

Wood, Well-being and Performance: The Human and Organizational Benefits of Wood Buildings



Report by:
Graham Lowe, Ph.D.

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**Forestry Innovation
Investment**

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Photo credits for front cover

Mountain Equipment Co-op headquarters, Vancouver, B.C. | Photographer: KK Law

About Forestry Innovation Investment Ltd. (FII)

Forestry Innovation Investment Ltd. is an agency of the Government of British Columbia. Its mission is to help maintain, create and diversify markets for B.C. forest products to ensure the forest sector continues to be a key contributor to the B.C. economy.

<https://www.bcfii.ca/about-fii/corporate>

About the author

Graham Lowe has over 30 years of organizational, labour market and policy consulting experience across Canada and internationally. He is president of The Graham Lowe Group Inc., a workplace consulting and research firm, and a Professor Emeritus at the University of Alberta. His latest book is *Creating Healthy Organizations: Taking Action to Improve Employee Well-being* (University of Toronto Press). www.grahamlowe.ca

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To find out more about the British Columbia buildings in the images go to <https://www.naturallywood.com/wood-design/project-gallery>.

Executive Summary

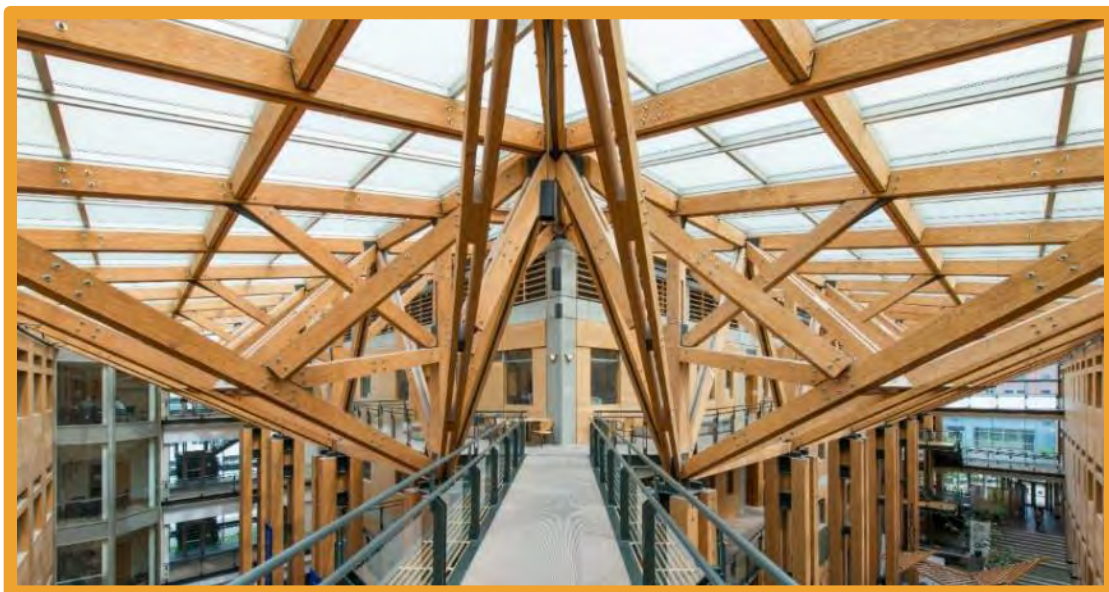
This report examines the use of wood in offices, healthcare facilities, schools and other commercial and institutional buildings by synthesizing state-of-the-art knowledge from research literature. The report also suggests future actions that decision-makers can take to monitor and evaluate the human and organizational impacts of wood building structures and interiors.

Purpose

The report is guided by the following questions:

1. What insights from research on the health and productivity benefits of green buildings are relevant for wood buildings?
2. How do the environmental credentials and natural features of wood construction and interior finishing benefit occupants and employers?
3. What are the key questions about the human and organizational benefits of wood buildings that need to be addressed in future?
4. What are the most appropriate methods and metrics for assessing the human and organizational benefits of wood buildings and interiors?

The main audiences for the report are building owners and leasees, employers and policy makers. Building designers, general contractors, manufacturers and researchers will also be able to use the findings.



Forest Sciences Centre, University of British Columbia | Photo credit: Don Erhardt

Converging trends promoting wood buildings

A convergence of four major trends strengthens the case for the environmental, organizational and human benefits of wood buildings and wood interiors:

- Changes in building codes are permitting larger and taller wood buildings.
- The public and major investors are pushing for action to address climate change, while the diffusion of green building certifications is promoting sustainable construction and renovation of buildings.
- Employers' focus on improving employee well-being is providing opportunities to view the physical workspace as health-promoting. An expanding body of research documents the health and productivity benefits of green buildings, particularly those using wood construction or finishing.
- Corporate sustainability strategies are more closely linking environmental and human resource goals.

Health and productivity benefits of green buildings

Wood buildings are part of the green building trend, which uses building structures and processes that are environmentally responsible and resource efficient. Studies of wood buildings are informed by a solid foundation of knowledge about the human and organizational benefits of building green. Cumulative evidence based on occupants' self-reported outcomes shows that green buildings reduce symptoms of sick building syndrome and contribute to overall better health. There is growing interest in how green buildings contribute to occupants' psychological well-being. These studies converge with employers' efforts to address workplace mental health issues, particularly stress and burn-out.

Most of the research on green buildings, including those made of wood, focus on offices. Public health experts link the health and productivity advantages derived from working in green-rated office buildings. Working in a green building can improve employees' job satisfaction and job performance. Office workers in green-certified buildings, compared to those in conventional buildings, have better cognitive functioning, mainly due to better indoor environmental quality.

Health and productivity benefits of wood buildings and interiors

The strongest evidence of wood's human and organizational benefits is based on wood's biophilic properties. Biophilia refers to humans' innate need for connections to

nature. When individuals have contact with nature, their neurological, physiological and psychological responses result in less stress, lower blood pressure, more relaxation and positive moods, and increased concentration.

Biophilic design incorporates natural elements into the construction and interiors of buildings. Wood is one of the few natural elements that can simultaneously achieve four important goals: reduced carbon emissions; increased sustainability in a building's life cycle; improved occupant well-being; and increased organizational benefits from having happier, healthier and more productive employees.

Generally speaking, people like the look, feel and smell of wood interiors. This is a major marketing advantage for wood buildings and interiors compared to synthetic alternatives. Furthermore, building with wood enhances an organization's brand as environmentally responsible.

The organizational benefits of biophilia include reduced employer costs and increased productivity based on the following employee outcomes: reduced illness, absenteeism and presenteeism; increased retention; increased job performance; and reduced stress and fatigue. However, more detailed information is needed about the specific tactile, olfactory, visual and auditory properties of wood interiors that positively affect occupants' psychological and physiological responses.

Important human benefits of wood interiors include improved indoor air quality as a result of wood's hypoallergenic properties, reduced off-gassing of formaldehyde and other volatile organic substances, and better sound absorption. Wood interiors also help to meet human's natural affinity for nature. Studies document that wood interior design is associated with higher occupant satisfaction. Furthermore, wood surfaces in an office environment can reduce the body's stress responses.

Mounting evidence points to health and well-being benefits of wood interiors in schools and hospitals. Wood in healthcare settings has restorative properties, resulting in improved patient recovery. In school classrooms with wood interiors, students experience less stress and better learning outcomes. These findings reinforce the more general understanding that humans thrive in natural settings.

In addition, mass timber buildings benefit workers involved in the construction process because of reduced construction time and safer, cleaner building sites.

Next steps

The key practical lesson emerging from the reviewed studies is that more can be done to improve the methods and metrics for evaluating the human and organizational benefits of wood buildings and interiors. The result will be higher-quality evidence that can inform decision-making throughout the planning, design, construction and occupancy phases of wood buildings.

All studies reviewed in this report raise future questions that, when answered, will provide a better understanding of how green buildings, and specifically wood buildings and wood interiors, benefit occupants. Answering these questions requires collaboration between researchers and practitioners involved throughout the design, construction and operation of a wood building.

Practitioners and researchers should focus on measuring building characteristics and occupant outcomes that can inform decision-making during a building's entire life cycle. New technologies such as mobile and wearable sensing devices will make this measurement easier.

Conclusion

Wood can create healthy and productive buildings. British Columbia is ideally positioned to continue taking a leadership role in wood building design and construction. Research conducted in a wide range of disciplines points to the same evidence-based conclusion: wood is good for the environment, for people and for organizations.

Introduction

Wood is a natural, versatile and renewable building material. While humans have built with wood for millennia, its use is now on the rise, especially in non-residential building projects, in response to pressing needs to address climate change and improve human health in indoor environments. Advances in wood science, building design and engineering, and building codes have greatly expanded the innovative use of wood in construction. This report documents how the use of wood in the construction of non-residential buildings and their interiors is the next big step in the evolution of healthy and productive buildings.

Architects are calling for a return to wood as the basic building material. Over the past decade, mass timber has started to move into the mainstream of non-residential construction. Large mass timber buildings are going up in Australia, Canada, Europe, Japan, New Zealand and the United States. As *Canadian Architecture* magazine predicted: “Wood will be the future for Canadian architecture and construction. It doesn’t take any boldness to make this proclamation.”¹

Mass timber is becoming a ‘market disrupter’ in Canada, offering a viable alternative to concrete and steel construction. For example, the 18-storey Brock Commons Tallwood House, built with mass timber on the University of British Columbia campus in Vancouver, is North America’s tallest wood building. Yet to realize mass timber’s



*Brock Commons Tallwood House, B.C.
Photo credit: Michael Elkan*

potential, decision-makers in the design, construction and real estate markets need to better understand its benefits. The benefits of mass timber include its ease of construction, influence on the work environment, light carbon footprint, and positive effect on human health and well-being and organizational performance.

However, of all the areas where mass timber adds value, the least understood are its human and organizational benefits. This report aims to fill that gap. Researchers are still unravelling precisely how a building's green design features affect its occupants' health and performance. This report highlights that future research on the human and organizational benefits of wood buildings can further explore these important issues. The result will be an even stronger case for using wood in commercial and institutional buildings.

Mass timber construction uses large prefabricated wood members for a building's walls, floors and roofs. Mass timber products include glue-laminated timber (glulam), cross-laminated timber (CLT) and nail-laminated timber (NLT). Mass timber structural components can be left exposed, providing wood interior design features.

Purpose

This report examines the innovative use of wood in offices, healthcare facilities, schools and other commercial and institutional buildings by synthesizing state-of-the-art knowledge from research literature. The report provides evidence-based insights into the health and productivity benefits of using wood in the structure and interior finishing of non-residential buildings. Based on this review of evidence, the report also suggests future actions that decision-makers can take to monitor and evaluate the human and organizational impact of wood buildings.

The report is guided by the following questions:

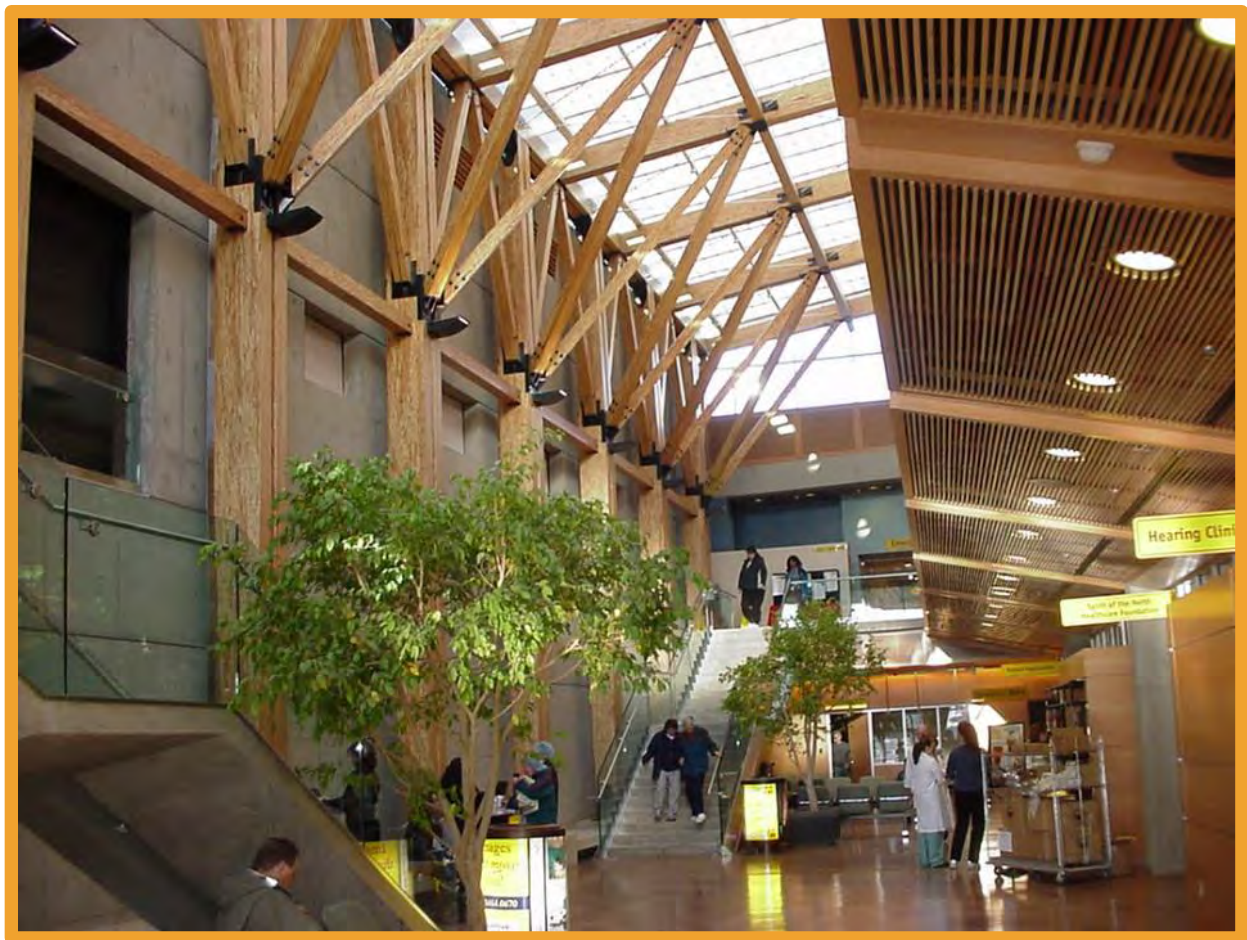
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The main audiences for the report are building owners and leasees, employers and policy makers. Building designers, general contractors, manufacturers and researchers will also be able to use the findings.

