Chapter 2
Health Outcomes Related to Built Environments

Abstract This chapter is dedicated to understanding the conceptual differences between healthy and unhealthy built environments (Sect. 2.1) as well as comfortable and uncomfortable conditions (Sect. 2.2) by using standardized professional terminology. In Sect. 2.3, the role of wellbeing in the sustainable building concepts is discussed and further addressed in the context of eco-friendly, green, and low-carbon buildings. The largest part of this chapter is devoted to various health effects related to exposure to health risk factors in the built environment (Sect. 2.4). In Sect. 2.5, health outcomes shown by reviewed epidemiological studies in Europe and worldwide are detailed. The chapter concludes with a determination of priority environments in public and residential buildings as well as vulnerable population groups (Sect. 2.6).

2.1 Healthy Versus Unhealthy Buildings

Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (WHO 1946).

The term health was defined by the World Health Organization (WHO) in 1946 and entered into force on 7 April 1948. The definition has not been amended since 1948 (WHO 1946).

The definition of health has evolved. In 1948, in a radical departure from previous definitions, WHO proposed a definition that aimed higher: linking health to well-being, in terms of “physical, mental, and social well-being, and not merely the absence of disease and infirmity” (WHO 2005). Moreover, in 1986, WHO (1986) adopted a broad definition of health: “Health is a state of well-being and the capability to function in the face of changing circumstances.” Currently, multiple definitions of health exist, from medical, sociological, psychological to physical definitions.
The health statuses of individuals and communities are influenced by many factors known as “health determinants”. A model of wider health determinants was developed by Dahlgren and Whitehead (1991) and adapted by Barton and Grant (2006) to focus on neighbourhoods and planning. It emphasises the role of place and the built environment in contributing to health and well-being.

According to the WHO, the main health determinants include the social and economic environment, the physical environment, and the person’s individual characteristics and behaviours (WHO 2017a, p 1).

Between levels of health determinants, a continuous interaction exists (Fig. 2.1). In this respect, dynamic relationships among major influences on health and well-being were emphasized in a model created by Evans and Stoddart (1990): social environment, physical environment, genetic endowment, individual response (behaviour and biology), health care, disease, health and function, well-being, and prosperity.

According to the model of Barton and Grant (2006), the natural and built environments are critical health determinants, both of which can influence a population’s health.

| Natural environment | Individuals | Community | Built environment |
|---------------------|-------------|-----------|-------------------|
| • Air, water, land, soil, food |
| • Natural habitats |
| • Biodiversity |
| • Global ecosystem, etc. |
| • Age, sex, hereditary factors |
| • Lifestyle, diet, physical activity |
| • Income |
| • Culture |
| • Activities |
| • Work-life balance, etc. |
| • Social capital |
| • Networks |
| • Local and macro-economy, politics |
| • Global forces |
| • Health care service, social service, etc. |
| • Rural, suburban, urban |
| • Landscape, cities, regions, Earth |
| • Streets, routes |
| • Products, materials |
| • Buildings, interior, structures: active spaces, functional zones |
| • Places |
| • Transportation, etc. |

Fig. 2.1 Conception of the health determinants and total built environment
A Dictionary of Epidemiology defined the term “environment” as “all that which is external to the individual human host and it can be divided into physical, biological, social, cultural, etc.” (Last 2011).

The environment, environmental factors (or influences) and their interactions have an essential role in creating disability, as well as the relevance of associated health conditions and their effects. Therefore, the built environment and other external factors have also been added to the International Classification of Functioning, Disability and Health (WHO 2001) as important determinants of health and disability.

Before we define a healthy building, environmental health should be mentioned, because it is the main element that contributes to it.

WHO (1989) defines environmental health as “those aspects of human health and disease that are determined by factors in the environment”.

The concept of the healthy building was introduced by Ho et al. (2004) and defined as a “built environment that encourages positive well-being of human beings”.

Environmental health includes both the direct pathological effects of chemicals, radiation, and some biological agents, and the effects (often indirect) on health and wellbeing of the broad physical, psychological, social and aesthetic environment, which includes housing, urban development, land use, and transport (Novick 1999). Environmental health also refers to the theory and practice of assessing and controlling factors in the environment that can potentially affect health. In this respect, it presents a branch of environmental public health that is concerned with all aspects of the natural and built environment that may affect human health. Towards the efficient control of factors that can potentially affect health, the requirements that we have to fulfil to create healthy environment must be defined. In the comprehensive work on Environmental health by Yassi et al. (2001), five basic requirements for a healthy environment were listed:

1. Clean air
2. Safe and sufficient water
3. Safe and nutritious food
4. Safe and peaceful settlements
5. A stable global ecosystem suitable for human habitation.

