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Boundary conditions for non-residential buildings from the user's perspective: Literature review

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ABSTRACT

Background and objective: This paper aims to review the boundary conditions (B/C) in specific categories (energy, building use, and lighting) within non-residential buildings to pave the way to a better understanding of users' requirements and needs of the built environment. For this paper, B/C are understood as unique *preconditions, specific characteristics* for use, determining specific features of buildings, enabling an accurate understanding of non-residential spaces concerning energy use, user behaviour, and lighting.
Methods: This paper describes the results of an overall quantitative (1st method) review and a systematic review (2nd method) of boundary conditions and their factors within different types of non-residential buildings from the users' perception. Followed by a qualitative experts' literature review (3rd method) on B/C within offices, schools, and hospitals chosen by a team of international experts working together on Subtask A: User perspective and requirements, Task 61 IEA (International Energy Agency): *Solutions for daylighting and electric lighting.*
Results: The first review method led to the selection of 21 papers. The second method resulted in the selection of 7 papers out of 93,143 found in Scopus; during the 3rd review, experts collectively chose 74 additional papers focussing on the users' factors contributing to specific B/C. The scope of this paper is limited only to offices, schools, and hospitals. Based on the findings, the authors recognise a broad definition of boundary conditions from specific values, and conditions to interconnected factors, user profiles, functions of the building types, and operating hours.
Conclusions: This paper is an overview of B/C factors found in the literature that can help explain the occupants' behaviour and the use of spaces. B/C are often type of building/user/location/situation/simulation input-values and method-specific. Therefore, they cannot be widely applicable but offer patterns and help to understand the correlations between various factors shaping the built environment. A better comprehension of the reasons for identifying B/C and their factors can help in developing a deeper knowledge of how we use buildings to find optimal ways to design them.

1. Introduction

Thought the history of architecture, the boundaries of building use have been constantly changed due to progress in building technologies, design, and alternations in occupants' behaviours and needs.

This publication offers a review of papers on boundary conditions within non-residential buildings. The objective of this review is to focus on the user's perspective by depicting the boundary conditions (B/C) and their factors influencing the user as a recipient of certain conditions, capabilities, and technology services (inputs and outputs).

Abbreviations: B/C, boundary conditions.
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The understanding of boundary conditions, what they are, how to explore them, and why their understanding matters, changes depending on the discipline. The term is traditionally used in disciplines such as fluid mechanics, engineering, and mathematics, and is defined as "a stated restriction, usually in the form of an equation that limits the possible solution" [1], which is also the case in built environment studies. [1]. They can be understood as "an amendment to theory and a means for theory development" [1, p. 31]. According to Busse et al.:

Theories provide answers to the "What", "How", and "Why". "What" refers to the variables that are involved in a causal model, "how" denotes the effects that relate these variables to another, and "why" identifies the causal mechanisms that explain the connection between these variables. Nevertheless, there is a fourth, somewhat less prominent feature, namely boundary conditions (B/C). B/C refer to the "Who, Where, When" aspects of a theory. These conditions relate, most importantly, to ***boundaries in time, space, and the researcher's values*** *and describe the limits of generalizability of a theory* [1, p. 1].

For this review paper, B/C are understood as unique *preconditions, particular characteristics* for use, which determine specific features of buildings, and enable an accurate understanding of non-residential spaces concerning energy use, user behaviour, and lighting. They help to test, validate and develop specific research-practice gaps. In the scope of this paper, the notion of B/C refers to any limitations in the use of buildings. They can be connected to activities that take place in a specific building type (e.g., learning in school buildings), to the state of users (e.g., suffering people in hospital buildings), or to the use of resources (e.g., lighting or energy).

Determining pre-set values, pre-determined values, border characteristics, or limits as B/C is seen as one of the basics steps to understand better the role of human behaviour within a space and its reflection on energy and lighting use.

1.1. Background: energy, occupant behaviour/building use, and lighting

Energy, use of space, and lighting are interlinked factors.

It is worth noting that buildings account for 40% of the energy consumption in the EU-28 [2]. According to European Commission's statistics, non-residential buildings use 40% more energy than residential buildings [2,3]. In the US, buildings are responsible for 40% of primary energy use, and green gas emissions, while in China, buildings consume 20.7% of the total energy consumption of the whole country [4]. Other sources have estimated that approximately a third of the worldwide greenhouse gas emissions are attributable to all types of buildings [5]. There is an understanding that energy efficiency (costs) and human needs (health, behaviour – realated spendings) are the main drivers pushing building design boundaries. Many studies indicate that energy use within non-domestic buildings is related to user activities, use of space, or occupancy patterns [6–8]. Some researchers argue that detailed information on occupancy patterns and users' behaviour could help to refine strategies for optimum energy performance of building and optimal lighting solutions [6–9].

Zhang et al. suggest that the energy-saving potential of occupant behaviour could be in the range of 5–30% for commercial buildings based on a review of the published research [10]. Harputlugil and de Wilde and Paone and Bacher, warn that many different models are used to predict energy consumption [7,11]. However, the obtained estimates deviate by more than 30% from the actual energy consumption levels partly due to complexities of the occupants' energy-use characteristics (understood as the presence of the people in the premises and the actions they perform or do not perform). Tam et al. argue that the actual occupant behaviour is the critical element to quantifying energetically or environmentally optimal building performance, which should be taken into account in the existing rating systems [6].

Electrical lighting is responsible for approximately 5% of greenhouse gas emissions and 15% of the total electrical power consumption [12]. These approximations depend on the method of energy assessment and the type of lighting sources. Some estimate that in a modern office with daylight-dependent lighting control, efficient façade design and users sitting close to windows, the use of daylight can lower energy consumption by about 70% [12,13]. Others claim that depending on the climate, and the design of the building and lighting technical solutions (LED sources vs. conventional ones), electric lighting can be responsible for on average 13–37% of the total electricity consumption in office buildings [14,15]. In artificially lit commercial buildings, electric lighting constitutes one of the most significant energy users. In the US, according to the most recent Commercial Buildings Energy Consumption Survey (CBECS), 17% of all electricity consumed by commercial buildings is for lighting, while heating, ventilation, and air conditioning (partly related to daylighting) accounts for 34% of total building energy, along with other appliances at 18% and miscellaneous, including electronics, at 31% [16,17]. It is often emphasised that integrating daylighting and electric lighting can reduce energy consumption and maximise occupants' visual, thermal, and psychical comfort [17].

1.2. Objectives

The global pandemic and social distancing restrictions have forced us to rethink how buildings are designed and used. A better comprehension of building boundaries and benchmarks from the users' perspectives offers us a chance to review the way people inhabit, move, and use the space.

The paper looks into various boundary conditions (~preconditions of use) and their factors for non-residential buildings in terms of energy and occupancy patterns/user behaviour and lighting. Further investigations refer to reasons for identifying B/C in categories: energy (energy assessment and optimisation), space use (users' behaviour and comfort) and lighting (values, performance and perception) as well as methods to define boundary conditions in specific types of buildings.

The main objective of this paper is to review the understanding of the boundary conditions and their factors in the defined categories: energy, use of space and lighting, within non-residential buildings, to pave the way to a better understanding of users' requirements, and needs of the built environment.

The specific objectives have been identified as:

1) Identifying and reviewing the boundary conditions within non-residential buildings in the categories: energy, use of space, and lighting;
2) Identifying the research methods and general data used while discussing boundary conditions;
3) Determining which boundary conditions and their factors might be affecting occupant preferences and performance in non-residential buildings, such as offices, schools, and hospitals.

1.3. Information about the SHC, IEA task 61

This review is a part of the Subtask A of the SHC Task 61 of an IEA (Solar Heating & Cooling Task 61 International Energy Agency) research initiative to investigate available integrated daylighting and electrical lighting strategies to obtain very high energy-efficient lighting schemes and solutions that offer the best lighting conditions for human beings [18]. This international effort is being undertaken to create foundations for future multidisciplinary research towards building design that accommodates the inhabitants' changing needs.

2. Methods description

2.1. Literature review: 3 methods

The literature review included a mixed-method approach based on a qualitative, systematic review, and an experts' collaborative, qualitative review. The reviews look into categories such as energy, use of space, and lighting. The paper scrutinises the mentioned categories along with the research methods used to establish: boundary conditions (i), building types (ii), locations (iii), and users involved in the study (iv).

During the first qualitative review, the available online scientific databases were scanned for relevant papers from 1979 onwards on the topic of B/C used for non-residential buildings. The search filters were the main keywords, types of buildings, and thematic categories: energy, space, and lighting. The main keywords were: boundary conditions, behavior, occupancy, occupant, agent-based modeling (Fig. 1). The initially proposed keyword "boundary conditions" returned no search results. The most valuable keywords proved to be occupancy, occupant and behavior, and their interrelations. The first method returned 21 relevant articles [6,19–38] (Table 3).

The second method started with a systematic literature review based on the results (categories and keywords) from the first method. The review was limited to the Scopus database, and it returned 93,143 peer-reviewed papers from the last five years. The search was limited to disciplines: engineering, computer science, environmental science, mathematics, energy, agricultural and biological sciences, medicine, earth and planetary sciences, materials science, and social science. The search was performed in three main stages. In the first stage, a total number of 93,143 documents were scanned. After that, documents referring to the phrases "residential", "dwelling", or "housing" were excluded. Next, 30 duplicates were removed, and only 388 remained. They were examined to confirm if they addressed the topic under review using the additional filter "education". 306 articles were found to be unrelated, leaving 52 primary documents which were scanned, and 45 were found to be tangential to the subject matter. Only seven articles were chosen for detailed analysis as a result of this systematic quantitative review (Fig. 2) [39–45] (Table 3).