Approach

The background research for this report cast a wide net. Using databases of scholarly and practitioner publications, the author conducted key word searches in a diversity of disciplines. These ranged from architecture, building design and engineering, and green buildings, to environmental psychology, public health, human resources, corporate sustainability and more. The author also made extensive use of reports by industry and government organizations related to green buildings and wood construction.

In screening the articles and reports to summarize here, priority was given to the latest research, publications which have been widely cited, and systematic literature reviews in relevant fields. In distilling this extensive literature, emphasis was placed on extracting practical insights that can be used by decision-makers involved in all stages of wood building design, manufacturing, construction and operation. This was done in the spirit of closing the gap between research and practice.



Prince George Regional Hospital, B.C. | Photo credit: Structurlam

Converging trends promoting wood buildings

A convergence of four major trends strengthens the case for the environmental, organizational and human benefits of wood buildings and wood interiors:

- Changes in building codes are permitting larger and taller wood buildings.
- The public and major investors are pushing for action to address climate change, while the diffusion of green building certifications is promoting sustainable construction and building renovation.
- Employers' focus on improving employee well-being is providing opportunities to view the physical workspace as health-promoting. An expanding body of research documents the health and productivity benefits of green buildings, particularly those using wood construction or finishing.
- Corporate sustainability strategies are more closely linking environmental and human resource goals.

We now will review each of these trends.

1. Building code changes

The construction of taller and larger buildings using wood is a growing trend in many countries, enabled by changes to building codes and regulations.²

The 2020 National Building Code of Canada allows encapsulated mass timber construction (EMTC) in buildings up to 12 storeys. EMTC is mass timber clad in fire-resistant materials. Previous to the new provisions, the National Building Code had allowed up to six storeys for wood-frame construction.³ In British Columbia, the provincial government has encouraged municipalities to be early adopters of the provisions in the 2020 National Building Code. Many communities applied for early adoption of taller wood buildings, recognizing these require less construction time, have environmental benefits and create new opportunities in the province's economy.⁴ The province of Alberta also adopted the new mass timber provisions ahead of the National Building Code changes.⁵

The International Code Council in the United States approved changes, effective in 2021, that will permit mass timber construction of up to 80 metres (18 storeys).⁶ None of these building code changes would have been possible without strong evidence of the fire safety properties of mass timber construction, coupled with governments' commitment to reduce CO₂ emissions.⁷

2. Actions on climate change

The Canadian public wants decisive action by governments and corporations on climate change. So do major investors.

Various public opinion polls taken in 2019 reveal that Canadians rank the environment as the number one challenge facing the country.⁸ Increasingly, Canadians are ready for actions that mitigate climate change. Because buildings account for 40 percent of all carbon emissions, we can expect building with wood to become a centerpiece of an effective climate action strategy.⁹

This shift in public attitudes is reflected in financial markets. BlackRock and other leading investment managers—with a combined US \$41 trillion in assets—are now making investment decisions based on how companies mitigate climate risks and reduce carbon emissions, and they are urging other institutional investors to do the same.¹⁰

Wood as a construction material plays a critical role in a low-carbon economy by storing carbon and displacing high-carbon cement and steel. For example, the BBC points out that enough concrete is poured each year globally to cover the whole of England.¹¹ By replacing concrete and other carbon-intensive building materials, wood construction results in a net reduction of carbon dioxide from the atmosphere. Because the construction process is faster and more efficient, that also benefits the environment.

Andrew Waugh, a London-based architect who has built a number of large buildings using cross-laminated timber (CLT), observed that a 16,000-square-metre CLT building he worked on would have needed about 1,000 cement truck deliveries just for the frame, whereas CLT for the entire building required only 92 deliveries.

Smedley, T. (24 July 2019). Could wooden buildings be a solution to climate change? *BBC Future*.
<https://www.bbc.com/future/article/20190717-climate-change-wooden-architecture-concrete-global-warming>

3. Emphasis on improving workers' well-being

The past decade has seen a remarkable increase in employer initiatives to improve workers' well-being. There is far more recognition now of the need to improve mental health, particularly reducing stress and burnout. Canadian employers have gained a better understanding of the costs associated with unhealthy working conditions, especially in terms of absenteeism, presenteeism (going to work but not being well enough to fully contribute) and work engagement.

Increasingly, employers recognize that promoting employee well-being ultimately contributes to humanly sustainable improvements in business performance. This is what it means to be a truly healthy organization.¹² Yet, lacking in this area of research and practice is a clear understanding of how the physical workspace contributes to employee wellness and engagement goals. Research on wood buildings, however, has begun to shed light on this important issue.



Surrey Central City, B.C. | Photo credit: Nic Lehoux

Bing Thom, the architect of a retail and commercial development at Surrey Central City, BC, explained that he selected wood for the building's structure "to provide a warm and tactile contrast to the smooth, synthetic environment of the modern high-tech workspace."

naturally:wood. (2015). *Health and Well-being. Building Green with Wood in BC, Module 6, 3.*

<https://www.naturallywood.com/sites/default/files/documents/resources/building-green-with-wood-toolkit-health-well-being.pdf>

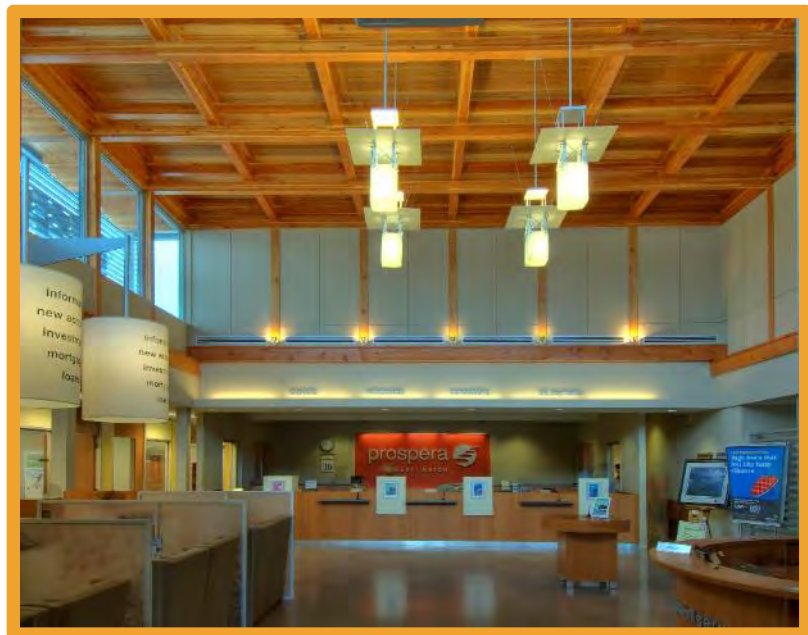
Many studies document the human health and productivity benefits of green buildings generally and wood buildings in particular. According to the World Green Building Council (WGBC), “There is overwhelming evidence which demonstrates that the design of an office impacts the health, wellbeing and productivity of its occupants.”¹³

4. Corporate sustainability strategies

More employers are adopting comprehensive sustainability or corporate social responsibility (CSR) strategies to guide actions that will improve the environment, benefit the communities in which they operate, and contribute to their employees’ well-being.

Corporate sustainability strategies are starting to align with human resource goals. An emerging trend in this regard is ‘green human resource management (Green HRM)’.¹⁴ This approach views employers’ sustainability actions and ‘branding’ as useful for achieving their employee recruitment, retention and engagement goals. Leading companies, such as Herman Miller and Bank of America, provide their workers with natural landscapes, green roofs, views of nature and green buildings as part of their recruitment strategy.¹⁵

Furthermore, employers’ growing awareness of their employees’ pro-environment attitudes and behaviour in workplaces—especially among younger workers—enables the adoption of Green HRM. Employers’ strategies and branding for sustainability can influence these pro-environmental attitudes and practices.¹⁶ In other words, employers who adopt wood as the main structural and interior design material for a new building stand to reap additional human resource benefits, given wood’s strong green credentials.

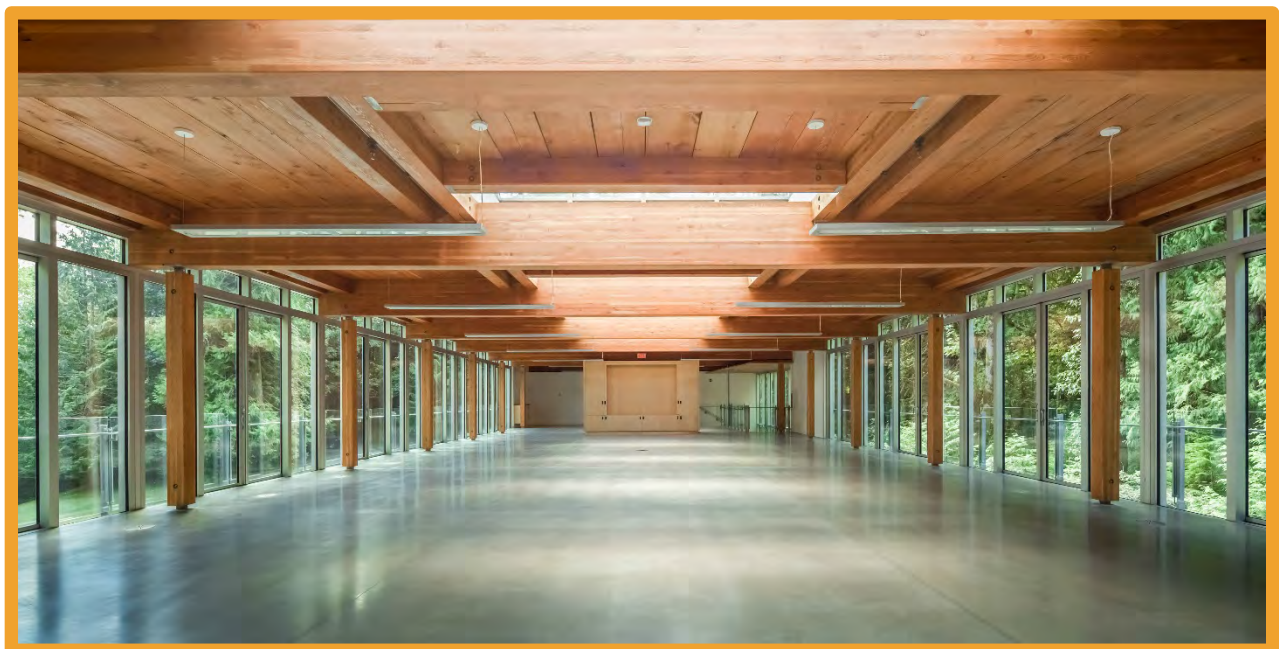


Prospera Credit Union, Vancouver, B.C. | Photo credit: Gord Wylie

Building Green

This section summarizes what we know about how green buildings impact the health, well-being and productivity of their occupants. According to the World Green Building Council, “A ‘green’ building is a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment. Green buildings preserve precious natural resources and improve our quality of life.”¹⁷ Given that wood buildings fit within this broader green building trend, research on green buildings can inform future studies of the health and productivity benefits of wood buildings. Continued progress in wood buildings depends on the wider acceptance of the total value-added of a green, sustainable building, including how it promotes human health and organizational performance.