As was presented in Chap. 1 in detail, buildings are a crucial component of the total built environment as well as a health determinant. Generally, the term “healthy building” is widespread in many national and international strategies, programmes, and actions and is used as an approach in many epidemiologic or building
engineering studies and projects. Ho et al. (2004) pointed out some characteristics that a healthy building should have:

- A healthy building should not be too densely populated
- Its window design and layout should facilitate natural ventilation and diffusion of daylight
- It should be isolated from noise and air pollution sources
- Its water supply and waste systems should be appropriately installed, maintained, and managed
- Its environmental conditions should be clean and hygienic.

On the Healthy Buildings website, a healthy building is described as “an efficient building that allows the people within the building to operate at their highest functionality. A building is a machine that works on behalf of us humans. The goal of the building is to enable the humans working within the structure to operate at their peak efficiency. If the building enables the people within to work in a productive, happy environment, then it creates a more efficient and profitable asset for the building owner” (Turner 2016).

Numerous researchers have attempted to define the main elements and factors of healthy buildings. For example, the multifactorial elements that contribute to the healthy building by Loftness et al. (2007) were:

- Healthy, sustainable air
- Healthy, sustainable thermal control
- Healthy, sustainable light
- Workplace ergonomics and environmental quality
- Access to the natural environment
- Land use and transportation.

In a comprehensive literature review by Mao et al. (2017), the meaning of “healthy building” was defined, and 30 impact factors in the life cycle of healthy buildings were identified using bibliometric analysis and expert interviews. Additionally, on a case study of Tehran, policies and strategies for the architectural design of healthy buildings were determined: quality of life, productivity, equity and social inclusion, environmental sustainability, and infrastructure (Mohtashami et al. 2016). A special issue on “Sustainable and healthy buildings” was published in the journal Energy and Buildings (Kim 2012), in which a strategic basis for understanding how sustainable, healthy buildings can be designed, constructed, and maintained was provided.

The relationship between the health of an inhabitant and the building’s state was studied in one of the largest Pan-European surveys, called Velux 2017. The survey included feedback from 14,000 respondents in 14 EU countries. For the purpose of the survey, nine indicators for healthy homes were defined, which cover:
- Indoor air quality
- Daylight
- Sleep quality
- Energy costs
- Environmental impact from building materials.

One of the main findings of the survey was “a healthy home is of primary importance for healthy living for Europeans” (Velux 2017, p 13).

In contrast to the terms “health” or “healthy environment”, there is no standardized professional definition of a healthy building. If we summarized the officially accepted definitions of health (WHO 1946; WHO 1989) and healthy environment (WHO 2017a), a healthy building may be better defined as:

A healthy building is a component within a healthy built environment and is the living or working environment where all health risk factors are fully prevented, and optimal conditions for the health and wellbeing of individual users are attained. Optimal conditions include stimulating and healing-oriented conditions, which result in the fulfilment of specific needs for individual users and vulnerable ones.

An unhealthy building is a living or working environment where users are exposed to health risk factors and their parameters, without the attainment of optimal conditions for individuals, especially vulnerable ones.

At this point, the most important question is: “Who is responsible for the design of healthy buildings within healthy built environments and, consequently, the prevention of health risk factors?”

The Velux study determined that 42% of Europeans assign owners the highest level of responsibility (Velux 2017). Experts often have the same opinion as the general public does, despite the fact that the responsibility is shared among all involved subjects throughout the entire life cycle of the buildings, according to the CPR 305/2011. Individuals are unlikely to be able to directly control many of the health determinants in built environments. Improving health is a shared responsibility of healthcare providers, public health experts, and a variety of other actors in the community who can contribute to the well-being of individuals and populations (Institute of Medicine 1997). In this context, designers have to collaborate with experts and building users in order to provide optimal conditions for users that promote health. Therefore, shifting the responsibility to the occupants shall not be allowed at any stage of the design of built environments.
2.2 Comfortable Versus Uncomfortable Conditions

Health is only possible where resources are available to meet human needs and where the living and working environment is protected from life threatening and health threatening pollutants, pathogens and physical hazards (WHO 1992).