The third method was based only on a qualitative review in several available databases by a team of dedicated international members of Task 61. The experts had backgrounds in architecture, lighting design, engineering, urban design, and psychology. The methodical approach for this review was based on the categories found during the first and second methods (Fig. 3). The results of this search were discussed and amended during two international Task 61 Subtask A meetings. The review was limited to building types: offices, schools, universities, hospitals, commercial buildings, as well as libraries and factories, and also to categories: energy, usage of space, and lighting. 95 articles (categories: 5 offices, 18 schools, 9 universities, 19 hospitals, 19 commercial buildings, 4 industrial buildings, 5 libraries; 4 publications concerned more than one building type) were chosen and analysed in detail [18]. Seventy-four of them were not selected during previous literature review methods. Only 42 papers (on offices, schools, and hospitals) were scrutinised for this paper. The detailed qualitative review framework for the offices, schools, and hospitals is presented in Appendix A.

All of the reviews were performed before the global coronavirus pandemic (COVID-19) outbreak as integral parts of the work on IEA Task 61 Subtask A.

3. Results

3.1. Results(methods 1–2): Categories and reasons for B/C

The conducted literature reviews resulted in the selection of 28 B/C-related papers (Table 3), with the oldest paper dated 1979 [34]. Twenty papers were written after 2010. The review categories: energy, space usage, occupant related factors, and lighting were divided into sub-categories explaining the specific aspects used for the analysis such as energy demand, modelling or consumption, widow control, occupancy detection, prediction modelling, and finally, lighting preferences control or savings (Table 1, Fig. 4).

The main reasons for identifying B/C within the *energy* category were energy assessment, optimisation, and evaluation of the possible energy savings. The purposes identified for the study of the *usage of space* category included users' profiles, comfort preferences, and the interplays between users' behaviour and energy demands. The rationales for the *lighting* B/C studies were establishing pre-set values for electrical lighting and daylighting in terms of visual and non-visual comfort and a description of peoples' interaction with lighting within the enclosed spaces and their perceptions of various lit environments (Table 2).

The reviewed papers demonstrated that B/C were primarily identified using methods based on literature reviews (10 papers) or case study methods (19 papers), including on-site

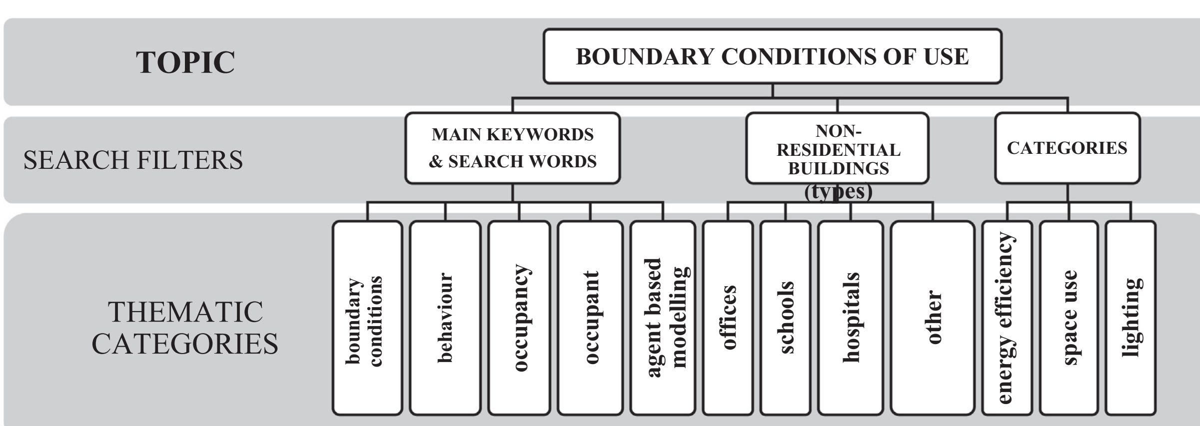

Fig. 1. Quantitative literature search filters (1st method).

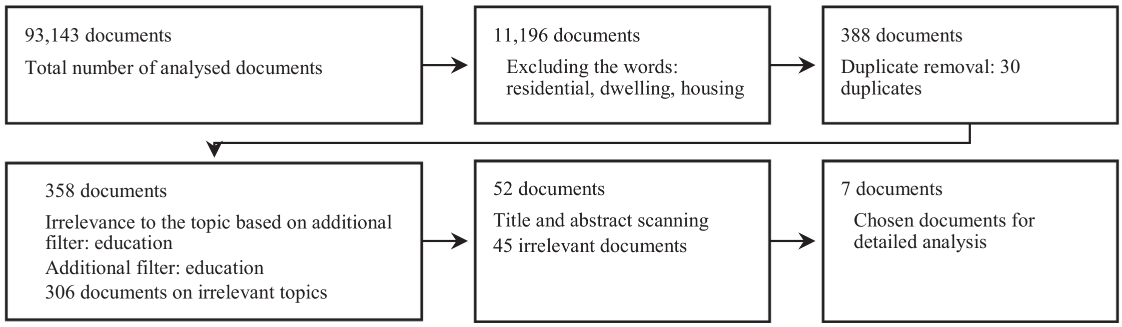

Fig. 2. Systematic review's phases (2nd method).

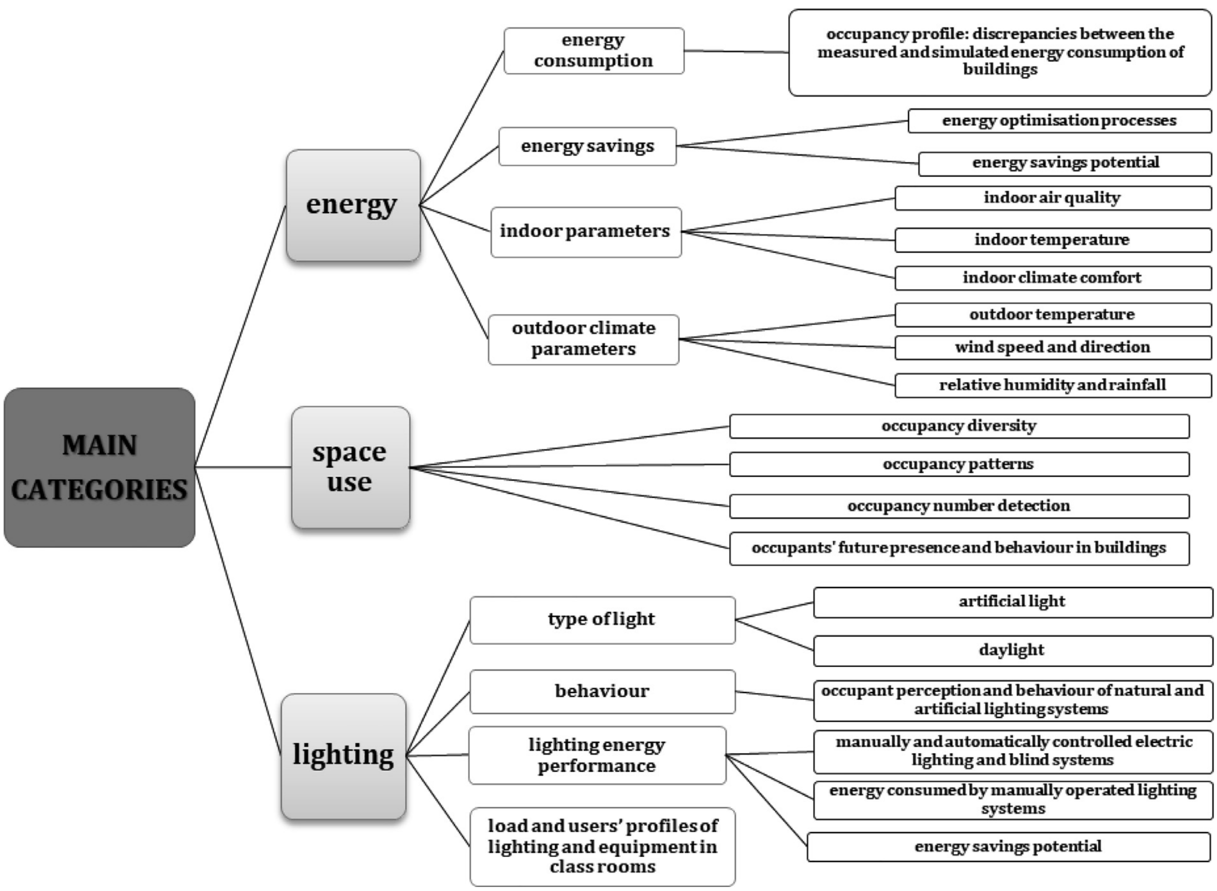

Fig. 3. Main categories of qualitative and quantitative literature review of B/C in non-residential buildings.

monitoring. Less often, computer simulation methods, surveys, or comparative studies were applied. The B/C case studies were mainly held in Europe, North America, and Asia. The B/C case study results were based on monitoring one building, less often several (from 2 to 35) buildings. The monitoring times ranged from a few days to several years. The studies were usually held in the most popular occupancy hours for the respective building type (i.e., schools: school year; offices: working days). However, 24-hour monitoring sessions were also applied in at least three studies.

Twelve reviewed papers focussed on office buildings, and eight research papers investigated school buildings and two papers researched hospitals. Other articles focussed on commercial buildings, or on non-residential buildings in general and libraries. The number of occupants in the investigated buildings was often not indicated in all papers but ranged from 19 to 300 people where indicated (Table 3).

The main building preconditions in the category of *energy* include the dependence of energy savings on the increasing and decreasing occupancy patterns [35], as well as on the type of visual control dimming systems [40]. The B/C are connected to the use of energy rating systems based on theoretical schedules, but that can lead to differences in actual building energy use [6]. Therefore, B/C should be based on big real-time data from sensors, data analytics and modelling, which can provide valuable information to improve the reduction of energy consumption in buildings [28] (Table 4).