Most of the research on green buildings, including those made of wood, focus on offices. According to the World Green Building Council, employees are 90 percent of an employer’s expenses, so even small improvements in employee health and productivity will yield value.¹⁸ Employers should fully consider how the use of wood in building construction and interior design improves well-being and job performance, leading to employee cost reductions. For building owners, this can translate into increased building value and rents.¹⁹



Cheakamus Centre / Blueshore Environmental Learning Centre, Brackendale, B.C. | Photo credit: Michael Elkan

The role of green building rating systems

Green building rating systems have promoted sustainable construction and renovation, particularly for offices and, to a lesser extent, other commercial and institutional buildings. The rapid diffusion of these rating systems is pushing the use of wood in building structures and interiors.

The Canada Green Building Council's (CaGBC) survey of building owners documents the economic benefits of green buildings.²⁰ Looking beyond economics, close to three-quarters of owners surveyed by CaGBC also considered occupants' health and well-being in their building design decisions. Prominent among building owners' goals in this regard were happier, healthier and more satisfied building occupants. However, the building owners surveyed also stated that occupants' health and well-being are viewed as lower priority in the real estate industry than cost savings and reduced energy use. Survey respondents also identified a need for more data on how buildings affect human health and performance.

An important implication of this CaGBC survey is that more must be done to communicate the human and organizational benefits of green buildings to decision-makers. A comprehensive perspective on the potential environmental, economic, human and organizational benefits of green buildings is needed.



The UBC Bioenergy Research and Demonstration Facility is certified LEED Gold | Photo credit: Don Erhardt

Currently, green building rating systems, such as BOMA BEST, Building Research Establishment Environmental Assessment Method (BREEAM), BuiltGreen, Green Globes, GreenMark, LEED and the Living Building Challenge, place little emphasis on the health and well-being of a building's occupants. Typically, these systems give few green credits for design features aimed at improving occupants' health and well-being, such as connections to nature.²¹ This is despite the fact that by far the largest expense for an employer is employee costs.

LEED does provide some credits for a building's impact on occupants' health, emphasizing indoor environmental quality (IEQ). This includes ventilation rates, control of environmental tobacco smoke, and cleaning practices that limit harmful biological and chemical exposure.²² However, a much broader focus than IEQ is essential to expand our understanding of the full range of health, well-being and organizational performance benefits possible to achieve by building with wood.

LEED and WELL Building Rating Systems

LEED, or Leadership in Energy and Environmental Design, is the most widely used and rigorous green building rating system in the world. It focuses on improving energy performance, while also emphasizing human health. Canada is the second largest market in the world for LEED-certified buildings.

The **WELL Building Standard** is a performance-based system for measuring, certifying and monitoring features of buildings that impact human health and well-being through air, water, nourishment, light, fitness, comfort and mind. It merges best practices in design and construction with evidence-based medical and scientific research on human health and well-being. WELL works in tandem with LEED and other international green building systems.

WELL views buildings as health promotion and intervention tools. The new **WELL v2** certification standards include building design points for: mental health promotion, prevention and interventions; promotion of physical activity; active commuting; ergonomic workspaces; access to healthy food and beverage choices; and elimination of building materials and ingredients that are hazardous to human health.

In Canada, Green Business Certification Inc. Canada (GBCI Canada) administers the **LEED** green building rating systems. The International WELL Building Institute's (IWBI) collaboration with GBCI Canada, the same organization that administers LEED certification, provides the **WELL** certification.

See: Green Business Certification Inc. Canada <http://www.gbicanada.ca/well.shtml>

Health benefits of green buildings

Cumulative evidence based on occupants' self-reported outcomes shows that green buildings reduce symptoms of sick building syndrome and they contribute to overall better physical and mental health. This solid foundation of knowledge about the human benefits of building green informs studies of the health and well-being benefits of wood buildings.

Studies of occupants' health in green buildings document the health benefits of improving IEQ. For example, in a study of 10 office buildings in five U.S. cities, all buildings were considered high performing, based on ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ventilation standards and low concentrations of volatile organic compounds.²³ The researchers compared occupants' experiences in a LEED-certified building in each city with a similar building that was not LEED certified. Compared with workers in non-certified office buildings, those in LEED-certified buildings scored 26 percent higher on a cognitive function test, reported 30 percent fewer symptoms of sick building syndrome, and scored six percent higher on a self-reported sleep quality test. These findings suggest that LEED-certified buildings can improve occupants' health and productivity.



Mountain Equipment Co-op headquarters has LEED Platinum certification | Photo credit: Ed White Photographics

Now that researchers and building owners have more refined techniques for assessing IEQ, the next step is to expand evaluation frameworks to include a broader set of building features and individual and organizational outcomes. This is beginning to happen, with calls for an interdisciplinary perspective that can capture the full range of building users' experiences.²⁴

For example, researchers are now looking beyond impacts on physical health to examine mental health and overall well-being. A 2018 study in the journal *Frontiers in Psychology* was the first study showing how LEED-certified green buildings affect employees' mental health and well-being.²⁵ It was conducted among 214 office workers occupying a newly-built, gold-certified LEED office building in a Canadian city. The study emphasizes the growing importance of addressing workplace mental health issues, given they are a leading cause of work absenteeism and presenteeism (which costs employers far more than absenteeism).²⁶

Research done by the Canada Green Building Council suggests that “the prognosis is good for increased investment for health and well-being as an integral part of green building design and construction in the years to come.”

Canada Green Building Council and Dodge Data & Analytics. (2016). *Healthier Buildings in Canada 2016: Transforming Building Design and Construction*, 5.
https://www.cagbc.org/cagbcdocs/Smart_Market_Report_Final_Web_PUBLIC.pdf

The more that studies of green buildings show positive mental health impacts on occupants, the more likely that building structures and workspace design will be integrated into corporate wellness strategies. This approach will resonate for Canadian workers and their employers, given growing concerns about mental health.²⁷ The aforementioned *Frontiers in Psychology* study used the World Health Organization's definition of well-being as “a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity.”²⁸ This definition also guides many corporate wellness programs, which highlights the potential to integrate green building features into corporate wellness strategies. Yet so far, workplace mental health research and practice—what's often referred to as workplace psychological health and safety—has had little to

say about the role of the physical workspace. Corporate wellness professionals and members of worksite wellness committees are likely to be a receptive audience for any insights about the health benefits of green, or more specifically, wood buildings.

The *Frontiers in Psychology* study measured physical and social aspects of the indoor environment in addition to employees' overall satisfaction with this environment. These indoor work environment measures correlated positively with multiple aspects of well-being: positive feelings, life satisfaction, psychological flourishing and reduced

symptoms of anxiety and depression. In other words, occupants who are satisfied with their indoor environment are likely to experience higher levels of mental well-being than coworkers who are dissatisfied with their indoor environment. This study underscores the importance of looking beyond design, construction and green certification requirements to consider a wider range of occupants' experiences.

Workplace health experts and employers are looking for effective ways to reduce employee stress and burnout. It is a positive sign that the architectural community also is asking: "Can architects solve employee burnout?"²⁹ The answer is yes, to the extent that workplace design can alleviate the causes of stress and burnout by giving employees more control over job demands, interruptions, distractions and breaks.

When design features include aesthetically appealing wood interiors or exposed mass timber, there may be added benefits for psychological health. This presents an ideal opportunity for collaboration among architects, mass timber specialists, ergonomists, environmental psychologists, workplace health experts and human resource professionals to plan and monitor healthy office designs. Furthermore, given the extensive research on stress and burnout, accurate self-reported measures of these conditions are readily available and could be included in building occupant surveys. This makes it relatively easy to monitor the impact of workspace design features on psychological health.³⁰

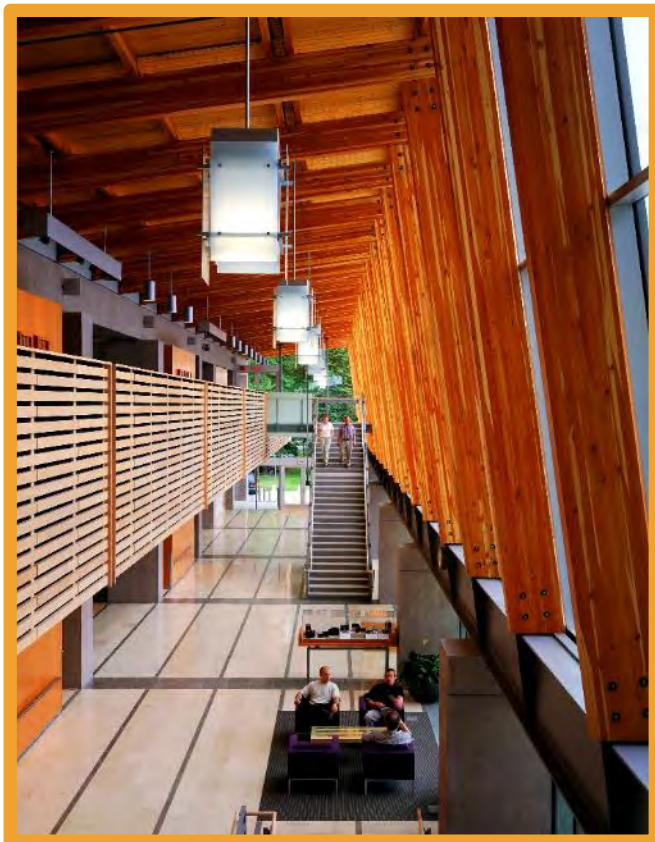


*Nadleh Whut'enne Yah Administration and Cultural Building, Fort Fraser, B.C.
Photo credit: Martin Knowles*

Productivity payoffs from green buildings

Working in a green building can improve an employees' job performance. Studies show that office workers in green-certified buildings, compared to those in conventional buildings, have better cognitive functioning (decision-making), mainly due to better indoor environmental quality. Public health experts have linked the health and productivity advantages derived from working in green-rated office buildings. Two case studies found that workers who had moved from a conventional office building to a LEED-rated building reported less absenteeism due to asthma, respiratory allergies, depression and stress, as well as improved productivity.³¹

Joseph Allen, a Harvard professor, calculates that employers can improve knowledge workers' productivity through improved cognitive functioning by U.S. \$6,500 annually just by doubling ventilation rates.³² This does not include additional cost-related health benefits such as reduced sick building syndrome, absenteeism and presenteeism. As Professor Allen concludes, based on evidence like this, buildings are a human resource tool that can yield substantial cost savings for employers.



Richmond City Hall, B.C. | Photo credit: Martin Tessler

Another study compared LEED-rated green office buildings with comparable green buildings that were not LEED-rated. Detailed measures of indoor air quality (i.e., ventilation, thermal comfort, daylight views and volatile organic compounds) were taken in both pairs of buildings. Twelve office workers in each building participated in health and cognitive functioning tests. These small samples, however, make it difficult to draw generalizations—one of several methodological weaknesses in this area of research that we return to later in the report.

A team of researchers at Canada's National Research Council (NRC) conducted what is perhaps the most thorough study to date of how green buildings affect employee productivity.³³ The study examined how features of a building, the second largest expense for most white-collar organizations, affect their largest expense category, namely employees. The NRC team compared a matched sample of 10 LEED-certified buildings with 10 traditional buildings, all of which were offices for a single large financial organization in the Canadian private sector. The study included a total of 14,569 employees. The researchers analyzed readily available corporate human resource metrics, specifically manager-assessed employee performance ratings and results from an annual corporate employee opinion survey (EOS), which included standard HR metrics such as engagement, collaboration, client focus, citizenship behaviour and retention.

While the NRC researchers are careful to note that not all green buildings out-perform conventional buildings, study participants in green-certified buildings had higher EOS scores and higher job performance ratings by managers—two key performance measures widely used by Canadian employers. This NRC study is state of the art, setting a high standard for future evaluations of the impact of wood buildings on occupants' job performance.

Corporate sustainability practices can positively influence employees' work-related attitudes and behaviour. A 2019 article in *Personnel Psychology* described the psychological processes connecting employees to their employer's CSR actions. When employees have positive perceptions of their employer's CSR strategy and practices, their pride in the organization increases, they feel more connected to the organization, and they are more likely to want to continue working for the organization.³⁴ Furthermore, employees who have a positive perception of their employer's actions to protect the environment are motivated to engage in spontaneous behaviour aimed at environmental improvement—or what's called environmental citizenship behaviour.³⁵

To summarize, there is a practical implication for employers planning to build or refurbish their workplace. Selecting wood as the construction and interior finishing material provides opportunities to strengthen employees' attitudes and behaviour not only about protecting the environment, but also about the organization as an excellent employer.

