CONSIDERATION OF THE USE PHASE IN CERTIFICATION PROGRAMS FOR RESIDENTIAL GREEN BUILDING

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ABSTRACT

The building industry is associated with several environmental impacts. In considering the total building lifecycle, the use phase has a strong influence on the level of impact. According to the literature, the use phase of residential buildings represents up to 92% of energy consumption, constitutes 95% of water consumption (indoor and outdoor), accounts for 45% of the weight of materials used, and produces 50% of the waste (maintenance, repair, and renovation). Green building and certification programs used in North America, such as *BOMA-BESt®*, *LEED®*, and *Living Building Challenge*™, aim to reduce the environmental footprint of housing. However, while these certifications provide a useful framework for practices related to buildings and their systems, a documentary analysis shows that they do not adequately take into account the use phase of residential buildings. The purpose of this paper is to show that consideration of the use phase is inconsistent with the impacts associated with it.

KEYWORDS

green building, residential, use phase, certification programs, environmental impact

INTRODUCTION

The building industry is associated with several environmental impacts. This article will begin by providing a detailed outline of these general impacts in terms of energy consumption, water consumption, materials and resources use, waste generation, and also impacts on indoor environments. Second, a review of the literature is used to quantify the specific impact of the use phase of residential buildings. When considering their total lifecycle, the use phase accounts for the majority of the effects related to energy and water consumption, as well as the management of resources, materials, and waste. Finally, in order to determine whether the green building movement is apt to respond to contemporary environmental issues, a documentary analysis of three certification programs used in North America (BOMA-BESt®, LEED®, and Living Building Challenge™) is carried out. The goal is to determine how these certifications address the environmental impacts of the design and construction of residential buildings, the conception and selection of the systems, and also use by the occupants.

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BACKGROUND

Environmental impacts of the building industry

The building industry generates several environmental impacts associated with energy consumption and greenhouse gas emissions, water consumption, materials and resources use, and waste generation, as well as impacts on indoor environments.

Energy

Energy consumption is a significant factor among the environmental concerns related to buildings. Energy used by buildings has steadily increased since the eighties and has even exceeded the consumption of the industrial sector since 1998 (McGraw Hill Construction 2010). Worldwide, the building industry consumes between 30% and 40% of total energy used and produces the most greenhouse gas (GHG), at 30% of total emissions (UNEP SBCI 2010). Buildings use energy directly throughout their lifecycles during the construction, use, renovation, and demolition phases, and indirectly through the material production phase and the transportation and delivery of materials and resources (Sharma et al. 2011, UNEP 2011).

Water

Water consumption is also an important aspect of a building's environmental issues since, excluding the water used for the production of electricity and materials, the construction industry, which includes buildings, uses approximately 12% of potable water in North America (UNEP 2011). In 2009, the distribution of municipal water consumption was as follows: residential sector (57.4%), institutional and commercial sectors (18.7%), industries and farms (10.6%), and leaking and maintenance of the distribution system (13.3%) (Environnement Canada 2011). Furthermore, the building industry is also responsible for the production of approximately 20% of waste water in urban areas (UNEP SBCI 2010, CEC 2008a).

Resources and materials

The environmental performance of the building industry also depends on the use of natural resources. Buildings utilize approximately 50% of the natural resources in Canada (CEC 2008a), while on the international level the proportion varies from 35% to 40% (UNEP 2011, Khasreen et al. 2009). This proportion is destined to grow with the construction boom observed in emerging economies such as India and China (UNEP SBCI 2010).

Waste

The construction industry, which includes buildings, is responsible for the generation of 30% to 40% of the global volume of solid waste (UNEP 2011, CEC 2008a). In Quebec, RECYC-QUÉBEC (2009) reported that in 2008 the waste generated through construction, renovation, and demolition (CRD) accounted for 35% of all waste produced in the province, a little less than half of which is associated with buildings.[3]

Indoor environment

Factors influencing indoor environment quality, such as thermal comfort (temperature, ventilation, humidity, etc.) and visual comfort (windows, natural lighting, artificial lighting, etc.)

3. Considering that the level of response of the sorting centres was too low, RECYC-QUÉBEC (2012) could not update the data about CRD waste in its *Bilan 2010-2011 de la gestion des matières résiduelles au Québec*.

can influence the occupants' wellbeing. These effects are difficult to link to environmental impacts; consequently, the focus is often put on Indoor Air Quality (IAQ). More and more studies on IAQ show the potential damage related to the presence of multiple chemical substances in the building, especially in a closed and badly ventilated space where occupants spend a majority of their time (Quale 2012). The sources of emissions are varied: moisture (molds); common chemicals related to materials (adhesives, paint, varnish, insecticide, fungicide, etc.); combustion devices (fireplace, heating appliances, etc.); and outdoor environmental factors (smog, pollen, radon, dust, etc.). Exposure to these building pollutants can lead to various health problems, such as allergies, asthma, tiredness, headaches, infertility, as well as a host of symptoms related to the respiratory, nervous, and immune systems (Coumau 2009).

ENVIRONMENTAL IMPACTS OF RESIDENTIAL BUILDING USE PHASE

As shown above, the building industry is responsible for various environmental impacts. Among these effects, the residential building use phase emerges as a critical aspect of performance. When considering the total lifecycle, the use phase corresponds to "the period after the home has been built and before it is demolished or deconstructed" (U.S. EPA 2014, 5). Considering that residential buildings have a lifespan that varies from fifty to a hundred years (Thomsen and van der Flier 2011, Palmeri 2009), the use phase covers almost the totality of that lifespan. Therefore, the use phase "is clearly the most prominent stage in the lifecycle, contributing in excess of 80% of the total climate change impact. The materials production stages (including original and replacement materials) contribute a significant amount of the remainder, at 12% overall, followed by transportation at 4%. The construction, maintenance, and demolition phases contribute only a small amount to the climate change impact [...]" (Palmeri 2009, 18).