Satisfaction of fundamental human needs (Maslow 1943) by reaching the optimal stimulating, healthy, and comfortable conditions for each individual user (WHO 1946) is the main goal of the design of built environments.

2.2.1 Satisfaction of Human Needs in the Built Environment and the Process of Homeostasis

Every human being is daily subject to a large number of needs that arise as a result either of some imbalances inside the body or outside factors. According to Maslow’s (1943) theory, human needs are positioned in the shape of a pyramid. The largest and most fundamental physiological needs (i.e., breathing, food, water, sleep, homeostasis, avoiding pain, sexuality, etc.) are positioned at the bottom level, and the psychological needs (i.e., safety, love, belonging, esteem, self-actualization) are positioned at higher levels. Maslow’s theory suggests that the most basic level of needs must be met before an individual will strongly desire (or focus motivation upon) the secondary or higher level needs (Maslow 1943). The absence of the fulfilment of basic needs is much more difficult to tolerate than any dissatisfaction regarding higher needs.

Environmental parameters of thermal comfort are one of the basic physiological needs (Maslow 1943). The physiological needs can be fulfilled with the mechanism of homeostasis or progressively (Musek and Pečjak 2001). This is a condition for the state of homeostasis of the human body, which enables dynamic equilibrium within the body and its surroundings. For example, the cell membrane maintains homeostasis through the processes of diffusion, osmosis and filtration, which are passive forms of transport. The total daily diffusional turnover of water across all the capillaries in the body is approx. 80,000 litres per day (Brandis 2013).

Homeostasis is maintained by regulatory mechanisms that operate through negative feedback mechanisms (Bresjanac and Rupnik 1999; Cannon 1926). Thermoregulation is part of the homeostatic mechanism that maintains the body’s null energy and mass balance (Bresjanac and Rupnik 1999; Cannon 1926). All homeostatic control mechanisms have three essential components: detector, integrator, and effector. The detector monitors and responds to stimuli in the environment (i.e., thermo-receptors in the skin and in the hypothalamus). It sends information to an integrator that sets the range at which a variable is maintained.
The integrator (i.e., thermo-regulatory centre in the hypothalamus) determines an appropriate response to the stimulus and sends signals to an effector (i.e., vasomotor system, metabolic effectors, sweat glands). After receiving the signal, a change occurs to correct the deviation by enhancing it with feedback mechanisms (Bresjanac and Rupnik 1999). The system works in such a way that deviations between the set point and the measured values are as small as possible. The result is a stable cell environment (Bresjanac and Rupnik 1999). In addition to Maslow, other systems of fundamental human needs and human-scale development exist, such as Manfred Max-Neef’s taxonomy of human needs (Manfred et al. 1989), in which needs are positioned without a hierarchy. Human needs in this taxonomy are understood as a system of interrelations and interactivities. Manfred et al. (1989) believed that what changes with time and across cultures is the way that these needs are satisfied.

### 2.2.2 Overall Comfort

**Comfort** is defined as: “a state of physical ease and freedom from pain or constraint” (Oxford Dictionaries 2017). **Uncomfortable** conditions are defined as those “not feeling comfortable and pleasant, or not making you feel comfortable and pleasant” (Oxford Dictionaries 2017).

The term “comfort” combines all impact factors that are related to the environmental quality of a healthy building: **thermal comfort**, **air quality**, **daylighting**, **sound comfort**, **universal design**, and **ergonomics**. There are constant interactions among parameters of environmental quality factors (Fig. 2.2).

The creation of comfortable conditions for all users is an essential task for building designers as well as system engineers. **But how can comfortable conditions be achieved in a building?** One good example of the total achievement of comfortable conditions is a breastfeeding baby in his mother’s embrace (Fig. 2.3), which represents a perfect microenvironment in which all the baby’s needs are fulfilled: basic physiological needs such as food, water; comfortable thermal environment, optimal level of illumination, the sweet smell and taste of breastmilk, high level of ergonomics, known sounds of the heart beating and breathing, as well as higher needs for love, safety, privacy, and protection. In the same way as the attainment of conditions in the microenvironment for a breastfeeding baby, we have to create conditions inside the active spaces (**medium environment**) of active zones (**macro environment of the whole building**). We have to take into consideration every parameter of overall comfort, with the primary definition of optimal parameters for individual uses.