Wood Buildings, Well-being and Performance

The research just reviewed on the health and productivity benefits of green buildings serves as a starting point for understanding how building and designing interiors with wood provides additional human and organizational benefits. This section summarizes current trends and issues in this rapidly expanding area of research and practice. Furthermore, the health and productivity benefits of wood buildings, beyond their environmental credentials, make a compelling case that wood buildings are the new sustainable standard for offices, other commercial buildings, schools and healthcare facilities.



*Wood Innovation and Design Centre, Prince George, B.C.
Photo credit: Brudder*

Wood and sustainability

When it comes to sustainability, wood is a triple win: it is the ideal renewable material for building construction; it demonstrates a tangible commitment to sustainability by building designers, contractors, owners and occupants; and in buildings, it contributes to occupants' well-being. Architects' attitudes and experience are shifting in favour of wood use in buildings.³⁶

The architecture literature is now addressing the importance of designing workspaces that promote employee productivity, engagement, collaboration and knowledge development and use.³⁷ Given the growing awareness of how building design influences occupants' well-being and performance, it is all the more important to document and communicate the health and productivity benefits of wood.

Greater public awareness of wood's benefits for occupants will also promote healthier buildings, with wood as the optimal solution.³⁸ One way to raise public awareness is to ensure that medical professionals understand the health benefits of wood buildings, so they too can become advocates for healthy wood buildings.³⁹ For example, a recent review of the health effects of green buildings in the *Annual Review of Public Health* makes no mention of wood building construction. However, this article emphasizes that from a public health perspective, building green will create healthier indoor environments.⁴⁰

Commenting on a new wood building in Toronto, designed to expose 80 percent of the wood used, Architect magazine stated: "There is a warmth to wood that can't be replicated in other materials. Wood has the ability to create a more complex and intimate environment even in an expansive, open space."

Architect. (March 2016). Wood: Warm, natural, response to commercial office space, 105 (3), 28.

Considerations of workplace design have advanced far beyond occupant comfort and now embrace the more comprehensive goal of creating an environment in which people can thrive at work.⁴¹ Thus, it is essential to document occupants' full range of experiences in the work environment, from physiological to psychological and social. Experts recognize that workers who

flourish at work also are more creative, collaborative, present and productive. Employers reap the benefits of reduced employee costs and improved organizational performance. And while there are fewer studies of wood use in healthcare and educational settings, evidence to date also points to a range of positive outcomes for patients and students.

Integrating wood into building standards

Demand for sustainable buildings will increase as design and construction professionals, building owners and leasees, public health and human resource experts, and occupants become more aware of the human, organizational and environmental payoffs of green

buildings. In this regard, the CaGBC highlights opportunities to adapt the new WELL Building standard in ways that promote the use of wood.⁴² The goal of the WELL Building standard is “better buildings that help people thrive.”⁴³

So far, none of the WELL-certified buildings in Canada use wood construction. However, an initiative at the University of British Columbia, which has several large wood buildings on its Vancouver campus, describes how to connect WELL certification with wood construction. The university conducted an extensive assessment of the applicability of the WELL Building standard to the university, particularly its new buildings.⁴⁴ The WELL v2 is based on a checklist of 112 features organized into ten categories: air, water, nourishment, light, movement, thermal comfort, sound, materials, mind and community. The standard also requires an enhanced survey to document occupants’ experiences in addition to their health and well-being.

Building projects must submit documentation that WELL criteria have been met. The UBC report recommends developing a WELL implementation guide for the university that aligns with its LEED implementation guidelines.

Furthermore, the University of British Columbia report recommends conducting occupant surveys to obtain feedback on users’ experiences of the interior environment. WELL v2 includes a focus on ‘community’, ‘movement’ and ‘mind’, all of which reflect the role of the built environment on occupants’ well-being. For example, WELL v2 includes in its checklist ‘a culture of health’. Recall our earlier discussion of the potential links between green buildings and corporate wellness strategies. Increasingly, corporations are striving to create a ‘culture of health’ that supports employee wellness initiatives. These converging goals and shared interests open the door for a much closer collaboration between facilities managers and their colleagues in wellness and human resources.

Wood meets our need to connect with nature

The strongest evidence for wood’s human and organizational benefits is based on wood’s biophilic properties. Biophilia refers to humans’ innate need for connections to nature. The word’s Greek roots mean love of nature.⁴⁵ When individuals have contact with nature, their neurological, physiological and psychological responses result in less stress, lower blood pressure, more relaxation and positive moods, and increased concentration.

'Biophilic architecture' is an emerging approach to design that provides humans with health-promoting psychological and physical connections to nature in their built environments.⁴⁶ This is an important public health goal in today's cities, where a lack of natural features contributes to high stress levels and other symptoms of ill health. Biophilic architecture includes the use of wood as a structural and interior design material.

"Humans feel good and do well in surroundings that are beautiful and connected to the living green world outside by thoughtfully designed wood materials inside."

Think Wood. (2016). *Wood and Indoor Environment. Creating Beneficial Spaces for Living, Working, Well-being.* Continuing Education, 7.
<https://1r4scx402tmr26fqa93wk6an-wpengine.netdna-ssl.com/wp-content/uploads/2019/08/Think-Wood-CEU-Wood-and-Indoor-Environment.pdf>



Surrey Memorial Hospital Critical Care Tower, B.C.
Photo credit: Ed White Photographics

Studies of the benefits of connections with nature have been conducted using diverse natural stimuli in a wide variety of settings, countries and cultures. The overall conclusion is that nature relatedness—the subjective sense of connection people have with the natural environment—is a universal psychological need.⁴⁷ The health and well-being effects of nature relatedness on how humans function fall into three broad categories: physiological stress reduction, recovery and immunization; psychological well-being; and cognitive or attentional restoration. Physiological benefits were first documented by Roger Ulrich, who showed how nature connection improved recovery from surgery (more on this study later). Evidence also suggests that people become more relaxed when exposed to nature.

An interdisciplinary team of researchers at the University of Washington conducted an extensive review of studies documenting health and well-being benefits of human contact with nature.⁴⁸ None of the studies reviewed focused specifically on wood; however, this research literature documents numerous benefits. These benefits include reduced stress, depression and anxiety, better sleep, improved mental health, increased prosocial behaviour and social connectedness, and improved post-operative recovery, pain control and general health.

Here are some examples of the health benefits of biophilic building design:

- A study conducted in British Columbia provides evidence that wood surfaces in an office lower the body's sympathetic nervous system (decreasing blood pressure and heart rate), thereby reducing stress.⁴⁹
- European research compared occupants' responses to wood and plaster indoor settings. Compared to the plaster setting, wood elicits more positive emotions.⁵⁰
- Cumulative evidence from studies examining the psychophysiological effects on occupants of wood indoor environments shows that wood can contribute to stress reduction or recovery from stress.⁵¹
- One of the first studies to examine the benefits of combining greenery and daylight in biophilic office design, published in 2018, documents resulting improvements in workers' well-being, performance, creativity and health.⁵²
- Studies conducted in various types of healthcare facilities with wood interiors and furnishings, plants and other natural materials show that patients or residents experience reduced stress and improved subjective well-being in these natural environments compared to individuals in similar facilities devoid of natural features.⁵³
- A study of office workers at the University of Oregon attributed 10 percent of employee absences to architectural design features that were devoid of nature. Those employees whose offices had a view of trees and landscape had fewer sick leaves compared with their coworkers who looked out onto parking lots or the building's interior.⁵⁴

Also relevant to our discussion is an extensive review of research on nature relatedness by University of Ottawa psychologists Daniel Baxter and Luc Pelletier. These psychologists raise important practical implications for anyone involved in designing, building and monitoring wood buildings.⁵⁵

University of Ottawa psychologists Daniel Baxter and Luc Pelletier use an interesting analogy to explain the restorative qualities of nature immersion: “we can consider a human being to be a ‘battery’ with respect to cognitive, psychological, and emotional energy, and the natural environment to be the ‘charging station’.”

Baxter, D.E., and Pelletier, L.G. (2019). Is nature relatedness a basic human psychological need? A critical examination of the extant literature. Canadian Psychology/Psychologie canadienne, 60(1):24.

Baxter and Pelletier distinguish between nature exposure and nature immersion. The former refers to viewing nature or being outside in nature. The latter refers to the psychological experience of being inside a natural environment—which is what occupants of wood buildings experience. The concept of ‘place attachment’—the emotional bond between person and place—enhances the benefits of nature-relatedness. Place attachment elicits stronger cognitive and emotional ties to one’s surroundings and often includes a sense of community and of belonging. These are the positive experiences many employers seek to cultivate among their employees. Repeated contact with the natural environment, as happens for workers in a wood building on a regular basis, also enhances these positive experiences.

Baxter and Pelletier conclude that existing research “supports the claim that human beings have a basic psychological need to feel a secure and pleasant experiential connection to nature in a cognitive, emotional, and physical sense.”⁵⁶ This conclusion can serve as a guiding principal for the design and construction of wood buildings and interiors. Another potential benefit of doing so will be to encourage pro-environment commitment and behaviours among the occupants of these buildings.

Biophilic design goes a step beyond green buildings by incorporating natural elements into construction and interiors. Wood is one of the few natural elements that can simultaneously achieve four important goals:

- reduced carbon emissions
- increased sustainability in a building's life cycle
- improved occupant well-being
- increased organizational benefits from having happier, healthier and more productive employees.

Wood buildings and occupants' health

Recognizing that people in North America spend most of their time indoors, natural elements in the indoor work environment have a positive effect on their health.⁵⁷ Important human benefits of wood interiors include improved indoor air quality as a result of wood's hypoallergenic properties, reduced off-gassing of formaldehyde and other volatile organic substances, and better sound absorption. Wood interiors also help with human's natural affinity for nature.

Studies document that wood interior design is associated with higher occupant satisfaction. To illustrate, a study published in 2017 conducted a post-occupancy survey of 36 occupants in two multifunction rooms.⁵⁸ One room had extensive wood interior finishing, while the other was devoid of wood. The rooms were otherwise similar. Occupants in the room with wood finishing were more satisfied with lighting, noise and temperature. These occupants described the wood room as bright, pleasant, modern and warm.

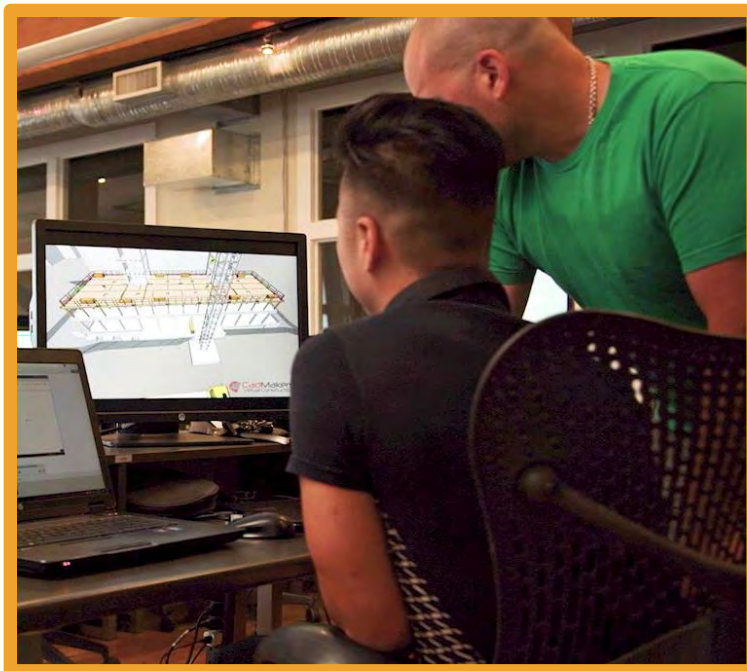
The Timber Research and Development Association (TRADA) articulates a basic objective that can be met by the use of wood in buildings: "Healthy buildings should support the physical, psychological and social health and wellbeing of people, recognizing the fact that buildings—how they are designed, built and operated—are key promoters of health and wellbeing."

TRADA. (2019). TRADA Briefing: The role of wood in healthy buildings, 1.

<https://www.trada.co.uk/news/new-trada-briefing-document-the-role-of-wood-in-healthy-buildings-packs-a-punch/>

David Fell's research at the University of British Columbia established direct links between workspace surroundings and individuals' health.⁵⁹ Fell's study built on earlier research showing that people's exposure to plants indoors had positive health effects. As Fell observes, considering that the typical Canadian only spends six percent of their time outdoors, it is important to bring nature indoors. His study achieved this by using wood finishing and wood office furniture. Visual wood surfaces in an office environment lowered the activation of the sympathetic nervous system of occupants, reducing the body's stress responses.

