World Conference on Timber Engineering Oslo 2023

CROSS-LAMINATED WOOD PANELS IN A PATIENT ROOM AND STUDIES OF INTERIOR ENVIRONMENT

Bror Sundkvist [1], Olena Myronycheva [1], Sarka Langer[2], Ingrid Liljelind[3], , Bo Glas[3], Tomas Nord[4], Björn Nordin[5]

ABSTRACT: Studies on the effect from biobased materials and products on humans have indicated positive effects. This has earlier been shown in studies for e.g. hospitals, where indications of lower stress and pain in patients with wood as part of interior solutions.

This paper describes the first step of a larger study that investigates the interior environment and the response of patients. The study presented here measured RH, temperature, emissions of volatile organic compounds (VOC) and microbial activities in two rooms at a hospital in Skellefteå, Orthopaedic ward. One room had a cross-laminated wood panel covering 42% of walls, window reveal and doors, and the other a control room with standard coverings.

Results indicated only a small difference between the rooms in terms of temperature and RH. VOC emissions varied in both rooms but all concentrations were lower or much lower than threshold values for interior air quality standard limits. Biological contamination of the surfaces and from air sampling was also performed.

Conclusions of this experimental study shows that from a regulatory perspective it is possible and safe to use wood as interior product.

KEYWORDS: wood, hospital environment, volatile organic compounds, ozone, microbial populations

1 INTRODUCTION

Studies on the effect of biobased materials and products on humans have indicated positive effects. What properties of wood as a material give these positive results? Do they come from what [1] showed as being natural (less strong medication to patients with a forest view compared with a "built" view), or what [2] measured as indications of lower stress and pain in patients with wood as part of interior solutions? Or is it from the anisotropic and hygroscopic properties affecting the interior air quality [3]. Hospital care is currently often performed in very sterile indoor environments with smooth painted walls and no components with natural materials. Applying a biophilic approach in places of recovery and recuperation has been considered as a means of improving recovery and reducing durations of stay. This was illustrated recently in a paper [4] that considered the contrasting effects of Sick Building Syndrome (SBS) and Building Related Illnesses (BRI) and a high Indoor Environmental Quality (IEQ). The use of wooden materials has been related to positive effects in terms of aesthetics, smell, air humidity and well-being [5].
The aim of this study is to investigate indoor air quality in two patient rooms in Skellefteå Hospital. One room (Room 4) is an ordinary patient room with painted concrete walls, while wooden wall panels have been installed in the other room (Room 5).

2 MATERIALS AND METHODS

2.1 SUB-CHAPTER TITLE

The measurements of indoor climate parameters temperature, relative humidity (RH) and concentration of carbon dioxide (CO_2) as well as concentrations of air pollutants nitrogen dioxide (NO_2), ozone (O_3), volatile organic compounds (VOCs) and aldehydes have been performed in the two rooms during one year. NO_2 and ozone were also measured in the outdoor air, and outdoor temperature and relative humidity were retrieved from SMHI:s measurement station at Skellefteå airport. Temperature, relative humidity and concentration of CO_2

[1] Bror Sundqvist, Olena Myronycheva, LTU Lulea University of Technology, Sweden, bror.sundqvist@ltu.se, olena.myronycheva@ltu.se
[2] Sarka Langer, IVL Swedish Environmental Research Institute, Sweden, sarka.langer@ivl.se
[3] Ingrid Liljelind, Bo Glas, Umeå University, Sweden, ingrid.liljelind@umu.se bo.glas@umu.se
[4] Tomas Nord, Research Institutes of Sweden (RISE), Sweden, tomas.nord@ri.se
[5] Björn Nordin, Swedish Wood, Sweden, bjorn.nordin@svenskttra.se

https://doi.org/10.52202/069179-0145

were measured with Wöhler CDL 210 CO_2-logger with a time resolution of 2 minutes. The chemical compounds were measured by passive/ diffusive samplers.

For measurements of NO_2 and ozone concentrations, IVL passive/ diffusive samplers were used [6]. These compounds were analysed by wet chemical techniques using a spectrophotometric method (NO_2) and ion chromatography (O_3). The analytical procedures are accredited by the Swedish accreditation agency SWEDAC.