B/C *on occupants' behaviour and use of space* are observed in various activities such as opening windows, switching off/on electrical lighting, controlling daylight (shading), and general occupancy habits that keep changing [36]. The occupant behaviour significantly impacts operation and energy consumption within buildings [28], but it is challenging to evaluate and predict occupants' movements and activities, which are comfort-, preference-, or need-driven and change dramatically with time [27].

Table 1
Categories and sub-categories of investigated boundary conditions.

ENERGY	SPACE USE	OCCUPANT (BEHAVIOUR)	LIGHTING
1. ENERGY DEMAND, CONSUMPTION - energy demand [19] - measured [29,39] and simulated [38,39] energy consumption - electricity consumption [41] 2. ENERGY EFFICIENCY - energy modelling: active modelling of occupancy [37] - wasted energy [23], energy-saving potential and operation [40] - improvement of building energy efficiency [27,35]	**1. WINDOW CONTROL** - window opening by occupants [32] - manual window control [36] **2. DIVERS** - evolving role, patterns of use, and costs of building use [24] - interplay between building users and physical environment, spatial ambiance, and the users' behaviours [43] - building stock performance [43]	**1. OCCUPANCY DETECTION** - occupancy detection in a building [20,24,46] **2. OCCUPANT BEHAVIOUR & PATTERNS** - occupancy patterns [21,27,35] - users' mood and saliva cortisol concentration [41] - user-behaviour [36] - energy-related occupant behaviour [6,28] **3. OCCUPANCY PREDICTION** - predicting the future presence of occupants in a building, predicting the occupancy profiles [22] - ways of improving the user flows and system capacity [25] **4. OCCUPANCY MODELLING** - modelling of occupancy [37] - modelling of occupants' adaptive actions [32]	**1. LIGHTING USE & PREFERENCES** - light environment [41] - light perception [41] - lighting performance gap [45] - occupants' use of lighting systems or electrical lighting [34,41] - preferred lighting factors on daylighting intensity [42] **2. LIGHTING CONTROL** - reduction of incident solar radiation, indoor environmental quality [44] **3. LIGHTING SAVINGS** - lighting energy performance [33] - lighting energy use [21]

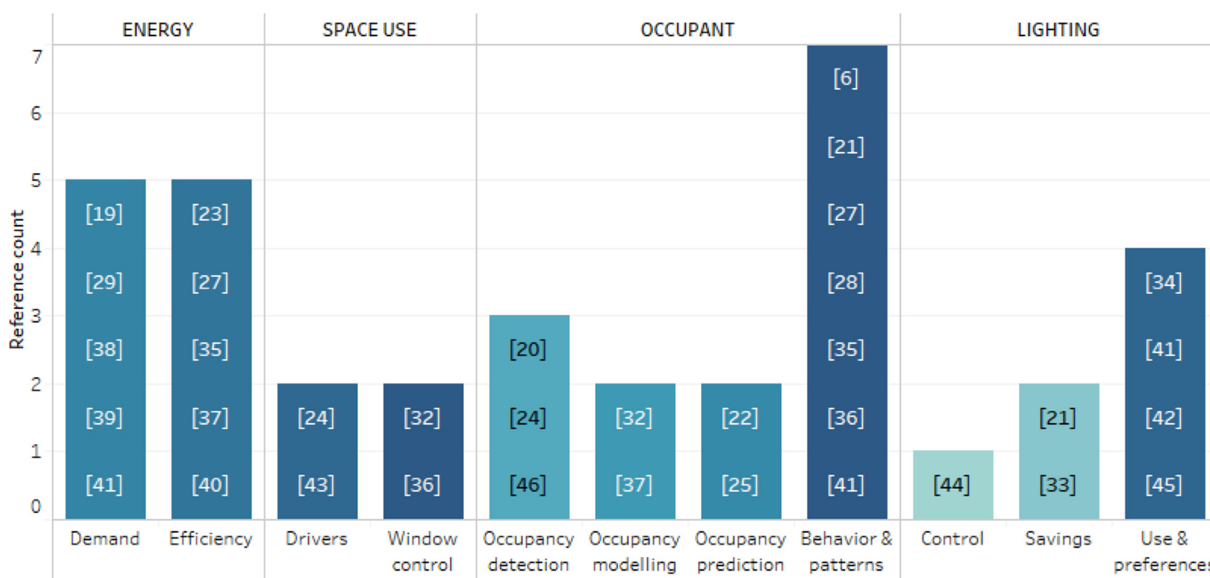

Fig. 4. B/C factors versus chosen categories and sub-categories.

Table 2
Main reasons for identifying boundaries depending on the category within a built environment.

ENERGY	SPACE USE	LIGHTING
• overall building energy assessment • energy optimisations and savings• standard energy estimation software typically deviates from actual (occupant-dependent) energy consumption levels • role of occupants' behaviours in building overall energy consumption • unavailability or inaccuracy of characteristics and standardised boundary conditions & energy demand • evaluation of the energy savings potential • detailing occupancy diversity factors to inform energy simulation parameters better	• revealing the users' and load profiles • users' comfort • occupants' behaviour in buildings • predicting occupants' future presence and behaviours • investigation on the interplay between users' behaviours and the physical environment • analysing the evolving patterns of use and costs • building occupancy • better design of physical interior spaces	• inaccurate pre-set values for the use of artificial lighting • measuring lighting energy performance • discovering how people use artificial lighting and daylight • discovering how people perceive daylit and electric-lit environments

In the *lighting* category, B/C were indicated by the lighting conditions which determined certain user behaviours. On the other hand, occupants' actions and preferences altered lighting usage and the operation of windows and a choice of light. Thus, lighting supports the visual performance and non-visual needs of occupants and influences mood, behaviour. It is not easy to measure all of its impact on the human body due to the subjectivity of the individual responses. Clear indications could be noticed in users' preferences of daylight to electric light, e.g., daylighting regulates cortisol more efficiently than electric lighting [41]. B/C of lighting control systems that change energy consumption [40] and can affect the users' behaviour were also mentioned (Table 4).

3.2. Experts' review results (method 3)

The full results of the expert review are published in IEA Task 61 Subtask A Reports [18]. The IEA review covers an exhaustive typology of non-residential buildings: offices, schools, university buildings, hospitals, commercial buildings, including factories. Due to the vastness of the findings, this publication discusses chosen B/C-related factors in offices (including some located on university campuses), schools, and hospitals only.

The experts' literature review highlights factors that make it possible to establish boundary conditions or interrelations between factors of office buildings in these categories: energy, space utilisation, and light conditions.

B/C in office buildings are affected by different aspects from energy savings, climate, occupancy density, user behaviour patterns to changing weather conditions. (Fig. A.1). Acting on these parameters, designers investigate correlations between users' comfort, satisfaction, and behaviours, such as the use of windows and daylight control and energy savings potential (Table B1). Researchers look into observed factors leading to establish B/C within office spaces from different perspectives, sometimes discussing the values of specific parameters or just investigating correlations and boundaries in time-space or input and output conditions.

Office workers' tasks, schedules, habits, preferences, and sitting arrangements, e.g., in relation to openings, often affect lighting patterns and energy consumption as they could be interpreted as B/C factors.

The experts' literature review shows that B/C of primary and secondary schools, kindergartens, and daycare centres are associated with space utilisation, energy aspects, lighting systems, and acoustic and thermal conditions (Fig. A.2). The studies reflect that due to the many educational levels, school buildings have various occupation densities, occupants' movement patterns, and operating times, which contribute to the multiple B/C values. The users' profiles also differ in age, tasks, behaviours, needs, and preferences. In some schools, the adolescent users frequently relocate after each class. In some not, therefore organisations' routines have a significant impact on many B/C factors. As numerous parameters impact the proper functioning of a school building (including safety, health standards, energy policies, and the design of the educational curricula), there are multiple factors affecting users' comfort (Table B1).

Hospitals are also complex environments with B/C factors relating to hygiene, infection prevention, and the specific design of varying spaces from recovery wards to operating theatres. They have at least three types of general users: staff and patients, and their families. Therefore, users' perspectives can vary fundamentally in spatial comfort, safety, security, autonomy, sensory and visual comfort, and privacy. The literature review demonstrates that the aspects of boundary conditions of hospital and health care buildings are associated with energy savings, indoor and outdoor parameters, space use, lighting control, sound and thermal aspects, and ventilation (Fig. A.3). These factors determine the comfort conditions and are important issues to be considered when developing the architectural design of healthcare services (Table B1).

4. Discussion

4.1. Literature review – Three methods overview

Despite the demanding character of all of the applied review methods, they proved complementary and made it possible to identify the B/C in the top research categories: *energy, space usage, and lighting*. The categories were the results of the initial literature search, but they also helped guide the investigators through the whole research process. The first and second methods identified the primary research strategies involved while investigating B/C within a built environment, which are usually based on in situ monitoring, literature reviews, simulations of a combination of all of these. Thus, the third method – the qualitative experts' review – was sufficient to investigate B/C concerning a type of building and its users' preferences. The overall review of B/C demonstrated a lack of standardised data due to the multidimensionality of the built environment. Many factors of buildings are interlinked, and B/C are often sought in terms of the investigated links. The review indicated disparities in the length of monitoring, numbers of buildings and their types, and number of users. The monitoring protocols also vary due to the issue of privacy regulations concerning data collection [28,30]. Often, pre-set values for energy schedules, control systems, and the use of electric lighting are too general to outline B/C [19]. Some researchers emphasise that energy simulation software programs fail to reliably predict the energy performance of buildings due to misunderstanding and underestimation of the critical role that occupants play in determining energy consumption levels [37]. Others estimate that the energy-saving potential of the buildings cannot be fully estimated. It is a complex issue depending on several building and system parameters, climate conditions, location, occupants' behaviour, and the type and quality of the daylight management control system. The need for a more interdisciplinary approach, more standardised monitoring protocols, and case studies from various geographical regions to get a fuller range of information on B/C is noted.