This is a growing area of research with practical implications for the future use of wood in buildings. In this regard, a 2019 study calls for more detailed information about the specific tactile, olfactory, visual and auditory properties of wood buildings that positively affect occupants' psychological and physiological responses.⁶⁰ Volatile organic compounds are generally understood as a negative impact on human health, but research on naturally occurring volatile organic compounds from wood suggests their emissions can have positive health effects. This is a growing area of research.⁶¹



When planning healthy wood buildings, important considerations include: project type (new or refurbishment); timber species, preservatives and coatings; glues; product emissions; tracking of the impact of building operations on occupants; post-occupancy evaluations of how the building affects users; and documentation on how the building can achieve environmental or well-being performance credits by using wood.⁶²

*Brock Commons' design and construction processes used virtual design and construction (VDC) modelling, which is supported through building information modelling (BIM).
Image credit: www.naturallywood.com*

Building Information Modeling (BIM) is a 3D digital system used to plan, design, build and operate buildings.⁶³ BIM can incorporate measures of occupants' responses into design features. The goal is to continuously learn what works best and use this knowledge to improve buildings throughout their life cycle. BIM tools are widely used for mass timber construction, making it relatively easy to incorporate data on occupants' experiences from existing buildings so that new designs can optimize future health and productivity benefits.⁶⁴ TRADA in the UK recommends that digital material specification and design tools, such as (BIM), be used to model a building's impact on the health of its occupants. BIM is required for all government construction projects in the UK. While Canada is not as advanced as the UK or some other European countries, its construction industry is increasingly adopting BIM to improve building design and facilitate the construction process.⁶⁵

Occupants' preferences for wood interiors

Generally speaking, people like the look, feel and smell of wood interiors. This is a major marketing advantage for wood buildings and interiors compared with synthetic alternatives.

A study commissioned by Forest & Wood Products Australia surveyed 1,000 individuals working indoors. Most respondents were not satisfied with their physical working environment, describing it using words such as "dull" and "enclosed."⁶⁶ However, those in work environments featuring wood were more satisfied, felt more connected to nature, experienced their workplace more positively and took less time off work. Furthermore, workers in workplaces with more exposed wood reported having higher productivity, better concentration and a more positive overall mood.

Similarly, focus groups conducted in Austria, Finland, France, Norway and Sweden found that professionals and laypersons prefer wood interiors.⁶⁷ The look and scent of wood interiors were associated with improved well-being. Planet Ark's survey of Australians showed a strong preference for wood furnishings compared to plastic in office design.⁶⁸ Additionally, a survey of staff at a Norwegian hospital asked them to rate pictures of different hospital rooms, which ranged from having no wood to all wood finishing.⁶⁹ Survey respondents showed a preference for working in a room with a moderate amount of wood compared to no wood or all wood. This intermediate level of wood in a room was described as pleasant, natural, calming and secure.

A recent study by organizational psychologists, *Biophilic Design in the Workplace*, surveyed 3,600 employees in eight countries. It found that employees' well-being, productivity and creativity improved in a natural office environment.⁷⁰ This study did not focus on the impact of wood interiors per se. However, it did find that employees in some countries in the survey—notably Germany and France—reported being more creative in offices with wood. Furthermore, office workers in the UK were happier in wood work environments. The study does not explain these national variations in how workers respond to wood in their office environment, so future research will need to account for national and possibly regional preferences for certain types of natural elements, including wood, in office design.



Whistler Library, B.C. | Photo credit: KK Law

Wood in healthcare facilities

Office buildings and office workers have been the focus of research on the human impact of green buildings because of their current pervasiveness. However, there is mounting evidence of the health and well-being benefits of wood interiors in schools and hospitals as well. In healthcare settings, recovery improves and in schools, students experience better learning outcomes.⁷¹ These findings reinforce the more general understanding that humans thrive in natural settings.

Wood in healthcare settings has restorative properties. Roger Ulrich's classic 1984 hospital patient study is a touchstone in biophilic research, demonstrating that views of nature improve patients' post-operative recovery.⁷² Subsequent studies have replicated this finding and also include the reduction of patient stress as a benefit of designing natural features into hospital rooms.⁷³ Reducing average length of stay in hospitals, reducing treatment time and improving patient outcomes are key goals for the healthcare system—goals that biophilic design helps to achieve.

These goals are motivating hospitals to incorporate more natural light, views of nature, healing gardens and wood interiors into their building design.

Biophilic research has now advanced to the point where experimental tests have been conducted on volunteers' physiological responses to hospital waiting rooms with wood interiors. Practical implications of the research include how to clean and maintain naked wood surfaces, given their known health-enhancing antimicrobial properties.⁷⁴



*Gateway Lodge Long-term Care, Prince George, B.C.
Photo credit: Derek Lepper*

In healthcare, growing interest in 'patient-centred design' is encouraging the use of natural restorative materials in patients' rooms and public waiting areas.⁷⁵ Public policy is supporting this. For example, the UK government recommends that the design of healthcare buildings should promote healing and reduce the risk of hospital-acquired infections.⁷⁶ The use of wood finishing can accomplish both goals.

For example, the Dyson Centre for neonatal care at a hospital in Bath, England was the first clinical healthcare facility in the UK to use exposed timber surfaces.⁷⁷ Researchers studying the effects of the new building on staff, parents and babies found it to be quieter and more energy efficient. Another interesting effect was that parents' interactions with their babies improved and babies slept 20 percent longer.

Scandinavian countries have also promoted wood use in hospitals and other healthcare buildings. A survey of patients and medical staff at a Norwegian hospital showed preferences for moderate amounts of wood, and it included suggested guidelines for how wood should be used in the future.⁷⁸ Marjut Wallenius, a psychologist at the University of Tampere in Finland, observes that, based on experiences in Finland, the use of wood in hospital construction and in buildings for the elderly contributes to physical and mental well-being, supports convalescence, reduces stress and raises spirits.⁷⁹ For these reasons, Dr. Wallenius encourages architects and designers to leave wood visible in the interiors of healthcare buildings.



Credit Valley Hospital, Mississauga, O.N.
Photo credit: Peter Sellar

The design of hospitals can influence patient recovery. As the *Harvard Business Review* puts it, better healing results from better hospital design.⁸⁰ Ulrich's influential study, mentioned earlier, compared two groups of hospital patients recovering from a common type of gall bladder surgery, one having a view of a brick interior wall and the other with an outside view with trees. The tree-view group had shorter post-operative hospital stays, used less medication and had fewer post-surgery complications. Wood is known to have a positive effect on people's well-being by reducing the body's natural stress responses.⁸¹ The use of wood in Maggie's Cancer Care Centres in the UK creates a calming effect on patients, their family members and caregivers. The cancer

centre at the Credit Valley Hospital in Mississauga, Ontario uses trees in its atrium, supported by a wood structure resembling tree branches. This natural environment inspires patients to feel more hopeful, an important psychological benefit.⁸²

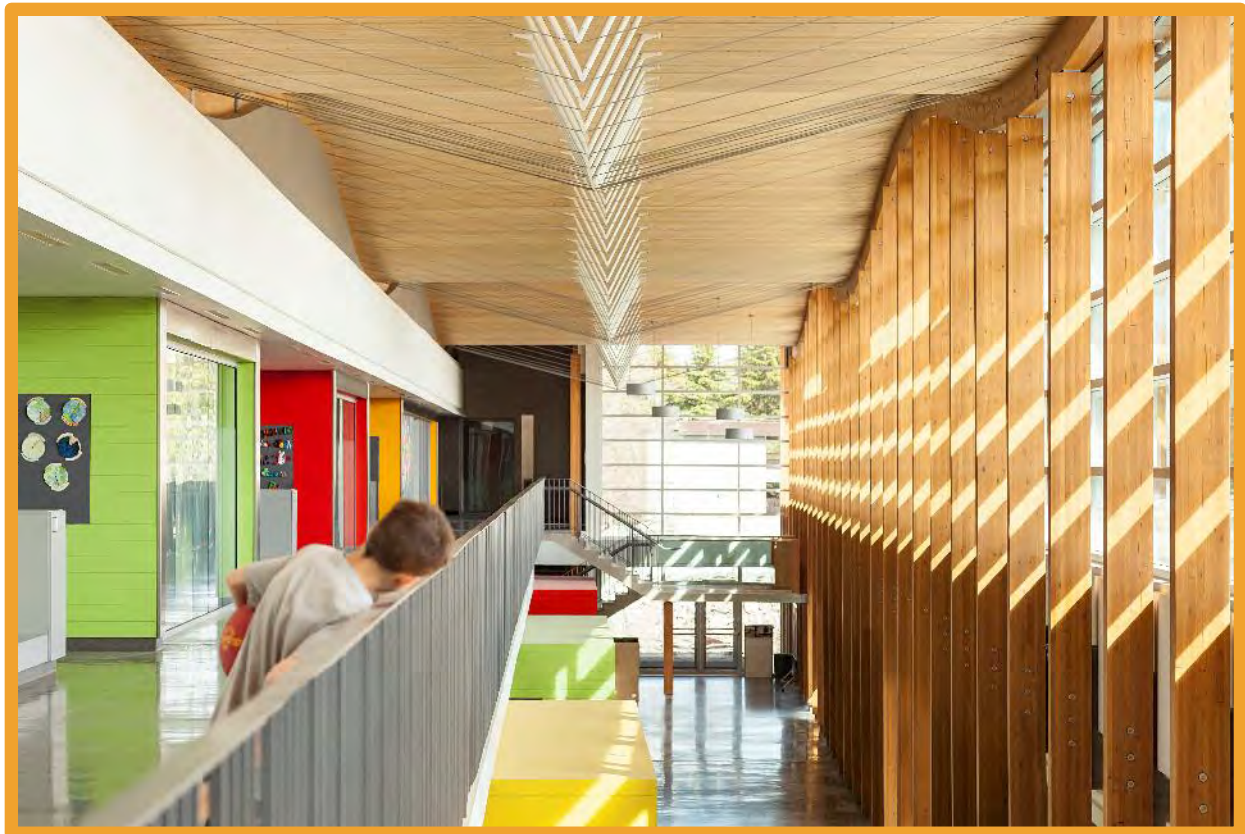
Furthermore, there is no doubt that hospital employees could benefit from the restorative and health-promoting properties of wood interiors. Healthcare providers have high levels of stress and, as one study showed, many have little if any contact with nature during their time at work.⁸³

Wood in schools

Turning now to schools, the use of wood in school construction and interior design is also increasing.⁸⁴ Schools can become less stressful for students by using wood interiors.⁸⁵ For example, a wood building at Marist College in Australia won the Australian Timber Design Sustainability Award and is described by the college principal as having "a noticeably calming effect on the students."⁸⁶

Studies document wood's positive effects on student health and performance. Austrian researchers followed 52 students for a year.⁸⁷ Children in classrooms with solid wood

finishing experienced less perceived stress and had lower heart rates. The comparison group consisted of students in classrooms fitted with linoleum floors, plasterboard walls and chipboard cupboards. Other studies in schools conclude that students' exposure to nature, especially on a daily basis, improves their learning and test performance. Cumulative evidence confirms that good daylight in classrooms can increase students' test scores between 5 percent and 18 percent. Furthermore, children's exposure to nature benefits their overall psychological well-being.⁸⁸



Samuel Brighthouse Elementary School, Richmond, B.C. | Photo credit: Andrew Latreille

The restorative benefits from exposure to wood are consistent with other biophilia research on the health benefits of plants and nature views. Wood is an ideal, eco-friendly way to bring nature into offices, healthcare facilities and schools. Research on restorative properties of wood in the built environment, especially our psychophysiological responses to wood, is a relatively new field of study.⁸⁹ Yet, available evidence leads to a clear conclusion: "wood prevents us from becoming more stressed by our environment."⁹⁰

Lessons from mass timber buildings

There is also mounting evidence of the positive impacts of mass timber buildings on occupants. Perhaps the most thorough evaluation of occupants' experiences in a wood building was done by Sylvia Coleman for her 2006 doctoral dissertation at the University of British Columbia.⁹¹ Coleman used a 'net positive' approach to study the Centre for Interactive Research on Sustainability (CIRS) Living Lab on the university campus. CIRS is a regenerative building, designed to be 'net positive' by having overall positive environmental and human benefits. Wood is the building's main structural material, and natural interior features include exposed wood, daylight and open spaces. CIRS has received a LEED Platinum rating.



Centre for Interactive Research on Sustainability (CIRS), UBC | Photo credit: Don Erhardt

Coleman's analysis of pre- and post-occupancy surveys, as well as interviews with occupants, found that occupants perceived the building as having positive effects on their health and well-being and, to a lesser extent, on their productivity. The latter finding reflected how workspaces affected noise and privacy—separate issues from the use of wood, but nonetheless potential influences on an occupant's overall satisfaction with a wood building.