Volatile organic compounds were passively sampled on Tenax TA (Perkin-Elmer) adsorbent tubes and analysed in compliance with the standard ISO 16017-2 [7]. The Tenax tubes were thermally desorbed (Markes International, Unity 1 and Ultra) and analysed by gas chromatography/ mass spectrometry (GC/MS) in electron impact ionization mode. The sum of individual VOCs in a sample (TVOC, Total Volatile Organic Compounds) was quantified in toluene equivalent, *i.e.* using the uptake rate and the response factor of toluene.

Formaldehyde was measured using passive samplers – DSD-DNPH Aldehyde Diffusive sampling Device (Supelco, Bellefonte,PA). The sampling period and the analytical technique (solvent extraction and high-performance liquid chromatography) followed the ISO 16000-4 standard [8].

The estimation of the water amount in dry air was done by using Mollier-Diagram [9].

Enumeration of the moulds in indoor and outdoor air was done by SS-ISO 16000-17:2008 [10]. The data represents the number of colony-forming units (CFU) of fungi or bacteria per sample. The malt-extract agar, potato-dextrose agar, dichloran 18% glycerol agar (DG18 agar) and nutrient broth agar were used as culture media. The plates were checked regularly for up to 7 days. The temperatures 25°C and 37° were used for the incubation. Calculations of the results were based on the colony count of the agar where the best growth occurs. The results are presented in colony-forming units per cubic meter.
The sampling from the walls and other surfaces was done according to ISO 16000-21:2013(E) [11] by sterile cotton swabs cultured on malt extract agar nutrient media. Incubation was done at 25°C.
The Adenosine Tri-Phosphate ATP bioluminescence was used to rapidly evaluate material surface cleanness [12]. The method is based on the correlation of biological residuals with the light generated during the reaction with luciferin/luciferase enzyme and measured by a luminometer 3M Clean-Trace™ Luminometer, St. Paul Minnesota, USA. The general acceptance for the cleanness is below 20 RLUs or Relative Light Units.
The sampling locations for swabbing and ATP measurement were:
- left and right dry walls of the left window
- left and right dry walls of the right window
- left and right walls of the room ca. 1.5 m from the floor
- left and right sides of the ceiling about 1 m from the ventilation channel
- nearby the ventilation channel
- doors of the patient lockers

The sampling periods are summarized in Table 1.

Table 1: *Sampling periods*

Week	Month, year	Start	Stop
1	October 2021	2021-10-04	2021-10-12
10	December 2021	2021-12-06	2021-12-13
19	February 2022	2022-02-07	2022-02-14
27	April 2022	2022-04-04	2022-04-11
35	May 2022	2022-05-31	2022-06-07
44	August 2022	2022-08-01	2022-08-08
53	October 2022	2022-10-02	2022-10-10

3 RESULTS AND DISCUSSION

3.1 INDOOR CLIMATE PARAMETERS

The values of temperature (Figure 1) were within the range of 20–24 ◦C defined by the EN 16798 standard [13] and by the Swedish regulations [14,15] during the whole period of measurements for one year. The values of relative humidity (Figure 2) were within the range defined by the EN 16798–1:2019 standard (25–60% RH) only during the non-heating season. During the heating season, the RH was <20%.

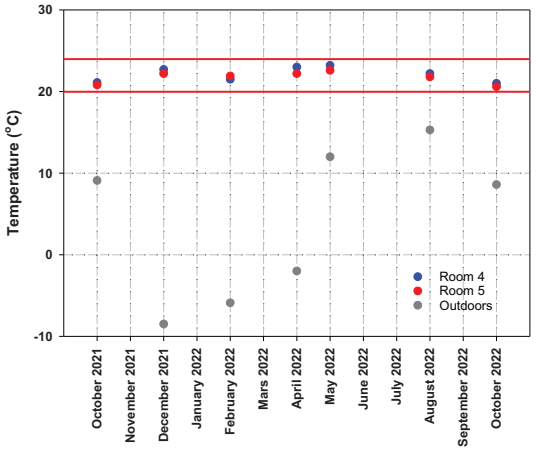

Figure 1*. The temperature in the studied rooms and in outdoor air. The full red lines indicate the range of comfortable indoor air temperature stated in standards.*