The next section presents a literature review on the environmental impacts associated with residential building in terms of energy consumption, water consumption, materials and resources use, and waste generation, but also impacts on the indoor environment. Collected data is presented by distinguishing between the pre-use, use, and post-use phases to demonstrate the level of impact associated with each phase (see Tab. 1).

TABLE 1: Environmental impacts associated with residential building

	Pre-use phase	Use phase	Post-use phase
Energy consumption*	8%	≤ 92%	< 1%
Water consumption*	5%	95%	0%
Material/resource use**	55%	45%	0%
Waste generation**	6%	50%	44%
Indoor environment***	N/A	N/A	N/A

* Source: U.S. EPA (2014)
** Source: Palmeri (2010)
*** N/A means that the data is not available.

Energy

Energy consumption related to the use phase of residential buildings represents the vast majority of its impacts on climate change, a proportion that can reach up to 92% (Sharma et al. 2011, U.S. EPA 2014). The remainder of the impacts are distributed among other lifecycle phases, either during the pre-use phase (production of materials for the initial construction, transportation, construction, etc.), which represents about 8% of the impacts, or during the post-use phase (demolition, transportation, etc.), which represents less than 1% (Palmeri 2010, U.S. EPA 2014). Generally, the energy consumption of the residential use phase is distributed between the heating of the building (60%), water heating (18%), the preparation and conservation of food (6%), lighting (3%), and other needs (13%) (UNEP SBCI 2007).

Water

Regarding potable water consumption, the Environmental Protection Agency (EPA) estimates that over the lifecycle of a single-family home, about 5% of water is used for the production of materials and during the construction phase, while 95% is consumed during the use phase (U.S. EPA 2014). In 2009, the average Canadian residential consumption of water was evaluated at 274 litres per capita per day (Environnement Canada 2011). The residential use is divided between the external needs related to irrigation and watering, which can represent between 50% and 75% of total consumption during the summer season; internal domestic water consumption breaks down as follows: 30% for toilet use, 35% for bath/shower use, 20% for laundry, 10% for the kitchen (drinking, cooking, washing dishes), and 5% for cleaning (UNEP SBCI 2010, Environnement Canada 2006).

Resources and materials

Regarding materials and resources, the State of Oregon Department of Environmental Quality (ODEQ) estimates that 55% of the total weight of materials is used in the initial construction of residential buildings (corresponding to an average of 33% in terms of impact categories), while 45% of materials are used during the use phase of the building for maintenance, repair, and renovation (corresponding to an average of 66% in terms of impact categories) (Palmeri 2010).

Waste

ODEQ's research shows that only 6% of the total volume of waste of a residential building is generated by the initial construction; 50% is generated during the use phase by way of maintenance and renovation activities, while 44% occurs at the end of the building's life through demolition (based on an estimated lifespan of seventy years) (Palmeri 2010).

Indoor environment

Influencing factors of housing indoor environment quality are related to thermal and visual comfort in regard to concerns about natural ventilation and natural lighting. As mentioned above, environmental impacts associated with residential buildings' indoor environments are mainly about IAQ and are not well documented. Nonetheless, a proportion of these impacts can be associated with the use phase of residential buildings. First, human actions such as smoking and maintenance activities (cleaning products), among others, can affect indoor air quality. Moreover, maintenance, repairs, and renovation activities can also affect IAQ through the selection of materials and finishes, the use of toxic products, the accumulation of dust, etc. Finally, the occupants' behaviour can also influence the indoor environment quality through actions related to the use and maintenance of combustion devices (fireplaces, heating appliances, etc.), HVAC systems, kitchen and bathroom local exhausts, and humidity control devices.

APPROACH

This paper has highlighted that the use phase represents the majority of the environmental impacts of residential buildings in terms of energy and water consumption, but also a significant proportion of impacts in terms of materials use and waste. From this observation, it is now appropriate to ask whether green building, through its certification programs, is able to respond to these contemporary environmental issues. To do this, a documentary analysis of three certification programs used in North America, *BOMA-BESt*®, *LEED*®, and *Living Building Challenge*™, was conducted in order to determine whether their consideration of the use phase is consistent with the environmental impacts associated with it.