4.2. B/C in different buildings types

B/C are specific to the building operational hours, users' profiles, and their major visual tasks. Some recommendations of B/C made in one type of building (e.g., office) could be invalid for another type of building (e.g., hospitals or kindergartens), where the usage of the space is different. The availability of daylight, the climate type, density of the surrounding built environment, and access to economic resources can also change B/C limits. Therefore, as the review research indicates, B/C are user- and place-specific, and sometimes even situation-specific. However, some conditions can be tasted in various working environments because many common spaces (transition areas, bathrooms, dining, rest and desk areas) could look similar in many buildings.

In offices, it is essential to take advantage of the natural light through daylight-responsive architecture while providing supplementary electric lighting through good lighting design. In addition, contemporary office buildings commonly experience changes in occupancy patterns and needs due to business practice and personal preferences, which are illustrated in several studies about occupancy patterns and space use. The definition of the number of people that occupy a particular space and for what duration is difficult to characterise because of unpredictable human behaviour

Table 3
B/C category, investigated methods, building, and monitoring data found in 28 selected papers.

	Investigated paper	CATEGORY OF INVESTIGATED B/C FACTORS				APPLIED METHOD OF INVESTIGATION			GENERAL BUILDING DATA									GENERAL OCCUPANCY DATA		
									INVESTIGATED BUILDING TYPE						BUILDING LOCATION		NUMBER OF ANALYSED BUILDINGS	NUMBER OF ANALYSED OCCUPANTS	MONITORING DATES	TOTAL MONITORING TIME
		Energy	Use of space	Occupants' behaviour	Lighting	literature review	case study, on-site monitoring	other	school	office	hospital	library	commercial buildings	non-residential buildings (general)	City	country ISO3166				
1st method	Wauman 2015 [19]	Ed	+		EL	+	+	Representational school building model based on 35 buildings. Simulations	+						Flemish Region	BEL	35	250	1. 09t.-30.06	±1200 h;
	Ahmad 2018 [30]	Ec		+		+		Survey						+	N/A	N/A	N/A	N/A	N/A	N/A
	Haldi 2009 [32]		+	+			+			+					Lausanne	CHE	1	20	19.12.2001 – 15.11.2008	7 years; 24 h/day
	Reinhart 2004 [33]	Ed, Es		+	DL, EL		+	Computer simulation		+					Toronto	CAN	1	N/A		2197 h Mon. – Fri. 8.00 am – 6.00 pm
	Hunt 1979 [34]			+	EL		+		+	+					N/A	N/A	1	N/A	(Jan–Jun, Jul–Dec)	6 months
	Oldewurtel 2013 [35]	Ee, Es		+	EL		+			+					N/A	CHE	1	35	N/A	N/A
	Herkel 2008 [36]		+	+			+			+					Freiburg	DEU	21	21	1.07.2002 – 31.07.2003	13 months
	Azar 2012 [37]	Ec		+		+	+			+					Madison	USA	1	10	N/A	3 years
	Duarte 2013 [38]	Ec	+	+		+	+			+					Boise	USA	1	N/A	N/A	23 months, 24 h/day
	Lam 2009 [20]		+				+	Computer simulation		+					Pittsburgh	USA	1	19	29.01.2008 – 7.03.2008; 17.03.2008 – 4.04.2008;	weekdays 8:00 am – 6:00 pm
	Yun 2012 [21]	Ec, Ed	+		EL		+			+					N/A	KOR	4	21	02.02.2010 – 29.06.2010	N/A
	Mahdavi 2015 [22]		+				+			+					Vienna	AUT	1	N/A	1.04.2012 – 25.07.2012	90 working days, 8:00 – 19:45
	Chang 2013 [23]		+	+			+			+					N/A	N/A	1	N/A	05 – 11 2011	76 weekdays and 34 weekend days and holidays
	Halpern 2010 [24]		+					Comparative study			+				Baltimore	US	3747	N/A	2000–2005	N/A
	Lattimer 2004 [25]		+				+				+				Nottingham	GBR	2	N/A	1998–2001	N/A
	Sugar 2012 [26]		+	+	EL, DL	+						+			N/A	MYS	N/A	N/A	N/A	N/A
	Wang 2017 [27]	Ee	+	+			+					+			Reading	GBR	1	N/A	N/A	30 days, 24 h/day: 15 days (summer term, 15 days summer vacation
	Tam 2018 [6]	Ec, Ee		+		+								+	N/A	N/A	N/A	N/A	N/A	N/A
	Hong 2016 [28]	Ec, Es		+	EL	+								+	N/A	N/A	N/A	N/A	N/A	N/A
	Rashid 2019 [29]	Ec,		+			+	Computer simulation					+		New Delhi	IND	7	N/A	N/A	52 months one-minute sampling rate
	Chen 2012 [31]					+								+	N/A	N/A	N/A	N/A	N/A	N/A
2nd method	Mateus 2017 [39]		+				+		+						Lisbon	PRT	2	N/A	N/A	N/A
	Delvaeye 2016 [40]	Es, Ec			DL		+		+						Haacht	BEL	1	N/A	1.12.2013 – 30.11.2014	Total: 1140 h
	Gentile 2018 [41]	Ee, Es		+	EL		+		+						Helsingborg	SWE	1	116	21.11.2012 – 09.04.2013	N/A
	Salem 2017 [42]	Ec, Ee			DL	+	+						+		N/A	N/A	N/A	37	N/A	N/A

(continued on next page)

Table 3 (*continued*)

Investigated paper	CATEGORY OF INVESTIGATED B/C FACTORS				APPLIED METHOD OF INVESTIGATION			GENERAL BUILDING DATA									GENERAL OCCUPANCY DATA		
								INVESTIGATED BUILDING TYPE						BUILDING LOCATION		NUMBER OF ANALYSED BUILDINGS	NUMBER OF ANALYSED OCCUPANTS	MONITORING DATES	TOTAL MONITORING TIME
	Energy	Use of space	Occupants' behaviour	Lighting	literature review	case study, on-site monitoring	other	school	office	hospital	library	commercial buildings	non-residential buildings (general)	City	country ISO3166				
Cortiços 2018 [47]	Es	+			+		+	+						Lisbon	PRT	1	300	N/A	N/A
Calama-González 2019 [44]	Ee			DL, EL			+	+						Seville	ESP	1	N/A	05 2017 – 04 2018	Annual hours (h) second floor: 2394 h first floor: 1680 h
van Someren, 2018 [45]	Ee, Es			DL, EL			+	+						N/A	GBR	3	N/A	2012–2013	**N/A**

Abbreviations: EL – electric lighting; DL – daylighting; Ee – energy efficiency; Ed – energy demand; Ec – energy consumption/use; Es – energy savings.

and is considered stochastic [38]. Thus their arrival and leaving times and their locations within the building vary throughout the day, and this distribution can be valuable information when evaluating demand control strategies [35]. Therefore, detection of occupant presence as a B/C has been used extensively in-built environments for applications such as demand-controlled ventilation and security, and occupancy profiles are widely used in building simulations. Even though standards provide recommendations (pre-set minimum values describing different parameters) to ensure a comfortable office environment, they do not consider that the user requirements might differ due to mood, activity, preference, and space usage. For these reasons, providing everyone with satisfying conditions becomes a challenge, as the reviewed studies indicate.

The main factor contributing to the boundary conditions specific to schools, kindergartens and daycare centres is the use of space (Table B1). The space utilisation can be linked with design strategies, occupancy densities, hours of use, comfort, and positive distractions. The quality of outdoor environments (playground, activities, green space) and windows views (sky, weather, natural/urban landscape) constitutes positive distractions, especially for adolescent users.

The occupancy behaviour in primary schools, kindergartens, and daycare centres is influenced by the energy aspect, which is determined by the indoor and outdoor climate environment, and is also related to energy savings (Table B1). Indoor parameters such as air quality, temperature, and thermal comfort, and outdoor parameters, such as solar radiation, exterior temperature, wind speed and direction, relative humidity and rainfall, and noise from planes can all affect the users' perspectives and B/C. Energy savings are related to the energy optimisation process and the energy savings potential, which are often parts of national or global schemes for more maintainable educational buildings. As noted in a study on B/C for energy assessment methods for Flemish schools, the design, physical characteristics, and use of space depend on the local building typology, and they cannot be generalised. Therefore, the specific B/C has to be evaluated in every case, but the simulation codes can be used for other building types in other regions [19].

Lighting can affect occupants' behaviour in schools, kindergartens, and daycare centres (Table B1), and influences their healthy growth and educational progress [48]. Electrical lighting, daylight, and how users perceive and react to these are parameters to consider for establishing B/C. More specifically, concerning the electric lighting, various features affect the occupancy. First, the light sources must be arranged to obtain a uniform distribution of the lighting. Then, the type of the light source needs to be chosen with the appropriate correlated colour temperature and Colour Rendering Index. Finally, the lighting system must be designed, including flickering (ballasts). Furthermore, visual comfort is impacted by glare, light quantity, and uniformity, which also involve control and shading systems. The room characteristics (geometry and material properties) influence the lighting aspect as well. Finally, the lighting in school buildings has the potential for energy savings.

Acoustic comfort can influence the occupancy behaviour in schools, too (Table B1). Acoustics can be related to the sound level (environment) and how to control the noise. Thermal comfort influenced by ventilation, heating/cooling systems, and the thermal properties of the building envelope is also an aspect impacting the occupancy behaviour in educational buildings.

Hospitals and health care buildings are environments with a constant occurrence of critical and stressful situations involving interpersonal relationships, as well as places for recovery and healing processes. These facilities have to accommodate the needs of the users who might be physically and psychologically drained

Table 4
Primary B/C and B/C factors observed conditions in non-residential buildings in categories energy, use of space, lighting.