Mass timber buildings benefit not only their occupants, but also workers involved throughout the construction process. This topic is overlooked in studies of non-wood green buildings for reasons that will become clear below.

A Norwegian study compared the impact of the building process for two identical buildings, one using cross-laminated timber (CLT) and the other using steel and concrete, on construction workers.⁹² The same construction firm built both. Overall, the CLT building provided a better work environment in addition to a 25 percent reduction in carbon emissions. This conclusion is based on data from multiple sources: a monthly satisfaction survey of the company's employees, work absenteeism records, a work

environment survey among subcontractors, and interviews with employees of the contractor and the sub-contractors. The CLT building had less noise and dust, had physically easier work tasks, had lower absenteeism due to illness or injury, was tidier, and had higher overall project satisfaction.

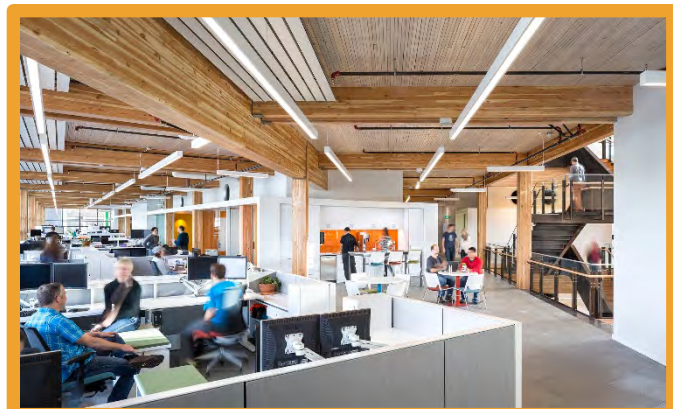


*Construction of First Tech Credit Union, Portland
Photo credit: Mike Brewington*

Because mass timber components are pre-manufactured to suit the building's design, on-site construction time can be reduced by up to 25 percent compared to traditional concrete and steel building methods.⁹³ For example, the new corporate head office of First Tech Federal Credit Union in Portland, Oregon was built with CLT, thereby reducing construction time by four months compared to a conventional steel-framed structure.⁹⁴ The

construction site was also safer, given that most work was done in a factory using a wider range of skills and offering improved career paths compared to traditional building sites.⁹⁵ Furthermore, building with wood—a renewable resource—directly aligned with First Tech's corporate values. According to the company's chief people officer, the new wood office has great aesthetics and encourages employees to come together and collaborate.⁹⁶

Building with wood also enhances an organization's brand as environmentally responsible. MEC, a Canadian outdoor gear retailer, built its new flagship store in Vancouver with locally sourced mass timber and prominently featured wood interior finishing. This wood design reflects MEC's green values and mandate, and its customers appreciate the natural wood interior.⁹⁷ Essentially, biophilic design reinforces MEC's culture.



*Mountain Equipment Coop (MEC) Headquarters, Vancouver, B.C.
Photo credit: Ed White Photographics*

The connection between culture and buildings is especially evident in wood community and health centres for several BC First Nations communities. The Tseshaht tribal multiplex and health centre on Vancouver Island reflects the cultural heritage of West Coast First Nations, particularly their respect of and attachment to nature, as well the importance of wood to their daily lives. The project embodies Tseshaht First Nation's values. The transfer of cultural values to the building design was accomplished through the active involvement of Chief and Council, community members, elders and the future users of the building. First Tech, MEC and Tseshaht First Nations are good examples of how organizations using wood as an integral biophilic design feature are discovering that it strengthens their culture.



Tseshaht Tribal Multiplex and Health Centre, Port Alberni, B.C. | Photo credit: Lubor Trubka Architects

When it comes to workspaces, as Rex Miller and his workplace design colleagues put it in their book, *Change Your Space, Change Your Culture*, a company's workspace is a proxy for its culture.⁹⁸ How employees experience the landscape of their workspace on a daily basis has a big impact on their level of job engagement—which in turn drives organizational success. This perspective on culture encourages a shift in thinking away from viewing commercial real estate as 'sunk costs' to seeing it as an investment that yields compound interest for occupants and the organization.

Next steps

This section outlines actions that building designers, building owners, mass timber manufacturers, contractors, employers, researchers and policymakers can take to further the use of wood in the construction of non-residential buildings and their interiors.

Above all, the key practical lesson emerging from the research we have reviewed is that more can be done to improve the methods and metrics for evaluating the human and organizational benefits of wood buildings and interiors. The result will be higher-quality evidence that can inform decision-making throughout the planning, design, construction and occupancy phases of wood buildings.

Questions to address in future research

All the studies reviewed in this report end by itemizing future questions that, when answered, will provide a better understanding of how green buildings, and specifically wood buildings and wood interiors, benefit occupants. Here are the most relevant questions for the different groups of decision-makers involved throughout the design, construction and occupancy phases of wood buildings:

- For policy makers:
 - How do the health benefits of wood buildings contribute to major public health goals?
 - What are the appropriate policy levers for encouraging researcher/practitioner collaboration and effective knowledge transfer of study findings to decision-makers?
- For building owners and leasees:
 - What are the economics (e.g., health-related cost-savings, performance improvements, efficiencies, and returns on investment) of wood buildings and wood interiors?
 - What duration of exposure to a wood structure and/or interior is needed to yield specific health and productivity benefits, and do these benefits change over time?
- For employers:
 - Does the move into a building with a wood structure and/or interior have a measurable impact on employee stress and burnout, job performance, engagement and well-being?

- How can available organizational data be mined to document wood's health and productivity benefits?
- For designers, general contractors and manufacturers:
 - How do specific features of a building influence occupants' experiences of the new facility?
 - Relevant features include building size, office layout (e.g., open plan), access to natural light, ergonomic and green features of office furniture, interior finishing materials, and occupants' input into building and interior design.
 - To what extent and how do preferences for and perceptions of wood construction and interiors vary by sociodemographic group and cultural context?
- For researchers:
 - What are the most accurate metrics for assessing health and productivity benefits of wood structures and wood interiors?
 - How do the demographic characteristics of occupants (i.e., gender, age, ethnicity, education, job type, annual average earnings), as well as their health status and level of work engagement prior to moving into a wood building, influence their health and productivity?

As Joseph Allen and his co-researchers at Harvard University's Chan School of Public Health, observe: "The studies of green buildings conducted to date... were all attempting to answer a seemingly straightforward question—are green buildings healthier buildings? ... For health researchers, the fundamental question that should guide future research is 'what constitutes a healthy building, and how do we measure this?'"

Allen, J. G., MacNaughton, P., Laurent, J. G. C., Flanigan, S. S., Eitland, E. S., & Spengler, J. D. (2015). Green buildings and health. *Current Environmental Health Reports*, 2, 255.

Answering these questions invites collaboration between researchers from universities and industry organizations, practitioners and decision-makers involved throughout the design, construction and operation of a wood building. Researchers need access to buildings and their occupants; building designers, contractors and leasees need accurate

evidence of how wood buildings impact occupants. Canada—especially British Columbia—is fertile ground for this sort of collaboration based on the research reviewed earlier.

Better research methods and metrics

Several research challenges must be overcome in order to accurately answer the above questions about how wood benefits humans and organizations. None of these challenges are insurmountable. Practitioners will benefit from better designed monitoring and evaluation methods by having more extensive and accurate evidence to inform future decisions on wood building design, construction and operations.

Here are examples of rigorous approaches for monitoring and evaluating the impact of wood buildings on occupants:

- Public health researchers, who are interested in building-related health outcomes, recommend using a longitudinal cohort research design. Basically, this tracks the same group of building occupants over an extended period of time, measuring their health pre- and post-occupancy of a new work environment built with wood.⁹⁹
- Some studies described earlier in this report used a ‘natural’ experiment research design. This design compares similar groups of individuals in different indoor environments, one with wood construction and/or interiors and the other with no wood.
- The World Green Building Council (WGBC) recommends monitoring eight physical attributes of a healthy office environment: indoor air quality and ventilation, thermal comfort, daylighting and lighting, noise and acoustics, interior layout and active design, biophilia and views, look and feel, and location and access to amenities.¹⁰⁰ These factors can affect occupants’ job performance, sleep, cognitive functioning, workplace satisfaction and absenteeism.
- Many employers track employees’ work engagement using surveys. It is important to link these results to pre- and post-occupancy surveys in wood buildings.¹⁰¹ It is possible that workers who are more engaged in their work, and therefore more satisfied with their employer, are favourably pre-disposed to a new wood building or wood interior renovation even before they move in.

- Three complementary data sources can be ‘triangulated’ to get a clearer picture of the health and productivity impacts of the use of wood structures and/or interiors in office buildings: available corporate data on employee engagement, absenteeism, staff retention and turnover, use of medical services, work performance, customer satisfaction, and customer complaints; evaluations of lighting, indoor air quality, and acoustic, thermal and humidity comfort; and online surveys and wearable technology to track occupants’ health pre- and post-move or office refurbishment.¹⁰²
- Studies show that workers with some control over their immediate workspace are more satisfied and productive than those lacking control.¹⁰³ Evidence-based design directly involves end-users in a wood building’s planning and construction. A good example of this approach is the Surrey Memorial Hospital’s Critical Care Tower in British Columbia. Extensive consultation with clinical staff assured that the new facility would enable the delivery of excellent patient care in a safe environment.¹⁰⁴



*Surrey Memorial Hospital Critical Care Tower, B.C.
Photo credit: Ed White Photographics*

- Organizations often collect and report ‘key performance indicators’ (KPIs) to measure progress toward their strategic goals. Evaluations of how a wood building or wood interior impacts occupants could use the following types of KPIs: employees’ work engagement or job satisfaction, students’ standardized test scores, or hospital patients’ recovery time.¹⁰⁵

In summary, practitioners and researchers should focus on measuring building characteristics and occupant outcomes that can best inform decision-making during a building's entire life cycle. New technologies will make these measurements easier. Future research on IEQ, building acoustics, thermal comfort, lighting and pollution will be able to utilize low-cost, easy-to-calibrate automated mobile sensing devices.¹⁰⁶ There are new tools to assess an occupant's cognitive, sensory and affective responses to indoor wood use in buildings.¹⁰⁷ Portable digital devices (wearables) enable the real-time tracking of building occupants' physical, psychological and social responses to their work environment. Finally, virtual reality can track occupants' responses to different workspace designs, helping architects, building owners and employers identify wood design features that promote health early in the design process.¹⁰⁸

Conclusion

Wood can create green, healthy and productive indoor environments. British Columbia is ideally positioned to continue taking on a leadership role in wood building design and construction. There is a convergence of social, political and economic factors accelerating the adoption of wood construction and wood interiors as the environmentally and humanly sustainable green building solution. Research conducted in a wide range of disciplines point to the same evidence-based conclusion: wood is good for the environment, for people and for organizations.

In the future, research on the health, well-being and productivity benefits of wood buildings needs to produce results that can inform decisions made by designers, general contractors, manufacturers, building owners, employers and policy makers. Above all, this need for such research calls for a tighter connection between the academic and practitioner worlds, as well as closer collaboration in future projects evaluating occupants' experiences. It also underscores the importance of learning from past studies, building on their strengths and addressing their weaknesses. Taking all this into account will provide the additional evidence needed to design and build tomorrow's high-performing wood buildings.