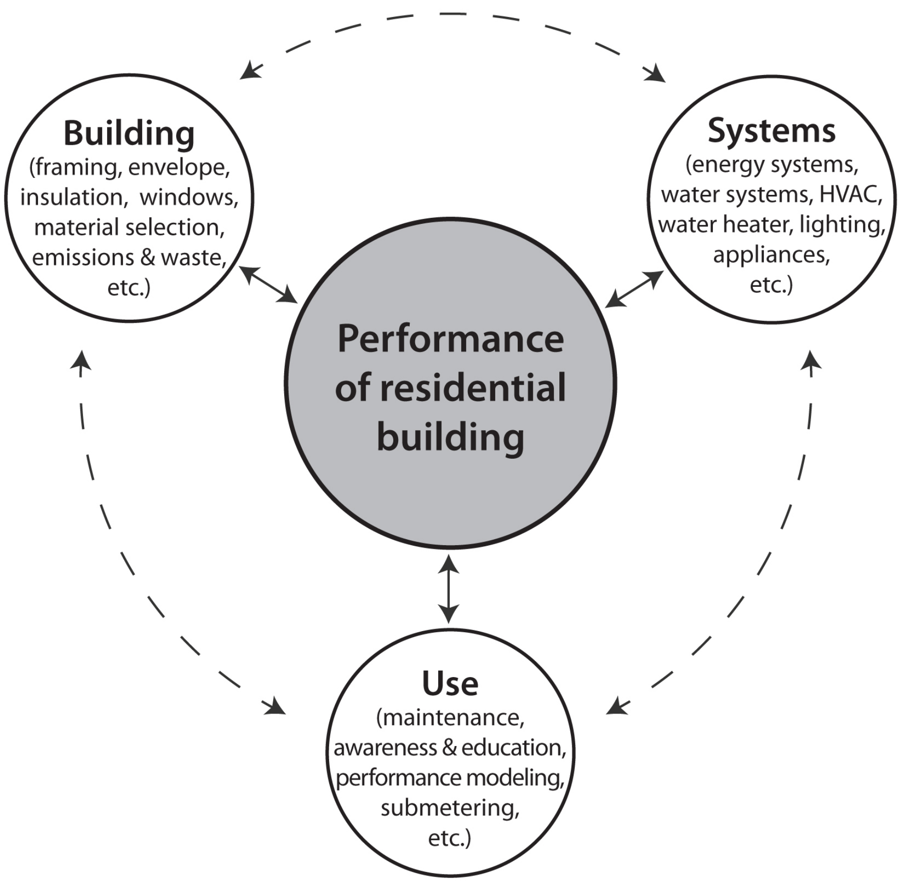
Green building

Green building seeks to reduce the environmental footprint of housing by employing a variety of strategies. The focus of the last forty years has been primarily on reducing energy consumption through increased energy efficiency measures (UNEP 2011). Therefore, a revision of building conception practices (insulation performance, windows, etc.), as well as energy systems (lighting, heating, cooling, ventilation, water heating, etc.), has created improvement in energy efficiency and thus reduced the costs associated with this use (Kats 2010). Green building is also concerned with the optimization of water use in order to protect the resource, to minimize its contamination, and to reduce the need for potable water and the strain on wastewater treatment infrastructures (UNEP 2011). To minimize the use of potable water, several solutions are put forward, such as harvesting rain water (for irrigation or toilet use), the use of low-flow faucets and other reduced or zero-water-consumption products (waterless urinals or composting toilets), the selection of low-water-use appliances, the reuse of greywater (from the washing machine, shower, and bath), etc. (Kats 2010). Green building also aims to use recycled, reused, and locally sourced materials as much as possible. A careful selection of these materials can significantly reduce waste as well as the environmental impacts associated with their production, composition, durability, origin, use, and end-of-life management (UNEP 2011). In addition, green building also aims at reducing impacts related to waste through the optimization of materials and the recycling and reuse of the waste that does get generated (CBDCa 2009, BOMA Canada 2013). Last, green building is known to bring benefits to indoor environments by improving indoor air quality (ventilation, VOC-free products, etc.), but also by improving the quality of life, comfort, and occupant experience (natural light, thermal comfort, views, etc.) (Häkkinen and Belloni 2011). To facilitate the achievement of these objectives, green building relies on certification programs. These programs seek to contribute to the dissemination and standardization of practices in the field.

Analysis

The performance of residential buildings is determined by three interdependent aspects: the design and construction of the building (framing, envelope, windows, material selection, emissions and waste, etc.), and the conception and selection of systems (energy systems, water systems, HVAC, water heater, lighting, appliances, etc.), but also the use by occupants (maintenance, awareness and education, modeling, submetering, etc.) (see Fig. 1). Based on this precept, the next section presents a documentary analysis of the main measures proposed by *BOMA-BESt*®, *LEED*®, and *Living Building Challenge*™ certification programs. The purpose of this analysis is to demonstrate the orientations of each program, but also to determine the level of consideration of the use phase. In order to do this, emphasis is placed on how these certification programs address the issues of energy consumption, water consumption, materials and waste, and indoor environment in their documentation. Following the documentary analysis, the results will be summarized in a comparative table (see Tab. 2) by distinguishing the three interdependent aspects.

Figure 1: Interdependent aspects of residential building performance



BOMA-BESt® (Multi-Unit Residential Buildings)

In 2005, the Canadian *Building Owners and Managers Association (BOMA)* launched the scoring program BOMA-BESt® (*Building Environment Standards*), which seeks to regulate the environmental performance of existing buildings. Depending on the amount of collected points, the program offers four levels of certification: *Level 1, Level 2, Level 3,* and *Level 4*. Presented in January 2012, the module assessing Multi-Unit Residential Buildings is divided into six key areas: Energy, Water, Waste Reduction and Site, Emissions and Effluents, Indoor Environment, and Environmental Management System (BOMA Canada 2013).

Energy consumption

In terms of energy consumption, this certification provides general measures that focus on building requirements and systems. These include the *Energy Assessment*, which analyses consumption and seeks means of improvement; the *Energy Management Plan*, which implements strategies to improve energy efficiency; and the written *Energy Policy*, which monitors a building's energy consumption and moves toward reduction objectives. Second, *BOMA-BESt®* focuses on the building itself by considering its envelope (airtightness, water tightness, thermal resistance, air flow, window efficiency, etc.). Third, this certification program targets different housing systems by focusing on *ENERGY STAR® Certified Products, Energy Efficient HVAC* (heating, ventilation, and air-conditioning), *Energy Efficient Lighting, High Efficiency Water Heaters, Hot Water Efficient Faucets*, and the use of *Renewable Energy*. Last, *BOMA-BESt®* considers the use phase through measures like the P*reventive Maintenance Program for the HVAC*, the *Mechanical Systems Maintenance Schedule*, and *Lighting Management (maintenance and replacement)* for optimum energy efficiency. Furthermore, some additional measures also take into account the use phase, as they address occupant behaviours: the *Energy Training* plan seeks to educate the building's operational staff, and *Occupant Awareness* aims to improve occupant behaviour toward energy efficiency. *BOMA-BESt®* goes further by including a *Submetering* measure to relate energy consumption to the occupant's use.

In the *BOMA-BESt®* certification process, energy consumption of the building is evaluated using the Level 1 verification approach (walk-through analysis) of ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). This procedure involves a visual inspection of energy consuming systems and a collection of billing data in order to evaluate and analyze energy consumption and then compare it to a "rating scale based on benchmarks derived from BOMA-BESt® data" (BOMA Canada 2012, 8). The literature consulted did not allow determining whether the rating scale takes into account factors related to the use phase. In addition, the *BOMA-BESt® Application Guide* mentions that if a building is occupied for a period of less than five years, the *Energy Assessment* can be replaced by an *Energy Study Report* carried out during the design phase, and "must have shown simulated energy consumption for different design scenarios, and identify which options were chosen for the actual construction" (BOMA Canada 2013, 24). However, this process provides no means of evaluating whether the actual results of the measures correspond to the modeling. Briefly, from the energy point of view, the measures proposed by *BOMA-BESt®* specifically target the performance of the building and its systems, while integrating some consideration of the use phase when addressing energy consumption through occupant behaviour and use.