ENERGY	USE OF SPACE/OCCUPANTS' BEHAVIOUR	LIGHTING
- observing energy savings vs. increasing and decreasing occupancy days [35] - looking into energy savings in relation to lighting control system and visual comfort [40] - explaining how energy rating systems use theoretical schedules as a form of normalising results, which leads to differences in actual building energy use [6]- understanding how big real-time data from sensors and ICT (Information and Communications Technology) , data analytics, and modelling provide valuable information for reducing energy consumption in buildings [28]	- researching how occupants' behaviour significantly impacts building system operation and energy consumption [28] - observing how occupancy patterns can change dramatically with time [27], e.g., higher occupancy on Mondays and early departure on Fridays – days before holidays have similar features as Friday profiles [38] - explaining how monitoring can help to reveal movement and help with stochastic modelling [38] - understanding that each occupant is unique and cannot be lumped into a general category such as 'wasteful' or 'austerity' [28] - emphasising that the more the occupants control the energy consumption sources of their environment, the more a change in their behaviour affects total energy use [37] - pointing out that CO2 and acoustic parameters have the most significant correlation with the number of occupants in the space [20]	- establishing the input parameter for predicted operational hours ≠ occupancy hours ≠ lighting hours [45] - impact of an efficient light source on energy savings, why the efficient solutions do not imply energy savings [41] - looking into lighting responsibility for amounts of energy consumption [42] - observing differences between the annual energy savings of the different daylight control systems [40]-understanding of controlled LED lighting which supports mood and biological functions; and reasons why stress hormones (cortisol) are more efficiently regulated by daylight than electric lighting [41] - describing how occupants may affect energy use and lighting by incorrect use of controls, shading, and window operation [6] - observing how strongly users' habits and rituals, as well as their arrival and departure, are connected to the control of the environment: window and lighting status [36]

by the situation in which they find themselves. The users include individuals with some degree of physical or psychological suffering – patients, and medical professionals who provide medical treatments to the highest standards possible despite working long hours, including night shifts, and under much pressure. Therefore, hospitals are very complex environments with diverse types of users, resulting in several various B/C and interrelating factors.

The occupancy behaviour in hospital or healthcare units is influenced by the space use (Table B1). The space use can be altered by design strategies, evidence-based design strategies, or positive distractions. The evidence-based design strategies can bring visual comfort, privacy, safety, and security. The positive distractions such as exterior views, artworks, and access to nature can lead to faster recovery [49].

The behaviour of the hospital's users may also be affected by energy solutions. At the same time, energy solutions and energy design are linked to indoor parameters such as air quality, indoor temperature, indoor climate comfort, and outdoor parameters, including the outdoor temperature, wind speed and direction, relative humidity, rainfall, and availability of daylight. The B/C can be associated with energy-saving potentials or energy optimisation goals.

The daylight distribution, timing, and spectral characteristics can also act as B/C and influence occupancy behaviour in health care facilities in terms of lighting control, thermal comfort, ventilation (opening the windows), and electricity usage (turning on the electric light when needed).

Several studies have found an association between the physical environment and human health and well-being that resulted in the postulation of evidence-based and patient-centred design of healthcare facilities. Three major research themes found in the literature on health care environments and patient outcomes are patient involvement with healthcare (e.g., the role of patient control), the impact of the ambient environment (e.g., sound, light, art), and the emergence of specialised building types for patients with specific illness (e.g., Alzheimer's patients). The researchers discuss the challenges presented in research focussed on health care environments and contrasts the contributions made by two different traditions: architecture and behavioural science [50]. For example, to investigate the physiological and psychological effects of windows and daylight on registered nurses. To date, evidence has indicated that appropriate environmental lighting with characteristics similar to natural light can improve mood, alertness, and performance. The restorative effects of windows have also been documented. Thus, many hospital workspaces such as operating theatres are often windowless. The impact of the lack of views out and daylight on healthcare employees' well-being has not been thoroughly investigated. The findings support evidence from laboratory and field settings of the benefits of windows and daylight. Some suggest a possible micro-restorative effect of windows and daylight may result in lowered blood pressure and increased oxygen saturation and a positive effect on circadian rhythms (as suggested by body temperature) and morning sleepiness [51].

Literature findings suggest that there is solid scientific evidence to show that the following indoor environmental factors have beneficial effects for all user groups when appropriately designed or implemented: the acoustic environment, ventilation and air conditioning systems, the thermal environment, the visual environment (e.g., lighting, and views of nature), ergonomic conditions, and furniture. In contrast, the effect of unique layouts and room type and floor coverings may be beneficial for one group and detrimental for another. Some of the physical factors may, in themselves, directly promote or hinder health and well-being, but the factors can also have numerous indirect impacts by influencing the behaviour, actions, and interactions of patients, their families, and the staff members. The findings of this research enable a good understanding of the different physical factors of the indoor environment on health and well-being, and provide a practical resource for those responsible for the design and operation of the facilities, and researchers investigating these factors. [52].

In research examining users' perception as a critical design indicator in enhancing their hospital experience, indicators such as design for cleanliness, environmental and safety design were the most valued. In comparison, the 'pleasant exterior view' indicator had the second-lowest mean score, followed by the item, 'ability to customise the space' [53]. There is a gap in the literature on users' perspectives on physical settings in the context of healthcare buildings. Moreover, the connection between care services and the facility's design is often overlooked partly due to the lack of evidence. Researchers who looked into outpatients' perspectives on design factors found that female outpatients were more perceptive of the 'sensory design' factors than males, indicating that some B/C factors are user-specific. Previous visits to the space (as previous experience of the users) were found to be associated with 'spatial' and 'seating design' factors. Finally, respondents ranked 'noise', 'air freshness,' and 'cleanliness' as essential factors from their perspectives [54].

The critical challenge for identifying B/C and their factors in various building types is that most evidence-based results are context specific. The transfer of specific design ideas or B/C values from one environment to another is complex, mainly because of the difficulties associated with the disaggregation of findings from the specific context. Thus, integrating users' perspectives requires an understanding of the relative importance of related design indicators, which the existing evidence-based research lacks to a large extent [54].

The overall results present discrepancies in boundary conditions and their factor ratings, and inconsistencies in boundary-related building reports. The conducted review highlighted the importance of making the occupants aware of the implications of their actions on the real-time performance of the building. The findings also emphasise the significance of occupant behaviour for pushing the existing boundary conditions of the occupied spaces.

4.3. The need for further studies and development on B/C

B/C help answer the 'who', 'where', and 'when' [1], but also the 'how' and 'to what extent' in the design process. Further studies on B/C within different types of buildings concerning their users are crucial in BIM (Building Information Modeling) design. The building users' needs and preferences are significantly studied since occupants' behaviours and actions impact energy use and building maintenance costs. The review of B/C exposes the need for supplementary methods to relate socio-economic trends, new technology developments [6], and unforeseen events such as global pandemics [55].

The review results suggest that detailed studies of energy-related occupant behaviour in offices and schools (due to the complexity of their systems) [6] as well as in hospitals (complexity of the services, and various patients' and medical personnel's perspectives) are needed. The demand for further development of the monitoring protocols and global comparative studies focussing on B/C is noticeable. The B/C research help to create more reliable models to simulate occupant behaviour and their needs and requirements within enclosed spaces, but they are often case-specific.

4.4. Future recommendations from literature review

The literature review recommendations for future studies are to focus on B/C regarding occupants' behaviours within various types of buildings and during the building life-cycle. The way occupants use a space is neglected in existing rating systems [6] and needs to be further investigated. Adjusting buildings' systems (HVAC, lighting) to constantly changing occupant behaviour may be a crucial element to achieve excellence in building performance, either energetically or environmentally, or both [6,35]. During the design phase of the building, comprehensive occupant behaviour data can influence design solutions and improve operational efficiency and comfort levels [6]. It is also recommended to study how occupants who are aware of the implications of their actions on the real-time performance of a building alter their behaviours, actions, and habits.

The results of this B/C literature review indicate a demand for more research dedicated to occupants' lighting preferences to increase building energy efficiency [42]. Additionally, the review also demonstrates that more diversity factors that resemble contemporary real-world data for energy predictions should be used to close in on matching real-world energy billing data [38]. The need for further studies is valid as the quintessential factors such as B/C related to *energy, space, and lighting* are not yet all elucidated.

Due to number of considered factors relating to B/Cs and the diversity of the cited papers as well as the considerable length of the text, this review does not provide detailed information on the (day)lighting, lighting sources, systems, control strategies and commissioning steps described in all of the mentioned papers. The authors belief is that the all of the discussed categories: energy, use of space and lighting, could benefit from a detailed review approach in the near future, especially in a light of recent extraordinary conditions – the global pandemic.

Finally, recommendations from this review should be confronted with post-pandemic B/C research. Covid-19 pandemic restrictions such as social distancing measures and home confinement change the use of many buildings and the occupants' attitudes regarding prolonged or atypical usage of enclosed spaces. Self-isolations and lockdowns resulted in limited access to outdoor open spaces. They influenced people's exposure to daylight and altered their perception of window view, which conveys information about the outside world [56]. Long-term home confinement also impacted humans' sleep and rest-activity rhythms [57–59]. The role of the built environment in mitigating the multi-dimensional effects of the pandemic has been analysed [55,60], as boundary conditions of buildings' operation were altered.

5. Conclusions

As this review demonstrated, the B/C for non-residential buildings in energy, occupancy patterns, and lighting vary from occupancy data through energy demands and usage numbers to lighting levels and design solutions. The B/C and their factors are often building type- or user-specific. The methods of their identification and evaluations also differ from short-term (hours) or long-term (years) on-site monitoring to simulations, mathematical model proposals, and even literature reviews. B/C seen as the *unique characteristics* for use and determining specific features of buildings enable a more accurate understanding of users' perspectives and needs in offices, schools, and hospitals, and bridge existing research-practice gaps. Furthermore, defining the most common border characteristics assists in comprehending the role of human behaviour within a space and its impact on energy and lighting use, and sheds light on the particular requirements of the buildings' occupants. The reasoning for looking into B/C within a built environment is usually to help it shape it better, especially for the users, to address their preferences and requirements.

