being more ecological compared to other materials and end-users would recommend wood material for interior spaces in care environments.

When designing for energy efficiency the results suggest that:

- The view from the windows affects the perception of the space
- Wooden surfaces in spaces are perceived positively
- Solid wood and untreated surfaces are perceived as most natural
- For personal comfort surfaces closest to the user, such as furniture, are important
- Solid wood structures are perceived as ecological and environmentally friendly

In care environments wooden surfaces:

- Are perceived positively
- Add to good acoustics and indoor air quality
- Are warm to touch
- Have a calming and natural look

However, details and joints should be designed carefully as to avoid the accumulation of dust and drafts.

Design is recognized as a key discipline to bring ideas to the market. Demonstrations and experiments on designing with wood, especially in a demanding context like bathrooms, were realized within Work Package 5. The results are presented in a book *Functional Wood* published by Aalto University in 2016. In addition to current research on human perceptions and the functional capacities of wood, this publication demonstrates the potential of wood in various applications. The

Figure 21. A Wooden Shower by Eve Zorawska

designs are the results of three design courses, implemented during 2015 and 2016 at Aalto University in Finland. The Masters' student courses included two *Wood Studios* at Aalto University's School of Arts, Design and Architecture and the *Integrated Interior Wooden Surfaces* course at the School of Chemical Technology at Aalto University. The students that participated in these courses have backgrounds in architecture, design and forest products technology.

Architects have a role in designing buildings that promote the well-being of users, are efficient in use and energy consumption. Architects also recognize the importance of qualitative aspects. However, to support design-for-all, well-being factors should be monitored. One option is the evolution from environmental assessment towards evaluating building resilience. The public procurement process could also be developed to increase end-user involvement in the planning phase. An open and credible user evaluation can lead to innovations in the building sector.

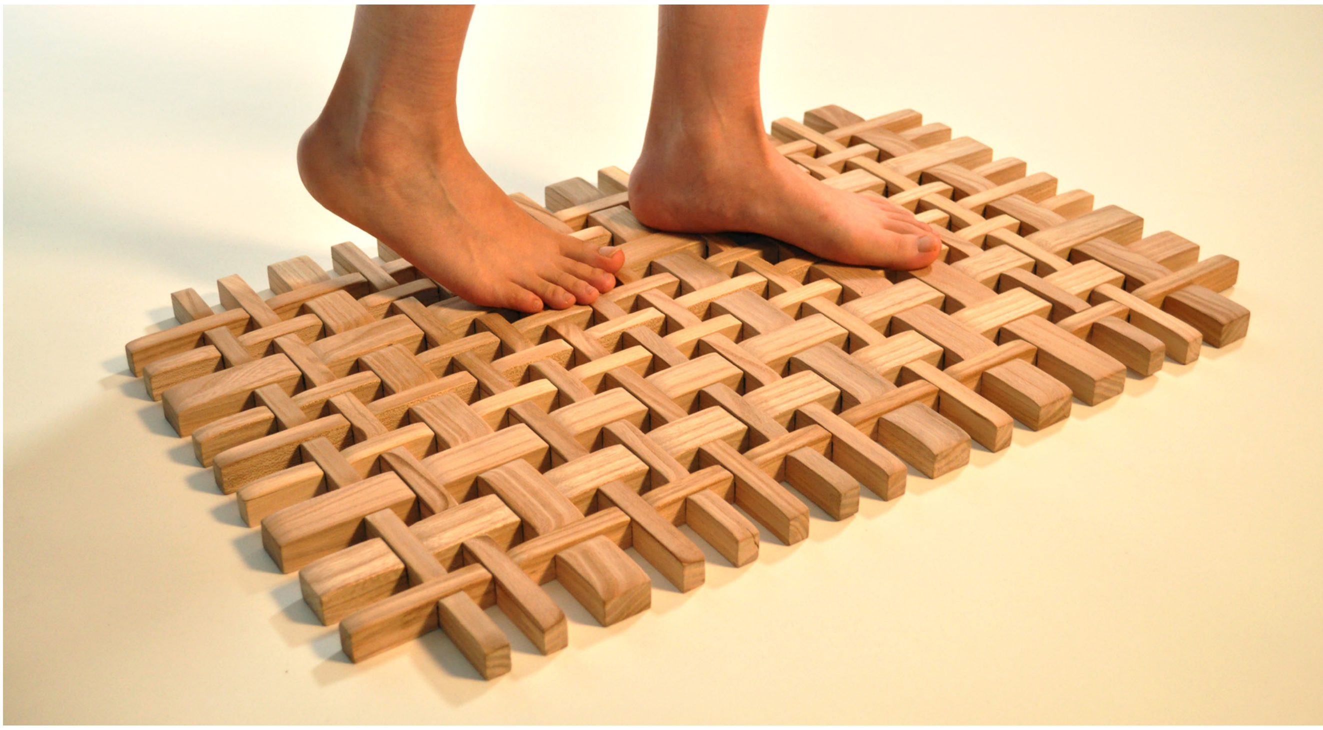

Figure 22. Kumiki Mat by Sei Yoshikawa

Commercialisation of the results

Environmental and health aspects of building materials are growing in interest although from a low level. This is especially the case when discussing key success factors in different market segments or unique selling points of firms' competitive advantage. The aim of Work Package 6 – commercialisation and business modelling – was to develop *a basis for market access of wood-based interior products and systems for refurbishment, building retrofits and new build*. The purpose then, was to present and discuss market dynamics and features of geographic markets of the segments interior panelling and flooring. Important factors included the composition of the supply chain and the role and interaction of actors. Furthermore, the work discussed the development of business models combining sustainable development values with competitive, end user oriented business concepts. The Work Package was led by Linköping University.