Water consumption

BOMA-BESt® seeks to reduce the consumption of housing systems by first providing a *Water Assessment* in order to determine the current water demands. This assessment also identifies reduction opportunities through the revision of maintenance procedures, upgrading, etc. Second, this certification program requires a written *Water Management Policy*, which commits building managers to meet reduction goals and implement conservation strategies. Third, *BOMA-BESt®* aims to decrease systems' consumption by installing *Water Efficient Fixtures* (toilets, faucets, shower heads, washing machines, etc.), implementing *Reduction Targets, Checking and Fixing Leaks*, but also through measures such as minimizing the need for *Landscape Irrigation* (selection of native plants resistant to drought) or using non-potable sources of water (rainwater and/or greywater). Last, *BOMA-BESt®* implies some consideration of the use phase through measures like *Occupant Awareness*, which aims to improve occupant behaviour toward water efficiency and wastewater effluents, but also by introducing *Submetering* to relate water consumption to occupants' use.

In the certification process, *BOMA-BESt®* establishes that if the building is occupied for a period of less than five years, it is possible to substitute the *Water Assessment* with a *Water Study Report* produced during the design phase, and "must have shown simulated water consumption for different design scenarios, and identify which options were chosen for the actual construction" (BOMA Canada 2013, 30). As with energy consumption, this process provides no means of determining if the actual use of the building corresponds with the modeling. In summary, in terms of water consumption, *BOMA-BESt®* targets mainly building systems, while integrating some consideration of the use phase when addressing water consumption through occupant behaviour and use. In this analysis, water consumption is deemed not applicable to the building aspect.

Materials and waste

First, *BOMA-BESt®* oversees the use of material resources through a written *Building Material Selection Policy* for construction and renovation. This measure is intended to minimize excessive waste, to encourage salvaging of reusable materials, and also to favour the use of reusable, high recycled content, low embodied energy, and low-maintenance materials. Second, this certification system aims at reducing the volume of waste and diverting it from landfills. It targets the building and systems with a written *Renovation/Construction Waste Reduction Policy*, which encourages on-site sorting of materials and recycling. Third, *BOMA-BES*t® seeks to reduce waste generation by targeting the use phase of buildings with measures such as a *Waste Diversion Program* (paper, cardboard, bottles, plastic, cans, and food waste), a *Composting Program* (organic waste), *Collecting Hazardous Waste* (batteries, compact fluorescent lamps, electronic waste, etc.), and *Waste Monitoring* (diversion rate and reduction targets). Last, this certification system also introduces consideration of use through measures like *Occupant Awareness and Environmental Purchasing*, which inform the occupant about environmental preferred practices.

In summary, the measures proposed by *BOMA-BESt®* to regulate the use of materials and the waste generation mainly target the building and its systems. However, while this certification introduces the consideration of the use phase through the measures mentioned above, it does not provide the means to validate precisely the performance after certification. However, *BOMA-BESt®* appears to address the use phase of the building through the *Material Selection Policy*. It states that "[t]he policy committing the organization to using low environmental impact building materials and equipment in its facilities should be part of the tenant construction guidelines or in an appendix to a lease where tenant improvement restrictions are mentioned" (BOMA Canada 2013, 40).

Indoor environment

BOMA-BESt® mainly aims to respond to concerns about indoor air quality (IAQ) by controlling pollution sources through a variety of measures: first, by considering the building using measures like the *Hazardous Building Materials Survey*, to inventory materials and substances like asbestos, lead, PCBs, radon, etc.; the *IAQ Standard Checklist*, to address materials and finishes emissions (VOCs content, urea-formaldehyde resin, etc.); *Dirt Track-In Devices* in entryways, to capture dust and contaminants; and *Operable Windows*, to allow natural ventilation and lighting. Second, *BOMA-BESt®* focuses more specifically on housing systems via measures like the *Indoor Air Quality Audit*, which analyzes HVAC systems in detail. This certification implements IAQ monitoring measures, such as *Local Exhaust* (kitchen and bathrooms), *Air-Filtration* and *Humidification* (filter efficiency and microbial contamination), and *Carbon Monoxide* (garage pollutants). Last, *BOMA-BESt*® introduces consideration of the use phase through measures that aim to ensure *IAQ during Repairs/Renovations* (emissions, dust, humidity, etc.); *IAQ Management* to address occupant concerns; a *Hazardous Product Management Plan* (solvents, pesticides, herbicides, etc.); and *Occupant Awareness* and *Environmental Purchasing* (environmentally friendly cleaning products). In summary, for the indoor environment, *BOMA-BESt*® targets mostly the building and its systems. However, even if this certification introduces consideration of the use phase through various measures, it does not provide the means precisely to validate the performance after certification.

LEED®-Homes

In 2002, the Canada Green Building Council (CaGBC) launched the scoring program *LEED*® (*Leadership in Energy and Environmental Design*) to support the development of green building. Depending on the total of earned points, the certification allocates four levels of performance: Certified, Silver, Gold, and Platinum. Launched in Canada in early 2009, *LEED®-Homes* is divided into eight categories: Innovation & Design Process, Location & Linkages, Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Awareness & Education (CBDCa 2009).