Several studies have indicated that there are **individual differences in perceptions of comfort**, determined by gender, age, ethnic differences, acclimatization, adaptation, the effect of health status, etc. Moreover, the thermal environment’s
influence on occupants’ perceptions of indoor environmental quality depends on various external (i.e., environmental conditions) and internal factors (i.e., user’s preferences, experiences, consciousness, etc.). Geng et al. (2017) performed a study on the impact of the thermal environment on occupants’ perceptions of indoor environmental quality (IEQ) and productivity in a controlled office under various temperature conditions. The results showed that the variation of the thermal environment not only affected thermal comfort but also had a “comparative” impact on the perception of other IEQ factors. When the thermal environment was unsatisfactory, it weakened the “comfort expectation” of other IEQ factors, which accordingly resulted in less dissatisfaction with other IEQ factors. Conversely, when the thermal environment was quite satisfying, it raised the “comfort expectation” of other IEQ factors, which lowered the evaluation of the real performance of other IEQ factors retroactively. In this respect, interactive influences among factors should be considered.

| Thermal environment | Air quality | Daylight | Noise, acoustics | Universal design, ergonomics |
|---------------------|-------------|----------|------------------|-----------------------------|
| Air temperature, temperature, mean radiant temperature, air velocity, relative humidity of the air, etc. | Concentration of CO₂, other air pollutants, etc. | Illumination, wavelength, contrasts, uniformity ratio, window area, etc. | Noise level, reverberation time, etc. | Principles of ergonomics and universal design: product-task-working area, etc. |

Fig. 2.2 Impact factors and parameters related to the environmental quality of a healthy building
2.2.3 Thermal Comfort

Thermal comfort is described as “a recognizable state of feeling, usually associated with conditions that are pleasant and compatible with health and happiness; and discomfort, with pain which is unpleasant” (Gagge et al. 1967).

According to the definition by the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (2013), thermal comfort is defined as a “condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”. Work on Human Thermal Environments by Parsons (2014) states that “thermal comfort is a state people strive for when they feel discomfort”.

A human being’s thermal sensation is influenced by metabolic rate and clothing, as well as the environmental parameters (air temperature, mean radiant temperature, air velocity and air humidity) (ISO 7730: 2005; Fanger 1970), individual
characteristics (e.g., gender differences, anthropometric characteristics, cultural differences), and health status (Dovjak et al. 2013; Dovjak 2012; Hwang et al. 2007). A significant effect of gender, age, acclimatization and health status on individual perceptions of thermal comfort conditions has also been proven by studies (Schellen et al. 2010, 2012; Hwang et al. 2007; Karjalainen 2007; Skoog et al. 2005; Parsons 2002; Wallace et al. 1994; Martin et al. 1992; Silverman et al. 1958).

In general environments, optimal thermal comfort conditions need to be achieved for the highest possible user satisfaction and productivity (Prek and Butala 2012; Dovjak 2012). Several studies have proved that the optimal thermal environment for the general population and built environments (mainly offices) tends to the slightly cool side of thermal sensation. Lan et al. (2012) proved that such comfortable “cool” environments are beneficial for the performance of office work. Avoiding elevated temperatures in winter and in summer can bring measurable benefits (Lan et al. 2012). Shukuya (2013) and Simone et al. (2011) showed that the minimum exergy consumption rate (i.e., the rate of exergy, which is used only for thermoregulation) was associated with thermal sensation votes (TSV) (“vote” in this context means a point of time when a human subject filled out a thermal sensation scale during exposure) close to thermal neutrality but tending to the slightly cool side of thermal sensation.

Furthermore, in the general environment and population, there are significant variations in thermal acceptance between individuals. A quantitative interview survey with a total of 3,094 respondents in Finland showed significant gender differences in thermal comfort and temperature preference. Females are less satisfied with room temperatures than males are, prefer higher room temperatures than males do, and feel both uncomfortably cold and uncomfortably hot more often than males do. Although females are more critical of their thermal environments, males use thermostats in households more often than females do (Karjalainen 2007; Schellen et al. 2012). However, several studies also indicate that the thermal neutral temperature and optimum thermal condition differ between young adults and the elderly. Schellen et al. (2010) concluded that the elderly preferred a higher temperature in comparison to young adults.

In reality, designers are often confronted with the highly demanding task of designing conditions for specific environments, such as hospitals, which are a complex environment that can be treated as a three-dimensional system of specific users (patients, staff, visitors), as well as specific activity and active spaces. In active spaces, the required conditions for patients need to support medical treatment and result in quicker recovery and positive health outcomes. Immediately after the definition of specific user needs for comfort conditions, the building systems that enable creating those conditions have to be defined.