For the first tasks, the following research questions were addressed:

- Which market segments in the different countries are suitable for marketing of wooden interior products with a health and an environmental aspect?
- What does the value chain look like - who are the actors?
- What are the key success factors
  - In the value chain?
  - For the different actors in the value chain?

Based on supply chain mapping and the power allocation between the industry's different actors according to Porter's five forces paradigm the following countries were included: Sweden, Norway, Finland, Germany, Austria, the United Kingdom and France. Data was collected through interviews and questionnaires with people in branch organisations as well as dominant firms and trade organisations.

The results indicate that there are differences between the countries in terms of material preferences. In the Nordic countries, wood is the main material used for flooring while materials like laminate, tile and vinyl are used to a greater extent in the UK, France, Germany and Austria. The environmental aspects are also more important for the end customers in the Nordic countries. There is a general trend that the market for builders' merchants and do-it-yourself (DIY) retailers are consolidating at the moment. The larger actors acquire the smaller ones, which adjusts the allocation of power with the manufacturer and the type of products being sold in the stores.

Also, it is more important to convince the end customer in the Nordic countries of wood's

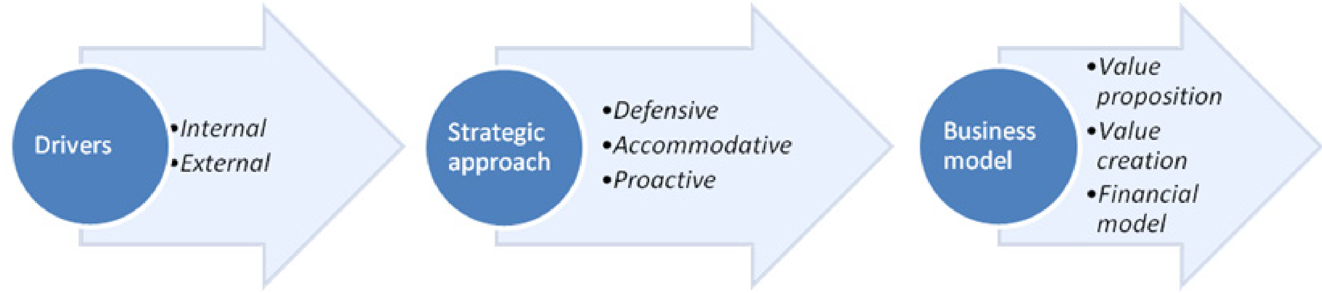

Figure 23. Interaction between drivers, strategic actions and resulting business model activities

superior health and environmental aspects. In the other countries, where the use of wood flooring is low, the challenge is to promote the qualities of wood in order to increase the market shares.

The conclusion is that manufacturers of interior wood products and suppliers targeting multinational markets need to gain a good knowledge of each market and to decide upon appropriate strategies, otherwise it is easy to develop strategies not suitable for any market. Specifically, environmental features should be used but differently in different markets.

How the development of sustainable business models could be achieved was the aim of the third task in the work package. Based on a case study methodology with a broad description of activities and processes in a company, and a deductive process of how to link two theoretical concepts – business modelling and sustainability – an example of how sustainable business models could be created was presented.

The model is based on a framework for how business models can be evaluated based on a strategic approach and the key drivers that affect sustainability integration in the business. This logical model consists of a sequence from drivers, to a strategic approach to the business model design. Companies' ability to sense and recognize internal and external drivers, determines their strategic approach to sustainability, which can be defensive, accommodative or proactive. The strategic focus will then decide how the three key dimensions of the business model; value proposition, value creation and the financial model is designed. By utilizing this framework, companies can identify what is driving the integration of sustainability in the business today, how this influences the strategic approach and how these two elements affect the company's architecture and logic to create, deliver and capture economic, social and environmental value; which is the business model.

In conclusion, the concepts of sustainability and business model can be integrated to achieve three-dimensional (economic, environmental and social) value creation and how the value creation is linked to internal and external drivers together with the strategic approach to sustainability. Based on this single case study, additional key findings are that investments in sustainability (trade mark, internal processes, suppliers and customer relations) require long-term ownership and leadership. A key factor in achieving the shift is that of a sustainability champion(s). This position can build up the company's ability to sense external drivers towards sustainability and implement them internally, and thus be a key factor in corporate sustainability initiatives.

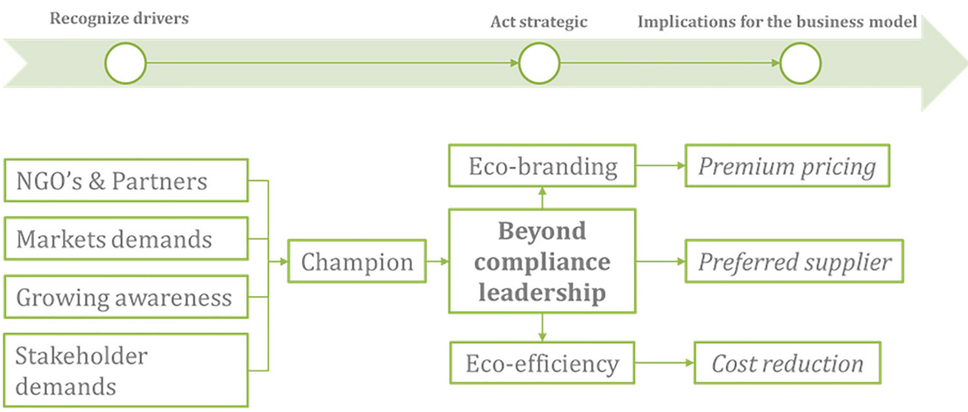

Figure 24. Example of creating a sustainable business model

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