Energy consumption

LEED®-Homes seeks to optimize energy performance by first focusing on the effectiveness of the building envelope with measures like *Insulation, Air Infiltration,* and *Windows*. Second, this certification focuses on building systems by considering the *Space Heating* and *Cooling Equipment* and the *Heating and Cooling Distribution System* (equipment selection and duct tightness); the efficiency of *Water Heating* (selection of equipment, insulation of piping, etc.); the performance of indoor and outdoor *Lighting* (selection of devices, ENERGY STAR® bulbs, etc.); the performance of *Appliances* (refrigerators, dishwashers, and washing machines), and, finally, the implementation of *Renewable Energy* production systems. In addition, to estimate the energy performance of the building, *LEED®-Homes* refers to two scoring systems: *EnerGuide* and the *Home Energy Rating System* (HERS). During the design phase, these are used to assess the annual energy consumption through modeling based on a standardized scenario. *EnerGuide* bases its calculations on a resident household of four and specific settings regarding the use of heating, hot water, lighting, and various electrical appliances. *LEED®-Homes* argues that these standardized parameters allow easy comparison of housing performance, while recognizing that "[the] number of occupants and their day-to-day habits and overall lifestyle may significantly influence your house's actual energy consumption and your future savings" (EnerGuide 2013, 2). The HERS rating system performs similarly, using parameters related to insulation, envelope airtightness and water tightness, windows, HVAC, and water heating, while stating that "estimates are based on typical occupancy patterns with regard to thermostat settings, hot water use, appliance use, and other factors" (CEC 2008b, 11). Thus, *LEED®-Homes* uses assessments and modeling to determine the performance of the building and its systems.

In summary, *LEED®-Homes* oversees energy consumption by solely targeting the building and its systems. No concrete measures are proposed to address the building's use phase. *LEED®-Homes* doesn't seem to consider the occupants as an influential factor in the building's performance since their participation is simply modeled through predetermined scenarios.

On the other hand, certification updates in *LEED®-New Construction (NC)* 2009 for Canada and *LEED® v4-Homes Design and Construction (HD+C)* 2013 for the United States introduce interesting changes that could be incorporated into *LEED®-Homes* in the future. In Canada, *LEED®-NC* adds the optional credit *Measurement and Verification* to "provide for the ongoing accountability of building energy consumption over time" (CBDCa 2010, 52). By installing measurement equipment, this criterion implicates the collection of energy consumption data over the course of a year in order to determine that the performance matches the predictions. If necessary, the project team must also implement corrective measures. In the United States, *LEED® v4-HD+C* includes an *Energy Metering* measure to monitor and analyse energy consumption during occupation, but also encourages building occupants to share data with the *U.S. Green Building Council (USGBC)*. *LEED® v4-HD+C* also adds the *Advanced Utility Tracking* credit, which requires permanent, real-time monitoring of energy consumption and provides data to USGBC for the certification process (USGBC 2013).

Water consumption

To address the issue of water consumption, *LEED®-Homes* aims to reduce indoor and outdoor building needs. The certification focuses on *Indoor Water Use* by targeting system efficiency, specifically toilets, dishwashers, and washing machines, but also the flow of kitchen and bathroom faucets. In terms of outdoor practices, *LEED®-Homes* seeks to reduce water demand related to the *Irrigation System* by encouraging the planting of drought-resistant plants and system efficiency. Finally, *LEED®-Homes* encourages *Water Reuse* of rainwater and greywater (from washing machines, showers, bathtubs, etc.) for landscape irrigation and/or toilet flushing. In summary, *LEED®-Homes* water consumption reduction measures deal only with building systems. In this analysis, water consumption is deemed not applicable to the building aspect. However, since the occupant is the main actor in water consumption, the potential benefits cannot be guaranteed if the use phase is not considered.

On the other hand, as with energy consumption, certification updates for *LEED® v4-HD+C* 2013 in the United States provide an interesting addition that could be subsequently integrated to *LEED®-Homes*. *LEED® v4-HD+C* 2013 includes a *Water Metering* measure to monitor and analyse the consumption of water, which also encourages occupants to share data with the USGBC (USGBC 2013).

Materials and waste

Regarding materials and waste, *LEED®-Homes* provides the measure *Material Efficient Framing* to optimize the use of materials and avoid unnecessary waste through better planning and management of building construction. Through the *Environmentally Preferable Products* measure, this category also focuses on material selection to identify the best products from an environmental perspective. Following these guidelines may result in the selection of FSC-certified wood, locally sourced products, low-emissions materials, or materials made with recycled content, for example. Last, *LEED®-Homes* aims to reduce construction impacts through better *Waste Management* practices that encourage recycling and reuse. In summary, *LEED®-Homes* proposes measures that strictly target the initial construction phase of construction and building systems. This approach neglects the use phase, which through various maintenance, repair, and renovation activities, uses a large amount of materials and generates a considerable amount of waste throughout the lifespan of the building.

Indoor environment

Regarding indoor environment quality, *LEED®-Homes* seeks to improve occupant thermal comfort by encouraging an efficient *Distribution of Space Heating and Cooling*. This certification also aims at air-quality improvements by controlling potential sources of pollution from building systems or from outdoor sources, with measures like *Combustion Venting*, which aims to eliminate exposure to combustion gases (fireplaces, heaters, water heaters, etc.), *Moisture Control* (mold), and airborne *Contaminant Control, Radon Protection,* and *Vehicle Emissions Protection*. This category also aims to eliminate remaining air pollutants via *Outdoor Air Ventilation* (systems providing air exchange), *Local Exhaust* (for kitchen and bathrooms), and proper *Air Filtering*. While these criteria potentially benefit the occupants, they do not specifically take into account the use of residential buildings. However, to validate air quality improvement, *LEED®-Homes* refers to the standard ENERGY STAR® Indoor Air Package. This approach states that "these measures alone will not guarantee that homebuyers will not experience air quality problems in their homes […] For example, factors such as unforeseen construction issues and homeowner behavior may negatively impact the home's indoor air quality and the performance of the measures specified in the ENERGY STAR Indoor Air Package" (U.S. EPA 2005, 3). This excerpt demonstrates that the occupant is likely to have a compelling impact on indoor air quality.