User diversity is the main guidance when designing buildings, and systems. In most cases, conventional HVAC systems are designed as interventions in active spaces, based on the requirements of an average user and are not suitable for the selected individual user. Dovjak (2012) concluded, “to fulfil specific individual requirements, new systems are needed”. Individual climates have already been
introduced in cars. Local ventilation is used in working environments with a positive impact on productivity (Melikov et al. 2002). Overall individualization of personal space that would enable individual generation and control of all factors of environmental ergonomics has been implemented in a test environment by the research group of Dovjak and colleagues (Dovjak et al. 2013, 2014; Dovjak 2012).

The innovative system creates optimal conditions for health care and treatment of burn patients with lower human body exergy consumption rates, valid for thermoregulation, minimal evaporation, radiation, and convection. For health care workers and visitors, the low exergy (LowEx) system (i.e., heating-cooling ceiling radiative panels) creates individual thermal comfort zones by allowing the setting of air temperature and mean radiant temperature. For the LowEx system, the measured energy use for heating was 11–27% lower and for cooling 32–73% lower than for conventional systems (Dovjak et al. 2013, 2014; Dovjak 2012).

Improving comfort has to be one of the main drives for renovations and not just saving energy. Interestingly, users are aware of these issues. Velux (2017), a series of Pan-European surveys, determined that renovation, mainly due to increased comfort conditions and health, is one of the leading motives of occupants. Moreover, not only for renovation, but Europeans also value comfort the most when choosing a new home.

2.3 Wellbeing and Sustainable Buildings

As part of the definition renewal efforts in 1948, the term health was associated with the high level of well-being (wellbeing, or wellness) (WHO 1986).

High level of well-being is described as a dynamic process in which the individual is actively engaged in moving toward fulfilment of his or her potential (Medical Dictionary 2017).

Wellness refers to diverse and interconnected dimensions of physical, mental, and social well-being that extend beyond the traditional definition of health. It includes choices and activities aimed at achieving physical vitality, mental alacrity, social satisfaction, a sense of accomplishment, and personal fulfilment (Naci and Ioannidis 2015). It means in some sense the individual or group’s condition is positive.

There exist several models of wellbeing. Diener’s tripartite model of subjective well-being is one of the most comprehensive models of well-being in psychology (Tov and Diener 2013). Carol Ryff’s multidimensional model of psychological well-being (Ryff and Keyes 1995) postulated six factors that are key to well-being:
• Autonomy
• Environmental Mastery
• Personal Growth
• Positive Relations with Others
• Purpose in Life
• Self-Acceptance.

In Carol Ryff’s model, wellbeing is quantitatively evaluated by a series of statements reflecting the six areas of psychological well-being. Respondents rate statements on a scale of 1–6, with 1 indicating strong disagreement and 6 indicating strong agreement. For each category, a high score indicates that the respondent has a mastery of that area in his or her life. High scores indicate that the respondent makes effective use of opportunities and has a sense of mastery in managing environmental factors and activities, including managing everyday affairs and creating situations to benefit personal needs (Ryff and Keyes 1995).

The five-item WHO Well-Being Index (WHO-5) is among the most widely used questionnaires assessing subjective psychological well-being. Since its first publication in 1998, the WHO-5 has been translated into more than 30 languages and has been used in research studies all over the world (Topp et al. 2015). The WHO-5 is a short questionnaire consisting of five simple and non-invasive questions, which tap into the subjective well-being of the respondents. The WHO-5 items are (Topp et al. 2015):

(Q1) “I have felt cheerful and in good spirits”,
(Q2) “I have felt calm and relaxed”,
(Q3) “I have felt active and vigorous”,
(Q4) “I woke up feeling fresh and rested” and
(Q5) “My daily life has been filled with things that interest me”

We can note that the quality of built environments affects the subjective well-being and the quality of our lives. As people age, their quality of life is largely determined by their ability to maintain autonomy and independence (Public Health England 2016; WHO 2002). “Do the conditions in current buildings allow us to attain wellbeing of an individual or a group?” Supporters of popularized sustainable design, eco-friendly, green and low carbon architecture claim that their building practices expand and complement the classical building design concerns of economy, utility, durability, and comfort (EPA 2009).
Quality of life is “an individual’s perception of his or her position in life in the context of the culture and value system where they live, and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept, incorporating in a complex way a person’s physical health, psychological state, level of independence, social relationships, personal beliefs and relationship to salient features in the environment” (WHO 2017b, p. 1).