As the review indicates, the B/C allow for an objective evaluation of the building design. The pre-set minimal values regarding energy demands, heating schedules, control systems, electric lighting use, daylight control, ventilation system, and other aspects of building life are defined in the corresponding recommendations. These minimal values sometimes prove to be inaccurate or too general, which affects the initial design outcome. Then, the need for B/C research to provide more detailed data is justified. Thus, it is worth remembering that unpredicted occupant behaviours, weather, and situations (i.e., the COVID-19 pandemic) can radically change the building occupancy patterns, energy and lighting use, and other aspects of the building life-cycle. In that case, the B/C should be based on stochastic methods and uncertainty analysis, including the case studies' broader geographical and socio-demographical context.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Graphs illustrating the experts' literature review method (method 3) on B/C and their factors in relation to offices, schools, and hospital buildings from the perspective of the users' preferences.

A1. Offices.

Fig. A.1.

A2. Schools.

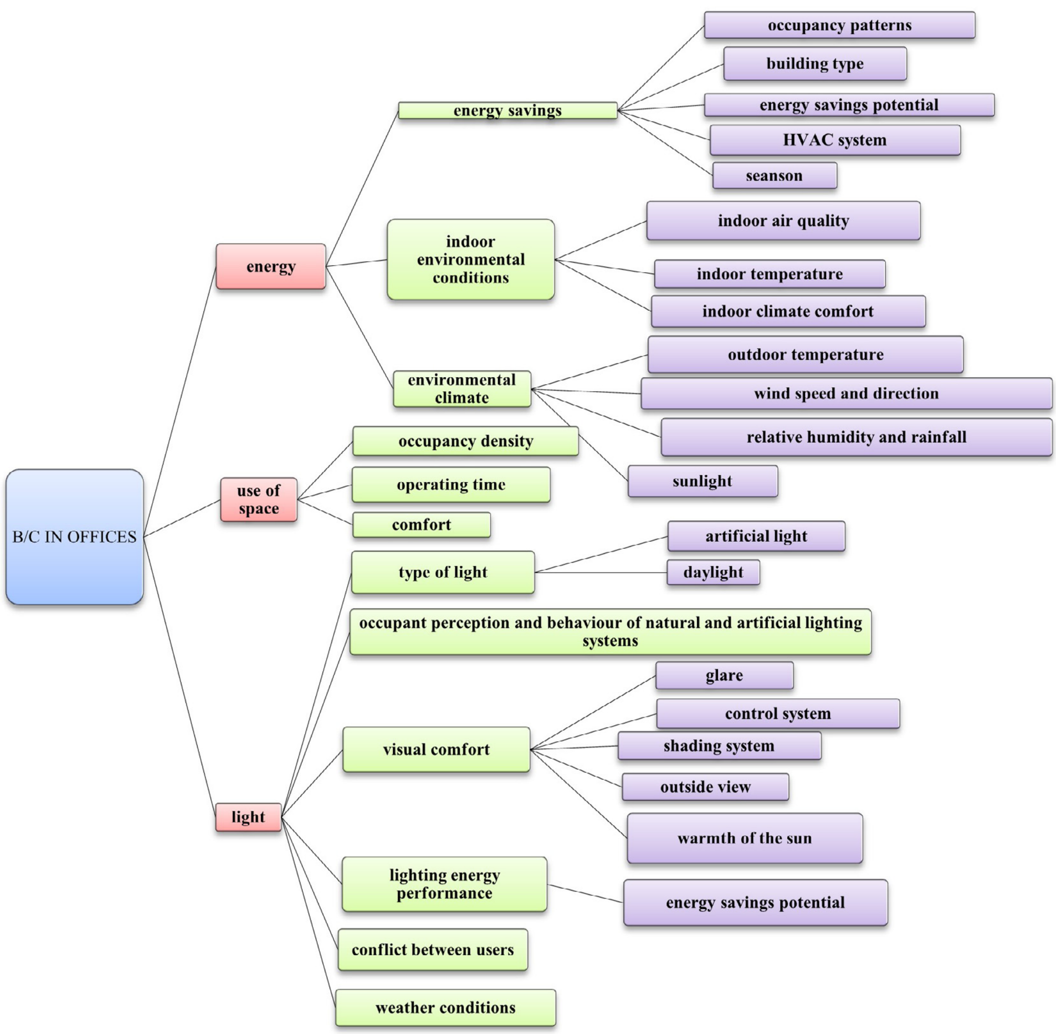

Fig. A1. Office buildings – experts' B/C literature review results: main categories and topics.

Fig. A.2.
A3. Hospitals.

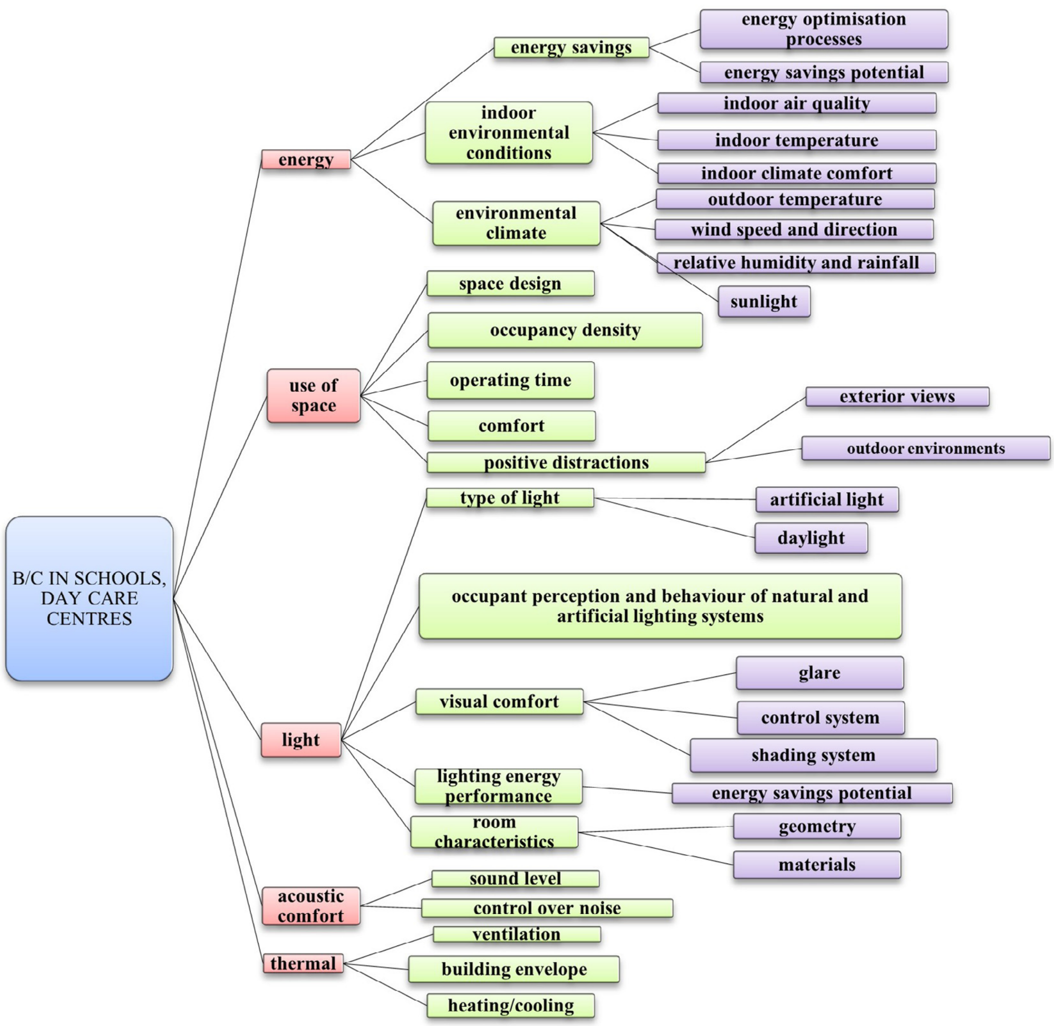

Fig. A2. Schools, kindergartens and day-care buildings -experts' literature review results: main categories and topics.

Fig. A.3.