Living Building Challenge™ (building)

Launched in 2006 and overseen by the International Living Future Institute, *Living Building Challenge™ (LBC)* claims to be the most rigorous building certification program in terms of environmental standards. More than a certification program, the LBC calls for a paradigm shift (ILFI 2012). Unlike *BOMA-BESt®* and *LEED®*, *LBC* does not use a scoring system. The *LBC* program is less prescriptive or specific regarding the means used to reach the objectives in each category, leaving to the project team the task of implementing the necessary compliance measures. *Living Building Challenge*™ provides three types of certifications: '*Living*' status, *Recognition* level, and *Net Zero Energy Building Certification*. This certification takes into account seven performance categories: Site, Water, Energy, Health, Materials, Equity, and Beauty (ILFI 2012).

Energy consumption

In terms of energy consumption, *Living Building Challenge*™ aims at a *Net Zero Energy* that eliminates dependence on fossil fuel, excludes any form of combustion and favours optimal exploitation of renewable energy sources. On an annual basis, the building's consumption must be balanced by its onsite energy production. For this purpose, sub-metering is necessary to determine the energy consumption of major building systems (heating, cooling, ventilation, lighting, plug loads, water heating, etc.). According to *LBC*, this approach has several advantages, since it "allows improvement of building performance over time, troubleshooting of unpredicted energy loads, and identification of repair/maintenance needs" (ILFI 2013a, 5). *LBC* does not directly address the performance of the building (structure, envelope, windows, etc.), but it is assumed that to achieve complete energy independence, for example, this criterion must be taken into account. In this context, without specifically addressing the issues related to use phase, *LBC* leans in that direction by requiring the installation of sub-meters, which inform the occupants of the energy used by the building systems, and by extension, the consumption related to the occupants who use them. This can be seen as the beginning of the consideration of occupant use. However, the chances of getting a fair representation of actual consumption due to occupant use are increased, as the final measures for certification are recorded during twelve consecutive months of occupation.

Water consumption

In terms of water consumption, *Living Building Challenge*™ seeks independence from water supply and treatment infrastructure by exploiting the capacity of collection and infiltration of water onsite, but also the reuse of water in the building. Firstly, *Net Zero Water* measure requires that, on an annual basis, the indoor and outdoor consumption of the residential building does not exceed the onsite water supply capacity. All the water needs of the project must be covered by collected precipitation and recycling of wastewater, treated without chemicals. For this purpose, sub-metering is necessary to determine the actual water use from each source on the site: rainwater, onsite groundwater, surface water sources, but also the reuse of greywater (from washing machines, showers, bathtubs, sinks, and washbasins) and blackwater (from toilets) (ILFI 2013c). Second, the *Ecological Water Flow* measure aims to promote good water management by using appropriate systems of treatment, reuse, and infiltration. To meet this measure, all stormwater runoff and wastewater (including greywater and blackwater) should be managed and treated onsite. Regarding water consumption reduction, *LBC* does not specifically address water use by the occupants, but it is assumed that if the consumption must be compensated by the recovery of water onsite, designers have every reason to put in place mechanisms to raise household awareness of consumption. Furthermore, installation of sub-meters can be considered a step toward consideration of occupant use of the building. As with energy consumption, the chances of getting an accurate representation of actual consumption are more likely, since the final measures used in the certification process must be taken over a period of twelve months following the occupation of the building. In this analysis, water consumption is not deemed applicable to the building aspect.

Materials and waste

In terms of materials and waste, *Living Building Challenge*™ first aims at reducing building and systems impacts via three measures intended to encourage better material selection. The first, *Red List*, forbids the use of materials or chemicals identified as toxic to human and ecosystem health (e.g. asbestos, formaldehyde, PVC, etc.). The second measure, *Responsible Industry*, encourages builders to deal with companies that use certification, performed by a third party, to validate sustainable practices for resource extraction and working conditions (e.g. FSC-certified wood). The third measure, *Appropriate Sourcing*, seeks to stimulate and support the regional economy through local alternatives for products, materials, and professional expertise needed for the project, thus reducing the environmental impacts associated with transportation.

Second, *LBC* aims to compensate for the effects on climate change on the building and its systems by estimating the *Embodied Carbon Footprint* of the project and neutralising it through the purchase of carbon offsets. This calculation integrates a lifecycle notion, since it includes the embodied carbon value of the "construction and projected replacement parts over the anticipated lifespan of the building. Superstructure and interior components of floors, walls and ceilings are included in the calculation of projected replacement parts based on the life expectancy of the building" (ILFI 2013b, 13).

Third, with the measure *Conservation + Reuse*, *LBC* aims to reduce the use of natural resources in the building and its systems by reducing or eliminating waste. To comply with this measure, the project team must develop a *Material Conservation Management Plan* to optimize the use of materials and resources in the building's different lifecycle phases: the design phase (appropriate durability according to use), the construction phase (optimizing the use of materials and collecting construction waste), the use phase (collecting consumables and durables), and the end-of-life phase (planning reuse and deconstruction) (ILFI 2013b).

In summary, the materials and waste measures deal mainly with the building, and, to a lesser extent, its systems. Aside from the collection of recyclable and compostable food scraps, the use phase is not specifically targeted by the measures of this category. However, the *Embodied Carbon Footprint* and *Conservation + Reuse* measures further integrate the concept of building lifecycle, which can be seen as a consideration of the use phase.

Indoor environment

Living Building Challenge™ aims to maximize physical and psychological wellbeing related to indoor environment. In order to achieve this, *LBC* includes measures such as *Civilized Environment*, which establishes that all occupiable interior space of a residential building must have operable windows giving access to daylight and fresh air. In addition, the measure *Healthy Air* establishes that indoor air quality must be maintained by systems such as dirt track-in devices, efficient ventilation systems, and independent exhaust systems in kitchens and bathrooms. The *Red Lis*t, presented above, also addresses these concerns by governing the use of materials and products that may have an effect on air quality. All of these measures, primarily targeting the building and its systems, hold great potential to improve indoor environments. However, since performance is dependent on use by the occupants, an assessment of air quality is performed before, and nine months following, the occupation to ensure that the measures yield results.