2.3.1 Sustainable, Eco-friendly, Green and Low Carbon Buildings

The term harmonized, nature-oriented (ecological) development was defined by the Council of Europe in 1966. It stands for a development in one direction, within a specific area. For example, economic development indicates a process of development of a country or region in the direction of increasing wealth in order to achieve the well-being of the population. The verb to sustain means “to maintain; keep in existence; keep going; prolong” (Bossel 1999). The term sustainable development was defined by the Brundtland Report in 1987 and by the UN Conference on Environment and Development in Rio de Janeiro in 1992 (WCED 1987; Rio Declaration 1992).

Sustainable development means the development where all four aspects are equally balanced: health, environmental, social and economic (Rio Declaration 1992).

The World Commission on Environment and Development (WCED) (1987) states that sustainable development is “a development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Therefore, it provides all the inhabitants of the planet appropriate quality of life. Sustainable development of human society has environmental, material, ecological, social, economic, legal, cultural, political and psychological dimensions that require attention (Bossel 1999). Their mutual interactions are emphasized in the framework of Environmental Impact Assessment (EIA) defined by Directive 2011/92/EU (Directive 2011/92/EU, Directive 2001/42/EC). Sustainability is a dynamic concept and involves a time dimension (Bossel 1999).

Nowadays, the term is often popularized and exploited, especially in the building sector. Generally, incorrect definitions are in use, where only one aspect of development is well considered, while others are ignored. Examples of buildings and their negative consequences on health were presented in Chap. 1.
Moreover, controversies exist among environmentalists who argue that sustainable development was formulated by economists, as an environmentally friendly capitalism, in order to pacify people and to promote environmental values. Consequently, it is necessary to understand that for humans the environment is irrelevant if one is not part of it as an active element that lives and works in it. An equitable, environmentally and physically sustainable society that exploits the environment at the highest sustainable rate would still be psychologically and culturally unsustainable. **Unsustainability** is one alternative to **sustainability** (Bossel 1999). **Unsustainable activities** are all human activities that have a negative impact on the environment and health. If it is assessed, for any human activity, that it is unsustainable, it should be abstained from and not performed (EC 1992).

Currently, several **building certification schemes** to measure the sustainability of the buildings (Ding 2008) exist: Leadership in Energy and Environmental Design (LEED), Research Establishment Environment Assessment Methodology (BREEAM), Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), Haute Qualité Environnementale (HQE), etc. These tools audit selected criteria, which score the investigated parameter and sum up and weight the partial scores to arrive at the final score that evaluates the sustainability of a building (Potrč et al. 2017). The parameters can be quantitative, and the score is obtained based on the quantitative result for a parameter. Qualitative parameters are most often assessed based on criteria that determine whether a certain standard is achieved or not (Forsberg and von Malmborg 2004).

The existing sustainable **building certification schemes** already include selected aspects related to **comfort, well-being, and productivity** of occupants. For example, air quality, water quality, visual and overall comfort (mostly related to thermal and acoustic comfort), are topics well covered in LEED, DGNB, BREEM. **Mind** (assessing parameters influencing the mental state of the occupants), **fitness** (assessing parameters connected to the increase of physical activity of the occupants), and **nourishment** (accessing parameters related to the fresh, wholesome food) are not covered in the existing certification schemes (Potrč et al. 2017). Currently, a **specialized certification scheme** called WELL, launched by The International Well Building Institute in 2014, focuses on the assessment of health-and well-being-related questions in the built environment (WELL 2016). A similar certification program is the **Living Building Challenge**, created by the International Living Future Institute in 2006 (Living Building Challenge 2017). Other tools that evaluate the sustainability of a building are **Health, Wellbeing and Productivity in Offices** published by the World Green Building Council (WGBC 2014) and **FitWell launched** by the Center for Active Design (Fitwel 2016).