Endnotes

- ¹ Zeller, J. (November 2019). Brick & Beam 2.0: 80 Atlantic, Toronto, Ontario. *Canadian Architect*, 64, 43-46.
- ² Ramage, M. H., Burrige, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D. U. et al. (2017). The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, 68, 333-359.
- ³ Government of British Columbia, *Tall Wood Initiative*. (2019). <https://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/the-codes/other-regulations/tall-wood-buildings-initiative>
- ⁴ BC Government News. Office of the Premier. <https://news.gov.bc.ca/releases/2019PREM0109-001840>
- ⁵ Hixson, R. (January 29, 2020). Alberta to adopt 12-storey wood building standard. *Journal of Commerce*. <https://canada.constructconnect.com/joc/news/associations/2020/01/alberta-to-adopt-12-storey-wood-building-standard>
- ⁶ Think Wood. (2019). *Taller Wood*. <https://www.thinkwood.com/building-better/taller-buildings>
- ⁷ Moriarty, N.A. (2018). Evaluating high-rise wood construction. *Consulting-Specifying Engineer*, 55 (6), 34-37.
- ⁸ Parkin, A. (November 12, 2019). *Regional Perspectives on Politics and Priorities*. Environics Institute. <https://www.environicsinstitute.org/projects/project-details/regional-perspectives-on-politics-and-priorities>; Angus Reid Institute. (September 5, 2019) Division remains over federal carbon tax, but most want to do more to meet 2030 emission reduction goal. <http://angusreid.org/election-2019-climate-change/>
- ⁹ Lorinc, J. (January 6, 2020). Five planet-saving building ideas we need to nail down in 2020. *Corporate Knights*. <https://www.corporateknights.com/channels/built-environment/five-green-building-shifts-canada-needs-nail-2020s-15783012/>
- ¹⁰ Massa, A. (January 14, 2020). BlackRock puts environmental sustainability at centre of strategy. <http://www.bnnbloomberg.ca/blackrock-puts-environmental-sustainability-center-of-strategy-1.1373467>
- ¹¹ Smedley, T. (July 24, 2019). Could wooden buildings be a solution to climate change? *BBC Future*. <https://www.bbc.com/future/article/20190717-climate-change-wooden-architecture-concrete-global-warming>
- ¹² For an extensive review of research and practice in this area see: Lowe, G. (2020). *Creating Healthy Organizations: Taking Action to Improve Employee Well-being*. Toronto: University of Toronto Press.
- ¹³ World Green Building Council (WGBC). (September 2014). *Health, Wellbeing & Productivity in Offices: The Next Chapter for Green Building*, 7. https://www.ukgbc.org/sites/default/files/Health%2520Wellbeing%2520and%2520Productivity%2520in%2520Offices%2520-%2520The%2520next%2520chapter%2520for%2520green%2520building%2520Full%2520Report_0.pdf

-
- ¹⁴ Leidner, S., Baden, D., and Ashleigh, M. J. (2019). Green (environmental) HRM: Aligning ideals with appropriate practices. *Personnel Review*, 48, 1169-1185; Dumont, J., Shen, J. and Deng, X. (2017). Effects of green HRM practices on employee workplace green behavior: The role of psychological green climate and employee green values. *Human Resource Management*, 56, 613-627.
- ¹⁵ Terrapin Bright Green LLC. (2012). *The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense*, 14. <https://www.terrapinbrightgreen.com/report/economics-of-biophilia/>
- ¹⁶ Young, W., Davis, M., McNeill, I. M., Malhotra, B., Russell, S., Unsworth, K., and Clegg, C. W. (2015) Changing behaviour: Successful environmental programmes in the workplace. *Business Strategy and the Environment*, 24, 689-703; Raineri, N. and Paillé, P. (2016). Linking corporate policy and supervisory support with environmental citizenship behaviors: The role of employee environmental beliefs and commitment. *Journal of Business Ethics*, 137, 129-148.
- ¹⁷ World Green Building Council. What is a green building? <https://www.worldgbc.org/what-green-building>
- ¹⁸ World Green Building Council. (2014). *Health, Wellbeing and Productivity in Offices: The Next Chapter for Green Building*. https://www.ukgbc.org/sites/default/files/Health%20Wellbeing%20and%20Productivity%20in%20520Offices%20-%20The%20next%20chapter%20for%20green%20building%20Full%20Report_0.pdf
- ¹⁹ Canada Green Building Council and Dodge Data & Analytics. (2016). *Healthier Buildings in Canada 2016: Transforming Building Design and Construction*. https://www.cagbc.org/cagbcdocs/Smart_Market_Report_Final_Web_PUBLIC.pdf
- ²⁰ Canada Green Building Council and Dodge Data & Analytics. (2016). *Healthier Buildings in Canada 2016: Transforming Building Design and Construction*. https://www.cagbc.org/cagbcdocs/Smart_Market_Report_Final_Web_PUBLIC.pdf
- ²¹ Hui, F.K.P., and Aye, L. (2018). Occupational stress and workplace design. *Buildings*, 8, 133; Suttie, E. (2017). Is wood good for your health? *Timber 2017 Industry Workbook*, 33. https://issuu.com/trada/docs/trada_2017_medium-res
- ²² Allen, J. G., MacNaughton, P., Laurent, J. G. C., Flanigan, S. S., Eitland, E. S., and Spengler, J. D. (2015). Green buildings and health. *Current Environmental Health Reports*, 2, 250-258.
- ²³ MacNaughton, P., Satish, U., Laurent, J. G. C., Flanigan, S., Vallarino, J., Coull, B. et al. (2017). The impact of working in a green certified building on cognitive function and health. *Building and Environment*, 114, 178-186.
- ²⁴ Gou, Z. (2019). Human factors in green building: Building types and users' needs. *Buildings*, 9, 17.
- ²⁵ Dreyer, B. C., Coulombe, S., Whitney, S., Riemer, M., and Labbé, D. (2018). Beyond exposure to outdoor nature: Exploration of the benefits of a green building's indoor environment on wellbeing. *Frontiers in Psychology*, 9, 1583.

-
- ²⁶ Terrapin Bright Green LLC. (2012). *The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense*, 13; *Human Spaces Report: Biophilic Design in the Workplace*. (2015), 15. <https://www.plus.nl/resources/articlefiles/Human-Spaces-report-web-res-3.pdf.pdf>. Also see: (2004). Hemp P. (2004). Presenteeism: At work--but out of it. *Harvard Business Review*, 82(10), 49-58, 155; World Green Building Council (2014), *Health, Wellbeing and Productivity in Offices: The Next Chapter for Green Building*, 56. https://www.ukgbc.org/sites/default/files/Health%20Wellbeing%20and%20Productivity%20in%20Offices%20-%20The%20next%20chapter%20for%20green%20building%20Full%20Report_0.pdf
- ²⁷ See Lowe, G. (2020). *Creating Healthy Organizations: Taking Action to Improve Employee Well-being*. Toronto: University of Toronto Press.
- ²⁸ World Health Organization. (2016). *Constitution of the World Health Organization*. https://www.who.int/governance/eb/who_constitution_en.pdf
- ²⁹ Timm, S. (September 23, 2019). Can architects solve employee burnout? *Well*. <https://resources.wellcertified.com/articles/can-architects-solve-employee-burnout/>
- ³⁰ See Lowe, G. (2020). *Creating Healthy Organizations: Taking Action to Improve Employee Well-being*. Toronto: University of Toronto Press.
- ³¹ Singh, A., Syal, M., Grady, S. C., and Korkmaz, S. (2010). Effects of green buildings on employee health and productivity. *American Journal of Public Health*, 100, 1665-1668.
- ³² Allen, J.G. (March 2017). Research: Stale office air is making you less productive. *Harvard Business Review*. <https://hbr.org/2017/03/research-stale-office-air-is-making-you-less-productive>
- ³³ Newsham, G. R., Veitch, J. A., and Hu, Y. (2018). Effect of green building certification on organizational productivity metrics. *Building Research & Information*, 46, 755-766.
- ³⁴ Ng, T.W.H., Yam, K.C., and Aguinis, H. (2019). Employee perceptions of corporate social responsibility: Effects on pride, embeddedness, and turnover. *Personnel Psychology*, 72, 107-137.
- ³⁵ Raineri, N. and Paillé, P. (2016). Linking corporate policy and supervisory support with environmental citizenship behaviors: The role of employee environmental beliefs and commitment. *Journal of Business Ethics*, 137, 129-148.
- ³⁶ See for example: *Architect*. (March 2016). Wood: Warm, natural, response to commercial office space, 105 (3), 28; *Architect*. (September 2019). Design and construction of taller wood buildings, 64-67; *Canadian Architect*. (October 2016). World's tallest timber building tops out in Vancouver, 15-16; *Canadian Architect*. (June 2019). D'Ambrosio Architecture unveils design for twelve-storey mass timber project, 7.
- ³⁷ Arsenault, P. J. (2017). The evolving workplace environment. *Architectural Record*, 205, 138-146.
- ³⁸ Canada Green Building Council and Dodge Data & Analytics. (2016). *Healthier Buildings in Canada 2016: Transforming Building Design and Construction*. https://www.cagbc.org/cagbcdocs/Smart_Market_Report_Final_Web_PUBLIC.pdf
- ³⁹ McGraw Hill Construction. (2014). *The Drive Toward Healthier Buildings: The Market Drivers and Impact of Building Design and Construction on Occupant Health, Well-being and Productivity*. American Institute of Architects. SmartMarket Report. <https://www.aia.org/resources/8351-the-drive-toward-healthier-buildings>

-
- ⁴⁰ Cedeño-Laurent, J. G., Williams, A., MacNaughton, P., Cao, X., Eitland, E., Spengler, J. and Allen, J.I. (2018). Building evidence for health: Green buildings, current science, and future challenges. *Annual Review of Public Health*, 39, 291-308.
- ⁴¹ Clements-Croome, D., Turner, B., and Pallaris, K. (2019) Flourishing workplaces: A multisensory approach to design and POE. *Intelligent Buildings International*, 11 (3-4), 131-144.
- ⁴² Canada Green Building Council and Dodge Data & Analytics. (2016). *Healthier Buildings in Canada 2016: Transforming Building Design and Construction*.
[https://www.cagbc.org/cagbcdocs/Smart Market Report Final Web PUBLIC.pdf](https://www.cagbc.org/cagbcdocs/Smart_Market_Report_Final_Web_PUBLIC.pdf)
- ⁴³ International Well Building Institute. (September 1, 2015). *Canada and the WELL Building Standard*.
<https://resources.wellcertified.com/articles/canada-and-the-well-building-standard/>; also see:
<http://www.gbcicanada.ca/well.shtml>
- ⁴⁴ Parsian, M. (August 2018). *Understanding the Applicability of the WELL Building Standard to UBC's Academic Context*. University of British Columbia, Sustainability and Engineering Department.
https://sustain.ubc.ca/sites/sustain.ubc.ca/files/Sustainability%20Scholars/2018_Sustainability_Scholars/Reports/2018-41%20Understanding%20the%20applicability%20of%20the%20WELL%20Building%20standard%20at%20UBC_Parsian.pdf
- ⁴⁵ Terrapin Bright Green LLC. (2012). *The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense*, 5.
- ⁴⁶ Soderlund, J. and Newman, P. (2015). Biophilic architecture: a review of the rationale and outcomes. *AIMS Environmental Science*, 2, 950-969.
- ⁴⁷ See for example: Grinde, B., and Patil, G. G. (2009). Biophilia: Does visual contact with nature impact on health and well-being? *International Journal of Environmental Research and Public Health*, 6(9), 2332-2343; McMahan, E. A., and Estes, D. (2015). The effect of contact with natural environments on positive and negative affect: A meta-analysis. *Journal of Positive Psychology*, 10, 507-519; Zelenski, J. M., and Nisbet, E. K. (2014). Happiness and feeling connected: The distinct role of nature relatedness. *Environment & Behavior*, 46, 3-23.
- ⁴⁸ Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn Jr, P. H., Lawler, J. J. et al. Nature contact and human health: A research agenda. *Environmental Health Perspectives*, 125, 075001.
- ⁴⁹ FPInnovations. (2014). *Wood and Human Health. Wood & Human Health Series, Issue 1*.
[https://www.nordic.ca/data/files/publication/Wood Human Health final-single.pdf](https://www.nordic.ca/data/files/publication/Wood_Human_Health_final-single.pdf)
- ⁵⁰ Demattè, M. L., Zucco, G. M., Roncato, S., Gatto, P., Paulon, E., Cavalli, R. et al. (2018). New insights into the psychological dimension of wood-human interaction. *European Journal of Wood and Wood Products*, 76, 1093-1100.
- ⁵¹ Burnard, M. D. and Kutnar, A. (2015). Wood and human stress in the built indoor environment: a review. *Wood Science and Technology*, 49, 969-986.
- ⁵² Ayuso Sanchez, J., Ikaga, T., and Vega Sanchez, S. (2018). Quantitative improvement in workplace performance through biophilic design: A pilot experiment case study. *Energy and Buildings*, 177, 316-328.