The results of the documentary analysis regarding considerations of the certification programs *BOMA-BESt*®, *LEED*® and *Living Building Challenge*™ have been summarized in the subsequent comparative table by distinguishing the three interdependent aspects: building, systems, and use (see Tab. 2). The symbols indicate the following: (✓) means that the certification considers this aspect; (✓ *) means that it partially considers this aspect; (✘) means that it doesn't consider this aspect; and the hatched box means that it's not applicable.

DISCUSSION

The previous analysis clearly demonstrates that the measures put forward by the certification programs *BOMA-BES*t®, *LEED*® and *Living Building Challenge*™ place emphasis mostly on building design and construction (framing, envelope, windows, material selection, emissions and waste, etc.) and the conception and selection of systems (energy systems, water systems, HVAC, water heater, lighting, appliances, etc.). In terms of residential building use by occupants (maintenance, awareness and education, modeling, submetering, etc.), consideration varies depending on the certification. The next table (see Tab. 3) presents in detail the certification programs' respective consideration of the various measures related to use phase of housing. The symbols indicate the following: (✓) means that the certification considers this aspect, and (✘) means that it does not consider this aspect.

TABLE 2: Comparative tables regarding certification programs considerations

BOMA-BESt® (Multi-Unit Residential Buildings)	Building	Systems	Use
Energy consumption	✓	✓	✓ *
Water consumption		✓	✓ *
Material/resources use	✓	✗	✓
Waste generation	✓	✓	✓
Indoor environment	✓	✓	✓ *

LEED® (Homes)	Building	Systems	Use
Energy consumption	✓	✓	✓ *
Water consumption		✓	✓ *
Material/resources use	✓	✓	✗
Waste generation	✓	✓	✗
Indoor environment	✓	✓	✓ *

Living Building Challenge™ (Buildings)	Building	Systems	Use
Energy consumption	✓	✓	✓
Water consumption		✓	✓
Material/resources use	✓	✓	✓
Waste generation	✓	✓	✓ *
Indoor environment	✓	✓	✓

TABLE 3: Consideration of use by certification programs

	Measures	BOMA-BESt® (Multi-Unit Residential Buildings)	LEED® (Homes)	Living Building Challenge™ (Buildings)	% of impact associated with use phase
Energy consumption	Planned maintenance	✓	✗	✓	≤ 92%
	Awareness and education	✓	✓	✓	
	Performance modeling	✗	✓	✗	
	Pre-occupation submetering	✓	✗	✓	
	Post-occupation submetering	✗	✗	✓	
Water consumption	Planned maintenance	✗	✗	✓	95%
	Awareness and education	✓	✓	✓	
	Pre-occupation submetering	✓	✗	✓	
	Post-occupation submetering	✗	✗	✓	
Material/resources use	Awareness and education	✓	✗	✓	45%
Waste generation	Awareness and education	✓	✗	✓	50%
	Recycling program	✓	✗	✓	
	Composting program	✓	✗	✓	
	Waste monitoring	✓	✗	✗	
Indoor environment	Planned maintenance	✓	✗	✓	N/A
	Awareness and education	✓	✓	✓	
	Pre-occupation submetering	✗	✗	✓	
	Post-occupation submetering	✗	✗	✓	

Consideration of use

As reported in this article, the residential building use phase represents up to 92% of energy consumption, constitutes 95% of water consumption (indoor and outdoor), accounts for 45% of the weight of materials used, and produces 50% of the waste (maintenance, repair, and renovation). In addition, the use phase is considered the most damaging stage of the building lifecycle, since it is responsible for more than 80% of the impacts of climate change. However, the documentary analysis of the certification programs previously presented does not demonstrate that the consideration of use is consistent with the impacts associated with it. It is clear that considering the use phase presents a great opportunity to reduce environmental impacts of the residential building.

First, *BOMA-BESt*® suggests an introduction to the consideration of use through planned maintenance measures such as *Preventive Maintenance Program for the HVAC, Mechanical Systems Maintenance Schedule* and *Lighting Management* (energy consumption and indoor environment only). This certification program also initiates occupant contributions to housing impacts by targeting awareness and education through measures like the *Energy Training Plan*, *Occupant Awareness*, and *Environmental Purchasing* (environmentally friendly maintenance products, energy-efficient equipment and appliances, etc.). Moreover, *BOMA-BESt*® considers housing use through *Pre-Occupancy Submetering* of energy and water consumption. Also, through the implementation of a *Material Selection Policy*, *BOMA-BESt*® has the potential to motivate occupants to buy materials and equipment with low environmental impacts for subsequent repair, maintenance, and renovation. Furthermore, this program considers the use in waste management measures, such as the *Recycling Program, Composting Program* and *Waste Monitoring*. However, most of these measures are based on a voluntary commitment, since no means of verification is provided by the program. In addition, the submetering only provides information about the general consumption of the building without providing concrete incentives to lower energy consumption and needs.

Second, *LEED*®*-Homes* mostly neglects consideration of the use phase by including but few measures. This certification program only considers use through *Awareness & Education* of the occupant and *Performance Modeling*, which evaluate energy consumption at the conception stage through standardized parameters. However, other LEED programs put forward interesting measures that could subsequently migrate to *LEED*®*-Homes*. On the one hand, *LEED*®*-NC* 2009 (CA) provides a measurement protocol to determine if energy consumption during building use corresponds to predictions (*Post-Occupancy Submetering*). On the other, *LEED*® *v4-HD+C* 2013 (USA) proposes a permanent monitoring and data sharing of post-occupation energy and water consumption to validate if it corresponds to claims (*Post-Occupancy Submetering*).

Third, the analysis of *Living Building Challenge*™ shows that it provides more targeted measures and more adequately considers the use of the building by the occupants. With a perspective of a full autonomy in energy, *LBC* requires the installation of sub-meters to monitor consumption. The data collected must demonstrate that the energy needs of the building are met by renewable energy installations located on the project site. In terms of water, the needs of the project must be satisfied by onsite collection and water reuse. The installation of sub-meters must demonstrate the building's water autonomy. In addition, in terms of waste generation, *LBC* introduces consideration of building use by addressing the collection of recyclable materials and compostable food scraps. Last, *LBC* considers the indoor environment by imposing assessment of building indoor air quality following occupation.