Based on established knowledge, Potrč et al. (2017) performed a comparative analysis of the existing building certification schemes on health aspects. Potrč and colleagues (2017) concluded that the WELL building certification scheme can be used as a complementary scheme that supports the existing building certification schemes. Some of the topics are duplicated, but generally, the WELL certification scheme focuses only on the aspects connected to health and wellbeing while other certification schemes put greater emphasis on other aspects.
Additionally, Markelj et al. (2014) highlighted that current tools and methods are either focused only on individual topics or are too complex and not adapted to independent use by architects. They proposed a simplified method for evaluating building sustainability that can be used in the early design phase. The use of building certification schemes is not required. Many of the investors decide to perform a certification to show their awareness and to gain a better insight into the performance of their buildings (Potrč et al. 2017).

The term “green architecture” only came into use in the 1990s (The Economist 2004), but the movement’s roots can be traced back a long way. Crystal Palace in Hyde Park, London, designed by Joseph Paxton (Crystal Palace 2008), and Milan’s Galleria Vittorio Emanuele II designed by Giuseppe Mengoni (Milan 2012), for example, built in 1851 and 1877 respectively, used roof ventilators and underground air-cooling chambers to regulate the indoor temperature. Green building (also known as green construction or sustainable building) has a similar approach as eco-friendly building and refers to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building’s life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition (EPA 2009). LEED (Leadership in Energy and Environmental Design) developed by the U.S. Green Building Council is a building certification scheme for the design, construction, operation, and maintenance of green buildings (EPA 2009).

Eco-friendly building or ecological construction is building a structure that is beneficial or non-harmful to the environment, and resource efficient. This type of construction is efficient in its use of local and renewable materials, and in the energy required to build it, and the energy generated while being within it (SustainableBuild 2017).

Due to legal requirements towards low carbon economy, low-carbon design emerged. Low-carbon buildings are buildings designed and constructed to release very little or no carbon at all during their lifetime. They are designed according to the standard Low-Carbon Buildings Method TM 2011, Buildings Construction, A Simplified Methodology for Estimating GHG Emissions from Buildings Construction. They are specifically engineered with greenhouse gases reduction in mind.

A low-carbon building is a building that emits significantly fewer greenhouse gases than regular buildings.

The existing movement towards eco-building, sustainable building, low-carbon building, and green building has been used in many studies,
especially in engineering. However, these studies cannot represent the health status of buildings comprehensively and appropriately (Mao et al. 2017).

**What is required to make all those energy efficient buildings healthy?** In the field of building design, many legal acts and standards that separately cover issues related to energy, environment or comfort exist. When all those requirements and recommendations are combined in the design process, they might be even contradictory. Moreover, current certification schemes are often not mandatory and performed after the decision has been made by investors. For the design of healthy and sustainable buildings, an integral certification system that combines existing “energy and environmental” schemes with “health and wellbeing schemes” are needed.

The passive house standard (IPHA 2018) defines criteria for the certification of passive building: space heating and cooling requirements, primary energy requirements, airtightness, and thermal comfort. Although the current standard stands for quality, comfort and energy efficiency in general buildings, the qualitative and quantitative criteria for indoor environmental quality, namely indoor air quality, daylighting, and noise issues are defined insufficiently, especially in relation to a building, system, and user characteristics. The defined criteria are presented as minimal values, which often results in insufficient indoor environmental conditions. Therefore, the design of overall comfort conditions in current practice often depends on the designer’s and/or investor’s awareness. Moreover, especially energy use and indoor quality issues are also related to user behaviour (Schweiker et al. 2018), and they might be changed as soon as the building is used. Designed values might not result in proper indoor air quality, so it is important to raise the awareness of building occupants how to change or regulate building and its systems.

The WELL Building Standard (WELL 2016) focuses solely on the health and wellness of building occupants. It identifies 100 performance metrics, design strategies, and policies that can be implemented by the owners, designers, engineers, contractors, users, and operators of a building. WELL certification can be applied to new and existing buildings (i.e., commercial, institutional), building interiors as well as core and shell. The WELL Building Standard is organized into seven categories of wellness called concepts: air, water, nourishment, light, fitness, comfort and mind. Every feature is ascribed to human body systems (e.g., cardiovascular, digestive, endocrine systems) and is intended to address specific aspects of occupant health, comfort, or knowledge. Projects become certified on the basis of the dynamic rating system, according to the number of features that are sufficiently satisfied. The final WELL Score is calculated based on the total preconditions and optimizations achieved across the board—not as a function of averaging independent concept scores. To maintain WELL certification, projects must be recertified a minimum of every three years, because building conditions can deteriorate over time to the point of adversely affecting the health and wellness of occupants. The WELL protocol requires highly qualified assessor (WELL 2016).