https://doi.org/10.52202/069179-0145

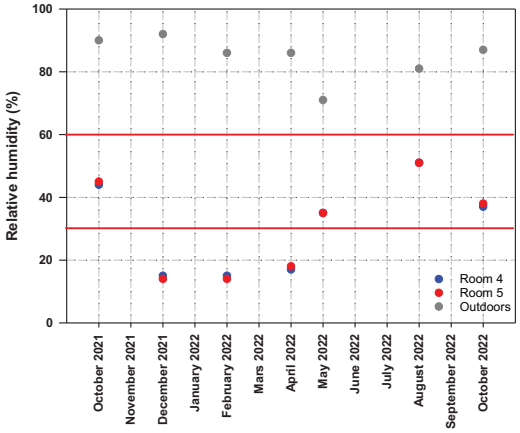

Figure 2. *Relative humidity in the studied rooms and in outdoor air. The red line indicates the range of comfortable indoor air relative humidity stated in standard.*

3.2 INDOOR AIR POLLUTANTS

The TVOC concentrations (Figure 3) were below the recommended long-term guideline value of 300 µg/m^3 in both rooms [16]. The TVOC concentrations did not differed significantly between the two rooms.

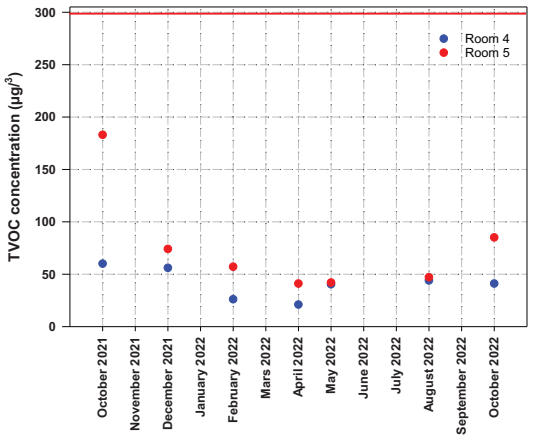

Figure 3. *Concentration of TVOC in the studied rooms. The red line indicates the recommended guideline value for TVOC of 300 µg/m^3.*

3.3 OUTDOOR/INDOOR WATER CONTENT IN DRY AIR

According to Swedish Public Health Agency's general advice on moisture and microorganisms "that the average value of the humidity should not exceeds 7 g water/kg dry air for a longer period during the heating season, which corresponds to approx. 45% relative humidity at 21° C" in a public building [17]. Such conditions might be favorable for microbial growth [19].

The evaluation of the climate was done to find the risk dates. The graph is presented in Figure 4.

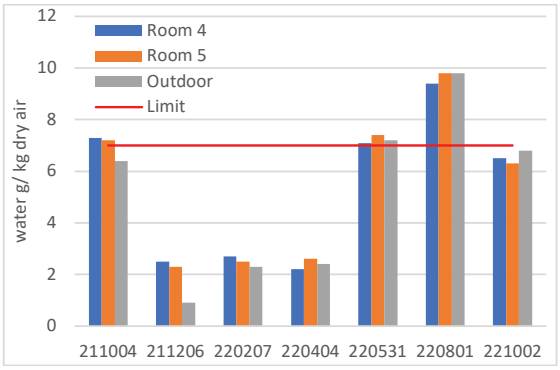

Figure 4. *The amount of water in g per 1 kg of dry air. The red line is a limit and parameters above are favourable for the microbial growth.*

3.4 INDOOR AIR MICROORGANISMS

The threshold limit values for biological contaminants such as microorganisms are difficult to define, and particularly for mould fungi the World Health Organisation (WHO) did not provide such values in their Indoor air quality guideline [18]. The threshold amount > 1000 CFU/m^3 in the whole mould is proposed as considered for dwellings at risk for allergic patients [19]. The total amount of microorganisms in the air of the sampling areas grown at 25°C and 37°C is presented in Figure 5 below.