Certification process

The consideration of use may also be evaluated in the programs' certification process. The documentary analysis shows that *BOMA-BESt*® and *LEED*®*-Homes* are based on simulations and estimates without real consideration of the use phase. The certification process is based on modeling and usually occurs before occupancy. This approach can lead to discrepancies between the claims and the actual performance of the building, since many agree that "actual building performance differs significantly from that anticipated during design" (Cole 2010, 589). This approach seems to 'decontextualize' the building, producing an incomplete assessment of its environmental performance. LBC offers a different approach, which includes extensive post-occupancy measures for water and energy consumption, as well as for IAQ.

First, *BOMA-BESt*® uses ASHRAE's Level 1 verification approach, which does not require direct measurement of energy consumption, but only a visual inspection of energy consuming systems and a collection of billing data. However, the documentation provided by the certification does not demonstrate whether the assessment takes into account factors related to building use. In addition, if the building is occupied for a period of less than five years, the *Energy Assessment* can be replaced by an *Energy Study Report* produced at the design stage and based on modeled scenarios. The certification process only takes into account information obtained prior to the occupation of the building, without conducting any subsequent controls to determine whether the claims are consistent with the actual occupant use.

Second, *LEED*®*-Homes* uses two scoring systems, *EnerGuide* and *Home Energy Rating System* (HERS), to evaluate energy consumption. These are based on standard scenarios to determine building performance at the design phase. This modeling uses standardized parameters in regard to the number of occupants, the insulation and airtightness of the envelope and windows, but also specific parameters in terms of performance and use of HVAC systems, water heating, lighting, etc. In addition, this building certification is based on data obtained before the occupation of the residential building, without providing any mechanisms to validate whether reality is in line with expectations. This modeling cannot be a true representation of building performance, as it does not take into account human factors, such as habits, behaviours, and lifestyles that affect, among other things, energy consumption.

Third, *Living Building Challenge*™ is the only program analysed in which the certification process is based on the actual building performance. The data is measured after occupation and is mandatory for the certification process. To confirm the building's complete energy and water autonomy, sub-metering must be conducted over a period of twelve consecutive months following occupation of the residential building. Furthermore, to ensure the maintenance of indoor air quality, *LBC* assesses *Respirable Suspended Particulates* and *Total Volatile Organic Compounds* concentrations before and nine months after occupancy. This verification process allows for a better representation of the actual environmental performance of the building by taking into account the use by occupants. The value of this certification is becoming even more significant.

CONCLUSION

The building industry is responsible for several environmental impacts. As reported in this article, the use phase of residential buildings accounts up to 92% of energy consumption, 95% of water consumption, 45% of materials used, and 50% of waste generation. However, the documentary analysis of the certification programs previously presented shows that consideration of the use phase is inconsistent with the impacts associated with it. To better consider the use phase of residential building, two major recommendations should be taken into account: the certification programs should reflect the real performance of residential buildings by integrating the use phase in the evaluation process, and the occupant should be actively implicated in determining the performance of housing.

First, as shown in the analysis, *BOMA-BESt®*, *LEED®-Homes* and *Living Building Challenge™* have been focusing mainly on the building and its systems. Based on simulations and estimates, *BOMA-BESt®* and *LEED®-Homes* do not adequately take into account building use, as their modeling of energy and water consumption is conducted prior to building occupancy. These measures seem to 'outsource' the building impacts by recognizing neither the use phase nor the impact of the behaviour of occupants. The *Living Building Challenge™* certification is the only program analyzed that carries out post-occupancy measures at the level of energy consumption, water consumption, and indoor air quality. However, some versions of *LEED®* are beginning to address the use phase through metering of water and energy consumption during the building use phase in order to compare the actual performance to the claims. To achieve better representation of environmental performance, green building certification programs should embed measures such as sub-metering and post-occupation evaluation of energy consumption, water consumption, materials and resources use, waste generation, and impact on the indoor environment. Such measures would bring performance to another level by assuring better consideration of the use phase and bringing a systemic dimension to environmental assessment of residential buildings.

Second, to ensure a better answer to contemporary environmental issues surrounding residential buildings, occupants must be placed at the centre of such considerations, as they play a crucial role in terms of impacts. This becomes all the more important when we consider that occupants tend to underestimate the environmental impact of residential buildings (Kats 2010). For example, people tend to estimate their impact as less than half of their total GHG emissions (WBCSD 2007), while a vast majority argue that housing either generates little or no impact, or that the impacts are acceptable (Kannan 2008). These perceptions illustrate that the impacts related to the use phase remain an abstract notion for households. However, occupant behaviours and lifestyles have a major impact potential for the performance of residential buildings. This consideration is important for environmental strategies of green building, since "achieving long-lasting sustainable solutions must give primacy to user behaviour. User behaviour cannot be used as an excuse by designers for performance deficits or unintended consequences, but must be understood and influenced appropriately" (Stevenson and Leaman 2010, 438).

To put the users at the centre of these concerns also means to actively implicate them in the environmental performance of the residential building. The first step would be educational programs designed to lead to the adoption of more sustainable practices. For example, *LEED®-Homes* is exploiting this idea in the category *Awareness & Education* by introducing measures like *Education of the Homeowner or Tenant*, which provides *Operations and Maintenance Training* and a *Public Awareness* program to help demystify green building. Another way to make the idea of environmental housing performance concrete and tangible on a day-to-day basis is to offer occupants ways to understand and influence it through their behaviour. This approach should prompt users to establish cause-and-effect links between daily activities and their consequences in terms of energy consumption, water consumption, indoor air quality, etc. For example, some monitoring mechanisms, such as direct feedback, allow the occupant to access real-time information on building performance. These opportunities must be made possible via simple and understandable mechanisms providing tangible and usable information.

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