-
- ⁵³ Ohta, H., Maruyama, M., Tanabe, Y., Hara, T., Nishino, Y., Tsujino, Y. et al. (2008). Effects of redecoration of a hospital isolation room with natural materials on stress levels of denizens in cold season. *International Journal of Biometeorology*, 52, 331-340; Weenig, M. W. H. and Staats, H. (2010). The impact of a refurbishment of two communal spaces in a care home on residents' subjective well-being. *Journal of Environmental Psychology*, 30, 542-552.
- ⁵⁴ Terrapin Bright Green LLC. (2012). *The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense*, 11-12.
- ⁵⁵ Baxter, D.E., and Pelletier, L.G. (2019). Is Nature Relatedness a Basic Human Psychological Need? A Critical Examination of the Extant Literature. *Canadian Psychology/Psychologie canadienne*, 60(1), 21-34.
- ⁵⁶ Baxter, D.E., and Pelletier, L.G. (2019). Is Nature Relatedness a Basic Human Psychological Need? A Critical Examination of the Extant Literature. *Canadian Psychology/Psychologie canadienne*, 60(1), 30.
- ⁵⁷ Think Wood. (2016). *Wood and Indoor Environment. Creating Beneficial Spaces for Living, Working, Well-being*. Continuing Education, 7. <https://1r4scx402tmr26fqa93wk6an-wpengine.netdna-ssl.com/wp-content/uploads/2019/08/Think-Wood-CEU-Wood-and-Indoor-Environment.pdf>
- ⁵⁸ Watchman, M., Potvin, A., and Demers, C. (2017). A Post-occupancy Evaluation of the Influence of Wood on Environmental Comfort. *BioResources*, 12(4), 8704-8724.
- ⁵⁹ Wood and Human Health. FPIInnovations. <https://www.naturallywood.com/sites/default/files/Wood%20and%20Human%20Health.pdf>
- ⁶⁰ Jalilzadehazhari, E. and Johansson, J. (2019). Material properties of wooden surfaces used in interiors and sensory stimulation. *Wood Material Science & Engineering*, 14, 192-200; Watchman, M., Potvin, A., and Demers, C. (2017). A Post-occupancy evaluation of the influence of wood on environmental comfort. *BioResources*, 12 (4), 8704-8724.
- ⁶¹ TRADA. (2019). *TRADA Briefing: The role of wood in healthy buildings*, 4-6. <https://www.trada.co.uk/publications/other-technical-guidance/the-role-of-wood-in-healthy-buildings/>
- ⁶² TRADA. (2019). *TRADA Briefing: The role of wood in healthy buildings*, 20-22. <https://www.trada.co.uk/publications/other-technical-guidance/the-role-of-wood-in-healthy-buildings/>
- ⁶³ Jutraž, A., Kukec, A., Otorepec, P., Lampič, L., Pohleven, J., Sandak, J., and Varkonji Sajn, M. (2019). Monitoring environmental and health impact data in BIM models to assure healthy living environments. *Zenodo*. <https://zenodo.org/record/3457814#.XelaZjNKiUk>
- ⁶⁴ Jutraž, A., Kukec, A., Otorepec, P., Lampič, L., Pohleven, J., Sandak, J., and Varkonji Sajn, M. (2019). Monitoring environmental and health impact data in BIM models to assure healthy living environments. *Zenodo*. <https://zenodo.org/record/3457814#.XelaZjNKiUk>
- ⁶⁵ Cao, Y., Hao Zhanga, L., McCabe, B, and Shahi, A. (2019). The benefits of and barriers to BIM adoption in Canada. Proceedings of the 36th ISARC (The International Association for Automation and Robotics in Construction), Banff, Alberta, Canada, 152-158. https://www.iaarc.org/publications/2019_proceedings_of_the_36th_isarc/the_benefits_of_and_barriers_to_bim_adoption_in_canada.html
- ⁶⁶ Knox, A., and Parry-Husbands, H. (February 2018). *Workplaces: Wellness + Wood = Productivity*. Forest & Wood Products Australia. <https://makeitwood.org/healthandwellbeing/wellness-study.cfm>

-
- ⁶⁷ Bysheim, K., Nyrud, A.Q. and Strobel, K. (March 2016). *Rapport 88, 2016 Building materials and wellbeing in indoor environments: A focus group study*. Oslo: Norwegian Institute of Wood Technology. <http://www.tretekensk.no/resources/filer/publikasjoner/rapporter/Rapport-88.pdf>
- ⁶⁸ Planet Ark. (2017). *Wood: Nature Inspired Design. An Update of the Wood – Housing, Health, Humanity Report*, 17. <https://makeitwood.org/documents/doc-1501-wood---nature-inspired-design-report-v3.pdf>
- ⁶⁹ Nyrud, A.Q., Bringslimark, T. and Bysheim, K. (2014). Benefits from wood interior in a hospital room: A preference study. *Architectural Science Review*, 57 (2), 125-131.
- ⁷⁰ *Human Spaces Report: Biophilic Design in the Workplace*. (2015), 7. <https://www.plus.nl/resources/articlefiles/Human-Spaces-report-web-res-3.pdf.pdf>. This study was sponsored by Interface, the world's largest manufacturer of commercial carpet tiles, and conducted under the direction of Professor Sir Cary Cooper, a leading work psychologist.
- ⁷¹ Terrapin Bright Green LLC. (2012). *The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense*, 9.
- ⁷² This study has been cited in over 5,400 other published articles. Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, 224, 420-421.
- ⁷³ Andrade, C. C. and Devlin, A. S. (2015). Stress reduction in the hospital room: Applying Ulrich's theory of supportive design. *Journal of Environmental Psychology*, 41, 125-134.
- ⁷⁴ Kotradyova, V., Vavrinsky, E., Kalinakova, B., Petro, D., Jansakova, K., Boles, M. et al. (2019). Wood and its impact on humans and environment quality in health care facilities. *International Journal of Environmental Research and Public Health*, 16, 3496. <https://www.mdpi.com/1660-4601/16/18/3496#>
- ⁷⁵ Gou, Z. (2019). Human factors in green building: Building types and users' needs. *Buildings*, 9, 17.
- ⁷⁶ TRADA. (2019). *TRADA Briefing: The role of wood in healthy buildings*, 1. <https://www.trada.co.uk/news/new-trada-briefing-document-the-role-of-wood-in-healthy-buildings-packs-a-punch/>
- ⁷⁷ Wood for Good. (2019). *The Healing Power of Wood in Healthcare Buildings*. <https://woodforgood.com/news-and-views/2018/07/04/the-healing-power-of-wood-in-healthcare-buildings/>
- ⁷⁸ TRADA. (2019). *TRADA Briefing: The role of wood in healthy buildings*. <https://www.trada.co.uk/news/new-trada-briefing-document-the-role-of-wood-in-healthy-buildings-packs-a-punch/>
- ⁷⁹ Puuinfo. (2014). The use of wood in hospital construction supports convalescence. <https://www.woodproducts.fi/articles/use-wood-hospital-construction-supports-convalescence-0>
- ⁸⁰ Yamaguchi, Y. (October 5, 2015). Better healing from better hospital design. *Harvard Business Review*. <https://hbr.org/2015/10/better-healing-from-better-hospital-design>
- ⁸¹ Wood for Good. (2019). The healing power of wood in healthcare buildings. <https://woodforgood.com/news-and-views/2018/07/04/the-healing-power-of-wood-in-healthcare-buildings/>
- ⁸² Planet Ark. (2017). *Wood: Nature Inspired Design. An Update of the Wood – Housing, Health, Humanity Report*, 10. <https://makeitwood.org/documents/doc-1501-wood---nature-inspired-design-report-v3.pdf>

-
- ⁸³ Trau, D., Keenan, K. A., Goforth, M., and Large, V. (2015). Nature contacts: Employee wellness in healthcare. *HERD: Health Environments Research & Design Journal*, 9, 47-62.
- ⁸⁴ ThinkWood. <https://www.thinkwood.com/news/geeks-are-chic-and-wood-is-cool-for-school-how-timber-is-transforming-school-design>
- ⁸⁵ Elias, M. J. (1989). Schools as a source of stress to children: An analysis of causal and ameliorative influences. *Journal of School Psychology*, 27, 393-407.
- ⁸⁶ Planet Ark. (2017). *Wood: Nature Inspired Design. An Update of the Wood – Housing, Health, Humanity Report*, 25. <https://makeitwood.org/documents/doc-1501-wood---nature-inspired-design-report-v3.pdf>
- ⁸⁷ Schule ohne stress (School without stress). http://humanresearch.at/newwebcontent/?page_id=75&lang=en; also see: Kelz, C., Grote, V., and Moser, M. (September 26–28, 2011). Interior wood use in classrooms reduces pupils' stress levels. Proceedings of the 9th Biennial Conference on Environmental Psychology, Eindhoven, The Netherlands.
- ⁸⁸ Terrapin Bright Green LLC. (2012). *The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense*, 21-22.
- ⁸⁹ Augustin, S., and Fell, D. (February 2015). Wood as a restorative material in healthcare environments. FPIInnovations. <https://www.bcfii.ca/system/files/reports/public/wood-restorative-material-healthcare-environments.pdf>
- ⁹⁰ Augustin, S., and Fell, D. (February 2015). Wood as a restorative material in healthcare environments. FPIInnovations, 17. <https://www.bcfii.ca/system/files/reports/public/wood-restorative-material-healthcare-environments.pdf>
- ⁹¹ Coleman, S. (2016). Normalizing sustainability in a regenerative building: The social practice of being at CIRS. Doctoral dissertation. University of British Columbia. <https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0319909>
- ⁹² Halseth, P.T. Comparing two identical buildings in wood and concrete: Health and work environment for workers. Norwegian University of Science and Technology. <http://www.treteknisk.no/resources/filer/aktuelt/tre-og-helse/1.-Petter-Toras-Halseth.pdf>
- ⁹³ Structurlam press release. (December 9, 2019). <https://www.structurlam.com/external/press-kit/StructurlamPressKit-NewsRelease-StructurlamSelectsConway-r2.pdf>
- ⁹⁴ Libby, B. (April 8, 2019). Using CLT, hacker architects helps connect a workplace to its surrounding nature preserve. <https://www.metropolismag.com/architecture/hacker-architects-first-tech-federal-credit-union-office/>
- ⁹⁵ Hairstans, R. (2019). A clean technology solution for a healthy built environment. *Timber 2019 Industry Yearbook*. Timber Research and Development Association (TRADA), 55. <https://www.trada.co.uk/publications/magazine-articles/a-clean-technology-solution-for-a-healthy-built-environment/>
- ⁹⁶ Libby, B. (April 8, 2019). Using CLT, hacker architects helps connect a workplace to its surrounding nature preserve. *Metropolis*. <https://www.metropolismag.com/architecture/hacker-architects-first-tech-federal-credit-union-office/>

-
- ⁹⁷ ThinkWood. (November 1, 2019). *Biophilic Brands: Can Wood and Nature Boost the Bottom Line?* <https://www.thinkwood.com/news/biophilic-brands-can-wood-and-nature-boost-the-bottom-line-2>
- ⁹⁸ Miller, R., Casey, M., and Konchar, M. (2014). *Change Your Space, Change Your Culture: How Engaging Workspaces Lead to Transformation and Growth*. Hoboken, N.J.: Wiley, 16.
- ⁹⁹ Cedeño-Laurent, J. G., Williams, A., MacNaughton, P., Cao, X., Eitland, E., Spengler, J. and Allen, J.I. (2018). Building evidence for health: Green buildings, current science, and future challenges. *Annual Review of Public Health*, 39, 302.
- ¹⁰⁰ World Green Building Council. (October 2016). *Building the Business Case: Health, Wellbeing & Productivity in Green Offices*. https://www.worldgbc.org/sites/default/files/WGBC_BtBC_Dec2016_Digital_Low-MAY24_0.pdf
- ¹⁰¹ Feige, A., Wallbaum, H., Janser, M., and Windlinger, L. (2013). Impact of sustainable office buildings on occupant's comfort and productivity. *Journal of Corporate Real Estate*, 15, 7-34.
- ¹⁰² Suttie, E. (June 6, 2019). Gathering the evidence – the Biophilic Office Project. Presentation at the Wellness & Biophilia Symposium, BRE, Watford, England. <https://www.bregroup.com/wp-content/uploads/2019/06/Ed-Suttie.pdf>
- ¹⁰³ De Croon, E., Sluiter, J., Kuijer, P. P., and Frings-Dresen, M. (2005). The effect of office concepts on worker health and performance: a systematic review of the literature. *Ergonomics*, 48, 119-134; Bodin Danielsson, C., Chungkham, H. S., Wulff, C., and Westerlund, H. (2014). Office design's impact on sick leave rates. *Ergonomics*, 57, 139-147.
- ¹⁰⁴ Canadian Wood Council. (2017). *Surrey Memorial Hospital Critical Care Tower: A Case Study*. <http://www.wooddesignandbuilding.com/wp-content/uploads/2017/04/SurreyCaseStudy-WEB.pdf>
- ¹⁰⁵ Allen, J. G., MacNaughton, P., Laurent, J. G. C., Flanigan, S. S., Eitland, E. S., and Spengler, J. D. (2015). Green buildings and health. *Current Environmental Health Reports*, 2, 250-258.
- ¹⁰⁶ Jin, M., Liu, S., Schiavon, S., and Spanos, C. (2018). Automated mobile sensing: Towards high-granularity agile indoor environmental quality monitoring. *Building and Environment*, 127, 268-276.
- ¹⁰⁷ Dematté, M. L., Zucco, G. M., Roncato, S., Gatto, P., Paulon, E., Cavalli, R. et al. (2018). New insights into the psychological dimension of wood—human interaction. *European Journal of Wood and Wood Products*, 76, 1093-1100.
- ¹⁰⁸ Yin, J., Arfaei, N., MacNaughton, P., Catalano, P. J., Allen, J. G., and Spengler, J. D. (2019). Effects of biophilic interventions in office on stress reaction and cognitive function: A randomized crossover study in virtual reality. *Indoor Air*, 29, 1028-1039.