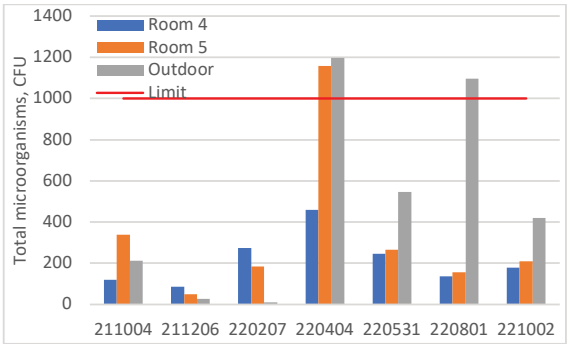

Figure 5. *Total amount of microorganisms CFU/m^3 grown at the temperature 25°C and 37°C. The red line shows the threshold value.*

The dominating effect of indoor/outdoor fungi is proposed for the determination of dominating effect of the microbial concentrations for the data interpretation [20]. The indoor: outdoor (I/O) concentration ratios related to the presence of indoor sources of microorganisms. I/O ratios are typically less than 1.0. However, if there is a strong microbial source indoors exists the ratio can exceed 1.0. Table 2 represents the ration of total microorganisms in the rooms for the sampling time.

https://doi.org/10.52202/069179-0145

Table 2. *The I/O concentration ratio for sampled time and locations in air samples of the microorganisms*

Day	I/O	
	Room 4	Room 5
211004	0.6	1.6
211206	3.3	1.9
220207	27.3	18.3
220404	0.4	0.9
220531	0.5	0.5
220801	0.1	0.1
221002	0.4	0.5

3.5 MICROBIOLOGICAL ASSESSMENT OF MATERIAL SURFACE

The ATP bioluminescence is applied essentially for hygiene status of the surfaces. It is an effective system to verify cleaning of surfaces from biological residues and microorganisms. The value below 20 RLU is considered moderate clean, when below 5 it is efficiently clean. Since the hospital environment is quite full of biological contaminations the value showed that surfaces are unclean. The distribution of the contaminated areas in the room showed in Figure 6.

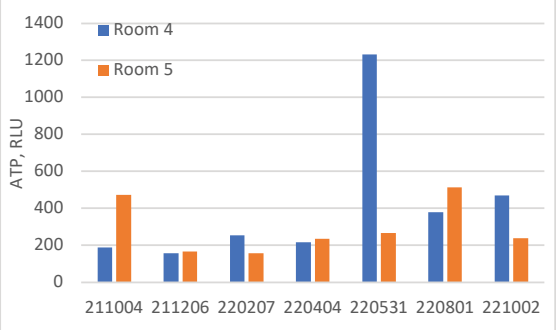

Figure 6. *The average value of ATP per room in RLU.*

The total amounts of the colony-forming units for fungal and bacterial microbial species are presented in Figure 7 and the number of fungi was much less than the amount of bacterial species on material surfaces.

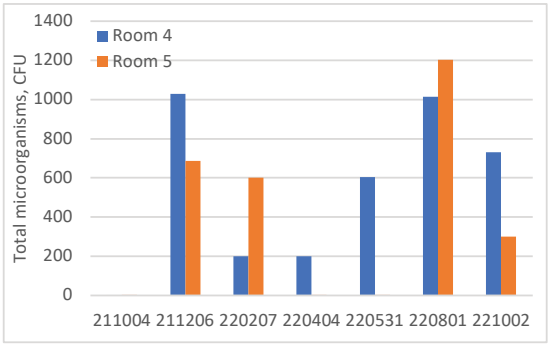

Figure 7. *Total amount of microorganisms CFU isolated from the material surface.*

4 CONCLUSIONS

The temperature was within the recommended comfort limits. The relative humidity was also within the recommended comfort limits with exception for the heating season (low RH) when the outdoor temperature was low.

The concentrations of all the TVOCs were low and below recommended guideline values and quite similar in both rooms.

The microbial contamination was low regarding generally suggested limits but influenced by indoor microbial source during heating season. The material surface was subjected to microbial contamination but mainly by bacterial isolates in both rooms.

From both the indoor climate and microbiological measurements, the values are within or well below limits for what standard regulations require for an acceptable indoor climate. Moreover, there was no or little difference between the rooms, this shows that it's possible to include biophilic design also in hospital environments.

These findings are a part of an ongoing study, and more results will be published, that involves clinical trials on patients and a survey for the staff of their perception of the rooms investigated. For the whole study at the hospital, we hope to gain new results and findings that clarifies the relation between indoor environments and human well-being.

ACKNOWLEDGEMENT

The research for this article was funded by Swedish Wood and EU regional funds. We would like to thank the persons involved from Skellefteå Hospital for their effort, support, and patience during difficult pandemic situations.