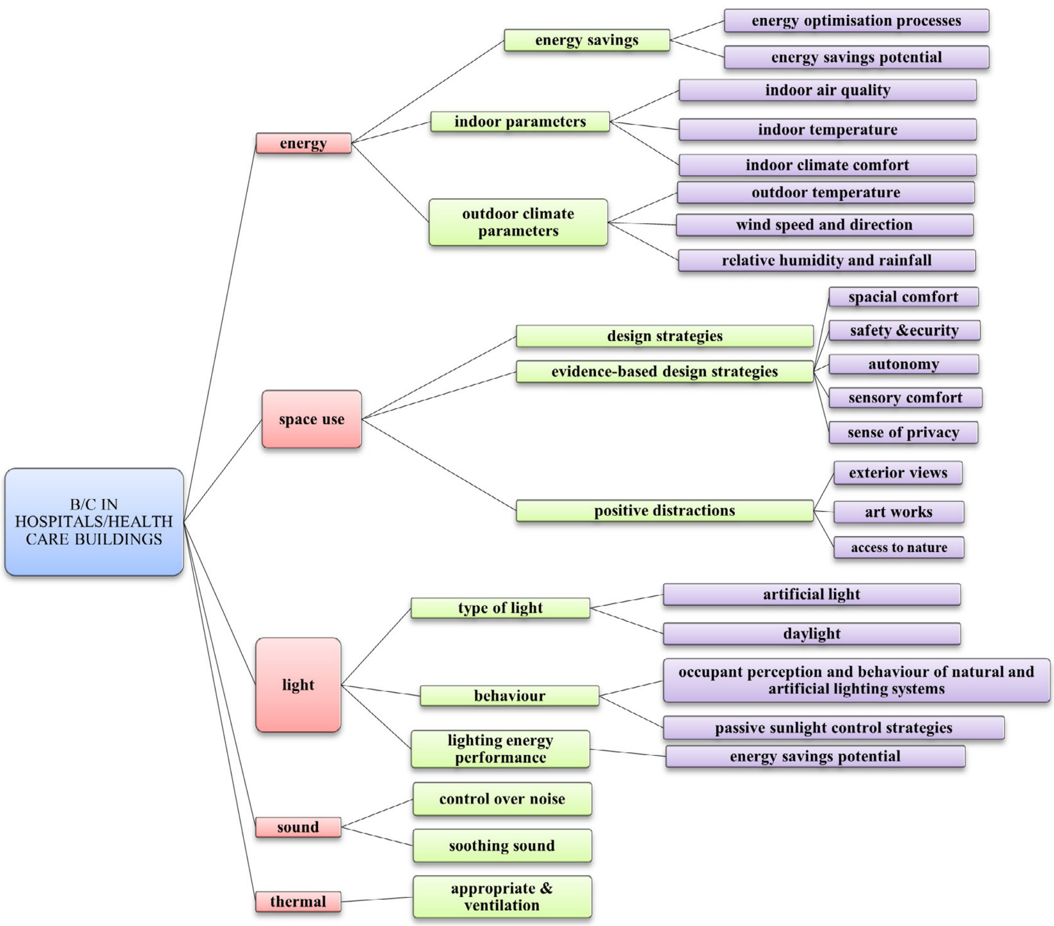

Fig. A3. Hospitals and health care buildings – experts' literature review results: main categories and topics.

Appendix B

B/C factors in offices, schools and hospitals chosen by experts using qualitative review method (method 3). Table B1.

Table B1
Boundary conditions in and their factors in offices, schools and hospitals.

OFFICE TYPE	USERS	OBSERVED FACTORS	RESULT	SOURCE
4 offices at a Korean university Each 1 wall with double glazed window and internal blinds. The azimuths of the main façades were 4°, 274°, and 94°	19 postgraduate students	Interrelation between **illuminance distributions**, **occupancy** and **lighting use patterns**, and **lighting energy demands**	**No significant relationship between the available daylight and use of lighting by occupants** in the investigated offices. A strong **tendency of turning on lighting by occupants' on first arrival in the morning and of keeping the lighting on. Lighting use patterns were significantly related to the occupancy patterns.** **Lighting control** in relation to **indoor daylight levels can save lighting energy use by up to 30%.**	[21]
2 open plan offices in the Netherlands (6 zones)	14x2 administrative workers	**lighting preference profiles of users** based on behaviour control: activeness in the use of space, tolerance to different illuminance levels, dominance in prevailing preferred lighting levels and	**Lighting preference profiles of the users and zone classification** can improve satisfaction with the lighting conditions by: Predicting **the probability of conflict between the users in the same control**	[61]

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Table B1 (*continued*)

OFFICE TYPE	USERS	OBSERVED FACTORS	RESULT	SOURCE
		preferences – maintaining control of preferred lighting levels	**zone** and facilitate in making consensus choices. **Allocating users to different zones matching their lighting preferences. Offering lighting conditions that meet the preference profiles of the users. Triggering a submissive user to express their preferences.**	
1 office building in Switzerland with Integrated Room Automation (IRA), i.e. integrated control of Heating, Ventilation, Air Conditioning (HVAC), lighting & blind positioning	35 office workers	Influence of **occupancy types** (homogeneous, alternating) and intervals on **energy savings**	**Homogeneous occupancy** showed **a savings potential of up to 34%** for the case of average vacancy and occupancy intervals of 5 and 10 days, respectively. with alternating occupancy, the savings are in the range of 50% of the savings with homogeneous occupancy.	[35]
an open plan office with 16 rooms (bays) and 1 conference room	5 faculty members, 12 PhD students 2 staff + visitors	Three machine learning methods were investigated for **occupancy detection** based on analysis of environmental data captured from existing sensors and ambient sensing networks	**CO2 and acoustic parameters have the largest correlation** with the **detection of the number of occupants** in the open office plan. Hidden Markov Models achieved reasonable tracking of the **actual occupancy profile (av. 80% accuracy).**	[20]
a large commercial, multi-tenant office building 223 private offices open offices, hallways, conference rooms, break rooms, and restrooms	office workers	**deterministic occupancy diversity factors**	The diversity factors presented differ as much as 46% from those published in ASHRAE 90.1 2004 energy cost method guidelines.	[38]
1 single-occupancy office, 2 semi-closed individual offices, and 5 open-plan offices in a building of the Vienna University of Technology	university workers	**different occupancy models**: two existing probabilistic occupancy models, a simple original non-probabilistic model of occupants' presence, and past monitoring occupancy data	Results of the case study do not assert the full fidelity of occupancy models in predictive building systems control.	[22]
1 building, 3 floors, 200 open-plan (cubicle) offices	Office workers	**occupancy profiles** based on measured lighting-switch data in five-minute intervals factors: average occupancy profile together with probability distributions of absence duration, and the number of times an occupant is absent from the cubicle	**Job category** may have more impact on occupancy patterns than the location of the cubicle.	[23]**c**
Solar Energy & Building Physics Laboratory (LESO-PB) Lausanne, Switzerland (46°31′17″N, 6°34′02″E, alt. 396 m.) 6 offices with 2 workspaces 8 offices with 1 workspace	university workers	**occupancy patterns**, **indoor temperature** and **outdoor climate parameters** (temperature, wind speed and direction, relative humidity and rainfall) on **window opening and closing behaviour**	The actions on windows are correlated with some parameters such as the **respondent's gender**, while the **outdoor temperature, perceived illumination, air quality and noise levels had a statisticallysignificant impact on on "perceived" window opening behaviour.**, Suggestion of using a hybrid modelling approach (based on logistic probability distributions, Markov chains and continuous-time random processes), which models stochastic usage behaviour in a comprehensive and efficient way.	[32]
3 medium-sized, multi-person offices; 2 school classrooms; and 2 open-plan teaching spaces UK	office workers, pupils, teachers	**manual lighting control vs. energy levels effected by occupants' arrival, manual shading control**	A cycle of occupation of the space determined when to switch the lights on. The probability of switching on the artificial lighting in a daylit space was most closely related to the minimum working plane illuminance.	[34]
1 office Toronto, Canada (43.67 N; 79.63 W)	various profiles of office workers simulated	**annual profiles of user occupancy and work plane illuminances compared** with **probabilistic switching patterns**	A simulation algorithm is proposed that predicts the lighting energy performance of manually and automatically controlled electric lighting and blind systems.	[33]
4 identical single-occupant office rooms located on Lund University's Campus (LTH), Lund, Sweden (55°420 N, 13°120E)	3 males, 1 female	**actual energy performance and occupants' satisfaction with efficient lighting control systems** (LCSs) LCS: presence detection PSD (occupancy-linked system with presence detection), absence detection ASD (manual switch at the door combined with absence detection), daylight harvesting with absence detection (DHS) and LED task lamp	Human factors should be considered. Users appreciated manual switch with absence detector. This solution achieved good energy performance (75% savings compared to the presence detector)	[62]

Table B1 (*continued*)

OFFICE TYPE	USERS	OBSERVED FACTORS	RESULT	SOURCE
SCHOOL TYPE	**USERS**	**OBSERVED FACTORS**	**RESULTS**	**SOURCE**
153 classrooms in 27 schools in order to identify the impact of the physical classroom parameters on the academic progress of the 3766 pupils UK	3766 pupils	**physical classroom parameters, academic progress** **user-centred design characteristics**	7 key design parameters were identified: Light, Temperature, Air Quality, Ownership, Flexibility, Complexity and Colour. Together, they account for 16% of the variation in pupils' academic progress achieved; the Light parameter had the strongest impact and accounts for 21% of all parameters.	[63]
five high schools US	94 high school students	**baseline attention and stress levels** **window-view** **green views** **ability to pay attention. stress levels during class activities and after the break.**	Window views to green landscapes promote high school students' attention restoration. Window views to green landscapes speed high school students' recover from stress.	[64] **Li and Sullivan (2016)**
6 classrooms in Florianópolis Brazil	84 children	**children's luminous and visual preferences regarding outside view**	Preschool classrooms with more natural views could be more stimulating for younger children, while classrooms with window views of built elements could be more stimulating for older children.	[65] **Vásquez, Felippe et al. (2019)**
School building model based on 35 schools Belgium	–	**Pre-set energy performance levels** **B/C of input data in energy standards** **energy demand calculations, school operational schedule, set point temperature, occupant density, ventilation, installed lighting power density, profiles of lighting and equipment**	The set point temperature, load and users' profiles of lighting and equipment in class rooms as the most dominant input parameters for the energy demand calculations.	[19] **Wauman, Saelens et al. (2015)**
80 day-care centres 74 schools Finland	children staff	**correlation between building occupancy, space efficiency and energy efficiency** **building usage and occupancy influences the measured energy consumption** **buildings' characteristics** **weather** **opening times**	Day-care centres are similar, schools have clearly identifiable user profiles but the variation between the buildings is greater. In one building, despite it having the same opening hours, small differentiations can be observed due to breaks and outdoor meetings/classes, which results in a change in the control of the HVAC system, lighting and equipment.	[66] **(Sekki, Airaksinen et al. 2015)**
18 primary schools, 70 classrooms UK	92 teachers 163 students	Impact of **aircraft noise** on **overheating levels** **habit of opening windows – natural ventilation** **temperature** subjective opinions on **thermal comfort, noise level lighting level, indoor air quality** **frequency of noise from different sources** **Teachers' speech intelligibility**	Natural ventilation through windows is not sufficient for keeping indoor temperatures at a comfortable level and for providing fresh air for schools which are located under flight paths. As control of ventilation is one of the methods of controlling overheating, it is possible to reduce the overheating risk by controlling solar gain, internal gain, design layout and by the use of heavy thermal mass material instead of low and medium ones.	[67] **(Montazami, Wilson et al. 2012, Puteh, Adnan et al. 2014, Salleh, Kamaruzzaman et al. 2015)**
3 secondary schools in Malacca 5° 25′N, 100°19′E Malaysia	917 students	Level of **teaching comfort vs climate change** Students' perceptions on climate change awareness, physical classroom environment, classroom thermal comfort, teaching and learning comfort, effects of thermal/heat and environments on health	Showed that the most frequent health problems faced by students is regarding their eyes, such as watery eyes, redness and blurring of the eyes. The study also found that the effects of temperature on teaching and learning comfort (heat) in the classroom is at a moderate level.	[68]
240 refurbished kindergartens Malaysia	404 questionnaires sent to kindergarten workers	**Indoor environmental quality (IEQ)** User perception and satisfaction on noise, smell, humidity, freshness, air quality, air movement, ventilation, temperature, daylight, distance to the windows, glare level, control, privacy colours, electrical lighting, colleagues, management, attractiveness	Colleagues, management, attractiveness, and colours, are considered as the most satisfactory IEQ factors followed by daylight. Noise, smell, glare level, and distance to window as the least satisfactory features.	[69] **(Salleh, Kamaruzzaman et al. 2015)**