REFERENCES

[1] Ulrich R (1984) View through a window may influence recovery from surgery. Science 224(4647):420–421

https://doi.org/10.52202/069179-0145

[2] Nyrud, A.Q., Bysheim, K., Bringslimark, T. Forthcoming. Do elements of nature have a healing effect? The impact of wooden materials and landscape pictures in patient rooms. Arkitektur N.

[3] Vahtikari K, Noponen T, Hughes M (2016). The effect of wood anatomy and coatings on the moisture buffering performance of wooden surfaces. In: Eberhardsteiner J, Winter W, Fadai A, Pöll M 2016, World Conference on Timber Engineering (WCTE 2016) August 22-25, 2016, Vienna, Austria

[4] Sadek, A.H., Nofal, E.M. Indoor Environmental Quality Effects of Indoor Environmental Quality on Occupant Satisfaction in Healing Environments. Building Simulation Cairo 2013 - Towards Sustainable & Green Life, Cairo.

[5] Vos, T., et al., (2020). Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. The Lancet (British edition), 396(10258), 1204-1222.

[6] Ferm M, Rodhe H. 1997. Measurements of air concentrations of SO_2, NO_2 and NH_3 at rural and remote sites in Asia. Journal of Atmospheric Chemistry 27, 17-29.

[7] ISO 16017-2. Indoor, ambient and workplace air - sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography - Part 2: diffusive sampling. Geneva: International Organization of Standardization; 2003.

[8] ISO 16000-4. Indoor air - part 4: determination of formaldehyde - diffusive sampling method. International Organization of Standardization, Geneva, 2004.

[9] Bernard. 2023. 'Mollier Diagram Calculator and Sketcher'. Mollier-Diagram.Com. 2023. https://www.mollier-diagram.com.

[10] SS-ISO 16000-17:2008. 2008. 'Indoor Air - Part 17: Detection and Enumeration of Moulds - Culture-Based Method. Geneva: International Organization of Standardization; 2008.

[11] SS-ISO 16000-21:2015. 2015. 'Indoor Air - Part 21: Detection and Enumeration of Moulds - Sampling from Materials. Geneva: International Organization of Standardization; 2015.

[12] Patel, P. D., ed. 1995. Rapid Analysis Techniques in Food Microbiology. Boston, MA: Springer US. https://doi.org/10.1007/978-1-4615-2662-9.

[13] SS-EN 16798-1. Energy Performance of Buildings – Ventilation for Buildings – Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics – Module M1-6, SIS, Swedish Standards Institute, Stockholm, Sweden, 2019.

[14] AFS 2020:1. Arbetsmiljöverket (the Swedish Work Environment Authority) 2020. Workplace design (in Swedish: Arbetsplatsens utformning), Stockholm, Sweden.

[15] FoHMFS 2014:17. Public Health Agency's general advice on indoor temperature (in Swedish: Allmänna råd om temperatur inomhus). Folkhälsomyndigheten, Public Health Agency of Sweden), Stockholm, Sweden, 2014.

[16] Fromme H, Debiak M, Sagunski H, Röhl C, Kraft M., Kolossa-Gehring M. (2019). The German approach to regulate indoor air contaminants, International Journal of Hygiene and Environmental Health 222, 347–354.

[17] FoHMFS 2014:14. 2020. 'Allmänna råd om fukt och mikroorganismer'. Folkhälsomyndigheten. http://www.folkhalsomyndigheten.se/publicerat-material/publikationsarkiv/f/fohmfs-201414/.

[18] Heseltine, E., Rosen, J. and World Health Organization, eds. 2009. WHO Guidelines for Indoor Air Quality: Dampness and Mould. Copenhagen: WHO.Institute of Medicine (U.S.), ed. 2004. Damp Indoor Spaces and Health. Washington, DC: National Academies Press.

[19] Reboux, Gabriel, Steffi Rocchi, Audrey Laboissière, Habiba Ammari, Martine Bochaton, Guillaume Gardin, Jean-Marc Rame, and Laurence Millon. 2019. 'Survey of 1012 Moldy Dwellings by Culture Fungal Analysis: Threshold Proposal for Asthmatic Patient Management'. Indoor Air 29 (1): 5–16.

[20] Shelton, Brian G., Kimberly H. Kirkland, W. Dana Flanders, and George K. Morris. 2002. 'Profiles of Airborne Fungi in Buildings and Outdoor Environments in the United States'. Applied and Environmental Microbiology 68 (4): 1743–53.