(continued on next page)

Table B1 (*continued*)

OFFICE TYPE	USERS	OBSERVED FACTORS	RESULT	SOURCE
3 school districts with 2000 classrooms US	6000 to 8000 2nd to 5th grade students	relationship between **presence of daylight** and human performance in buildings size and placement of windows, use of electrical light maths and reading test results, and the demographic characteristics	There are statistically significant effects of daylighting on human behaviour, as evidenced in the standardised test scores for elementary school students. The daylight had an influence on concentration and the academic performance of the children. Visual comfort is connected to student performance.	[48] **(Heschong, Wright et al. 2002)**
6 buildings 3 kindergarten classrooms, 3 primary school classrooms, 2 university classrooms and 2 university libraries Viseu Portugal	487 responders (children, young adults)	**thermal comfort models**, PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) index pupils' perception global comfort local comfort	Students felt comfortable and a large majority would maintain the indoor conditions unchanged.	[70] **(Almeida, Ramos et al. 2016)**
1 secondary school – 3 classrooms Haacht Belgium	School occupants	**daylight control systems** **energy saving potential** power and the electric energy consumption of the artificial lighting visual comfort	Annual energy savings of three different daylight control systems varied from, 18% to 46%.	[40] **Delvaeye, Ryckaert et al. (2016)**
secondary school Portugal	955 students, 99 teachers and 30 staff members	**energy performance** and **indoor climate conditions** indoor air quality and thermal comfort	11.2% reduction in energy consumption thanks to daylight harvesting.	[71] **(Bernardo, Antunes et al. 2017)**
secondary school buildings Portugal	pupils, teachers	**user behaviour and its impacts on energy use patterns** **light-use management**	Users' visual comfort, functional needs, and light use in schools is also strongly influenced by organisational habits. Favourable conditions exist for making natural light the main light source in schools. Improvements in the design and management of circulation areas could lead to significant reductions in artificial light (and energy) use.	[72] **Lourenço, Pinheiro et al. (2019)**
HOSPITAL TYPE	**USERS**	**OBSERVED FACTORS**	**RESULTS**	**SOURCE**
healthcare facilities (in general)	patients, patients' families, healthcare staff	**effects** of the **physical environment** on the **healing process and well-being**	Important design features: single-patient rooms, identical rooms, lighting. Outcomes: reduction of errors, increasing safety and security, enhancing control, privacy, comfort, organisation and functionality, technical support.	[49]
8 acute care hospitals	496 healthcare professionals	**evaluation** of **patient areas, staff areas**, **work spaces**	Importance of a safe and comfortable work environment via finishing materials, indoor air quality, and furniture design. Features addressing the visual quality of the work environment, such as window views and artwork – important in non-clinical staff areas: features improving the visual quality of the rest area.	[73]
neonatal healthcare units (in general)	premature human infants (in general)	**effect of reducing early environmental light exposure** on the incidence of any "**Acute Retinopathy of Prematurity (ROP)**", or "**Poor ROP**"	No reduction in Acute ROP, or Poor ROP outcome with the reduction of ambient light to premature infants' retinas.	[74]
healthcare facility	patients, families healthcare personnel	**physical characteristics** of the **indoor environment** that affect **health and well-being**	Important indoor environmental factors: the acoustic environment, ventilation and air conditioning systems, thermal environment, visual environment (e.g. lighting, and views of nature), ergonomic conditions and furniture. Not all the groups consider as crucial: the effect of special layouts and room type and floor coverings.	[52]
healthcare "environments" Specialised building types and units: (a) pastoral campus, (b) denser suburban, (c) new, urbanist village, (d) urban high-rise	patients	**patient involvement with health care** (e.g., the role of patient control), the **impact of the ambient environment** (e.g., sound, light, art), **the emergence of specialised building types for defined populations** (e.g., Alzheimer's patients)	Contrasts between the contributions made by two different traditions: architecture and behavioural science. Important factors: ambient environment, noise, music. In the patient room: windows, views, art, lighting and colour. Change in the way health care is now approached by architects – the monolithic hospital is being replaced by a variety of building types.	[50]

Table B1 (*continued*)

OFFICE TYPE	USERS	OBSERVED FACTORS	RESULT	SOURCE
1 neonatal intensive care unit Children's Hospital Mendoza, Argentina	infants	**performance of different passive sunlight control strategies**	"Adequate implementation of solar control systems and the appropriate layout of the space for different uses according to surrounding building design and the characteristics of the local luminous climate can increase the useful daylight illuminance by up to 13%, while avoiding the incidence of direct sunlight at all times". **Factors important in terms of daylight performance:** **-solar control system selection,** **-space layout,** **-dynamic simulation applied to daylight, performance analysis.**	[75]
4 hospitals Netherlands	379 adult patients, in 48 patient rooms	**design characteristics** of a **patient room** on self-reported patient **well-being** (Identified) Six themes creating healing environments: spatial comfort, safety and security, autonomy, sensory, comfort, privacy, social comfort	Factors mostly influencing patients' self-reported well-being in a patient room: spatial comfort, safety and security, autonomy, associated design characteristics. Privacy appears to have the smallest influence.	[76]
mental healthcare facility	senior-level hospital staff+12 architectural designers	**perceptions and feedback** regarding the **impact of specific design features**	The hospital staff were quite enthusiastic about two of the design innovations studied here (a new wayfinding strategy and the use of vibrant colours in specific areas of the facility). The third innovation, open-style communication centres, elicited more mixed evaluations.	[77]
children's hospital	staff, family members	the impact of **an existing and newly built hospital environment** on **family and staff satisfaction related to light, noise, temperature, aesthetics, amenities, safety, security, privacy**	Staff satisfaction: layout of the patient room, natural light, storage and writing surfaces, comfort and appeal. Family satisfaction: natural light, quiet space, parking, child's room Greater satisfaction with the newly built hospital environment compared to the old facility (of families and staff).	[78]
29 intensive care patient rooms in 3 intensive care units Sweden	72 staff questionnaires 9 staff interviews (+observation of patients)	how the **design and layout of the module impacts family involvement, staff efficiency, and the well-being of patients and staf**f criteria: **intended design goals, staff perceptions, and design best practice**	Single-bed rooms improved privacy and the ability to stay in the patient room. "Varying designs of the patient room module affect users in unique ways and must balance privacy, visibility, quietness, and staff access for assistance".	[79]
hospital patient rooms "typical solution of the Italian healthcare building stock, supposed to be located in Bologna Italy" L-shaped building volume with 7 stories	patients not involved in investigation	**role of windows size and glazing properties on heating and cooling energy needs**	Adoption of wider windows with appropriate glazing can lower the heating and cooling energy demand	[80]
healthcare facilities (in general)	patients	scientific evidence on **healthcare facilities and its impact on patients' health outcomes** under a holistic conceptual evaluative framework	The environment–occupant–health framework should support future research by: (1) identifying the HBE (healing built environment – HBE)) characteristics that affect health outcomes, (2) defining appropriate future research designs, (3) understanding the need for a holistic analysis of the integrated effects of diverse HBE characteristics on health outcomes.	[81]
clinical environments (in general)	staff, patients	**role of physical environmental factors in clinical environments** and their impact on patient and staff **wellness** with a **particular focus on physical and mental healthcare**	Incorporating physical environmental factors into hospital design can facilitate better user satisfaction, efficiency and organisational outcomes. Positive distractions for patients and staff: views of pleasant outside vistas, soothing sound, artwork and music.	[82]
"healthcare units" "taking care of those with dementia" (in general)	Patients	impacts of aspects of the **built environment on the well-being / living with dementia**	Needs-driven design principles (improving the quality of life of those with dementia): manageable cognitive load, clear	[83]

(*continued on next page*)

Table B1 (*continued*)

OFFICE TYPE	USERS	OBSERVED FACTORS	RESULT	SOURCE
			sequencing, appropriate level of stimulation.	
intensive care unit in Foothills Medical Centre in Calgary Canada	39 participants in total: 13 nurses, 7 respiratory therapists, 6 physicians, 5 other healthcare providers, 4 support staff, 4 family members	**atmosphere** (abundant natural light and low noise levels), physical spaces (single occupancy rooms, **rooms clustered into clinical pods, medication rooms, and the trade-offs of larger spaces), family participation in care (family support areas and social networks), and equipment** (usability, storage, and providers of connectivity)	Important aspects indicated by end-users –- design elements for creating a pleasant atmosphere: -attention to the trade-offs of space and size (benefits of additional space (e.g., fewer interruptions due to less noise) outweighed the disadvantages (e.g., greater distances between patients, families and providers), -designing family support areas to encourage family participation in care, -updating patient care policies and staffing to reflect the new physical space.	[84]

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