The design of a healthy buildings is a highly demanding process that requires participatory design, in which all stakeholders including end users are actively
involved. Regarding the fact that health issues are unsystematically and insufficiently covered in the existing sustainability building standards, they might be complemented with the concepts presented in the WELL Building Standard. Although the main advantage of the existing WELL Building Standard is its comprehensiveness, it can be upgraded by more systematic classification of the health and wellbeing concepts.

2.4 Health Effects in the Built Environment

Because of the busy pace of modern life—performing daily activities related to work, commuting, taking care of kids, cooking and cleaning, watching television, connecting on social media, and more—people are spending most of the day indoors.

The National Human Activity Pattern Survey (NHAPS) performed a two-year probability-based telephone survey (N = 9,386) of exposure-related human activities in the United States sponsored by the U.S. Environmental Protection Agency (EPA) (Klepeis et al. 2001). The results of the survey (total sample N = 9,196) showed that respondents spent 68.7% of the time in a residence, 5.4% in an office or factory, 1.8% in a bar or restaurant, 11% in some other indoor location. The total time spent indoors was 86.9%; 5.5% of the time was spent in a vehicle and 7.6% outdoors. These results are comparable with U.S. time-budgets reported by Robinson and Thomas (1991) from a 1985 study and Canadian time budgets reported by Leech et al. (1996). For both these studies, which span a period of about a decade, respondents reported spending 89% of their time indoors with 5% in a vehicle and 6% outdoors. Smith (1993) showed that the differences between developed and less-developed countries, and urban and rural environments. The percentage of time spent indoors in less developed countries was 79% for urban environments and 65% for rural environments. The percentage of time spent outdoors in less developed countries was 21% for urban environments and 35% for rural environments (Smith 1993).

According to the report of the European Commission, Directorate General for Health and Consumers (Jantunen et al. 2011) and the EC (2007), people spend 60–90% of their lives in indoor environments. Ribble Cycles surveyed (2017) more than a thousand adults in Britain, finding that the average person spent 92% of their time indoors on a weekly basis. However, vulnerable groups of people, such as the elderly, immobile persons, patients etc., spend even more time indoors. Most children spend approximately one fourth of the day in day-care centres, schools, and other educational institutions. The National Kids Survey determined that after school they prefer to choose technology-centred activities than nature-based activities (Larson et al. 2011). Data from the National Kids Survey by Larson et al. (2011) (N = 1,450 U.S. households with children ages 6–19, from 2007 to 2009)
showed that, in general, most children (>62.5%) spent at least two hours of time outdoors daily. Similar conclusions were made in a National Trust survey (N = 1,001 parents with children aged between four and 14), in which researchers found, on average, children were playing outside for just over four hours a week, compared to 8.2 h a week when the adults questioned were children (The Guardian 2016).

During the time spend inside built environments we are exposed to numerous environmental hazards.

An environmental hazard is a substance, state or event that has the potential to threaten the surrounding natural environment and/or adversely affect people’s health.

A number of systems used to characterize environmental hazards exists (Stevens and Hall 1993). According to the book “Basic Environmental Health” by Yassi et al. (2001), environmental hazards are most commonly classified as either:

- biological,
- chemical,
- physical,
- biomechanical, and
- psychosocial.

Exposure to these hazards can affect human health. The extent of the effects is dependent on their exposure dose, type of pollutants, exposure time, and individual characteristics (Eržen et al. 2010; Yassi et al. 2001). Poor indoor environmental quality conditions (i.e., thermal discomfort, inadequate air quality, noise, lack of daylight, electromagnetic radiation, etc.), longer exposure times, the presence of vulnerable population groups, and increased user susceptibility may increase the risk of adverse health effects. Health effects (or health impacts) are changes in health resulting from exposure to a source.

Health effects resulting from exposure to a source in a built environment should be an important topic not only for environmental public health but also for the engineering sciences. The prevention of health effects in the built environment is the main activity in every step of design. In a review by Lavin et al. (2006), many health impacts in built environments were defined according to the type of health hazard (i.e., radon, environmental tobacco smoke, cooking pollutants, volatile organic compounds, asbestos). The most common health outcome in research studies and public media is Sick Building Syndrome (SBS). Sick Building Syndrome is often confused with Building-Related Illness (BRI). Therefore, for further understanding, it is important to distinguish between them.
2.4.1 Sick Building Syndrome Versus Building-Related Illness

The US Environmental Protection Agency (EPA 1991) describes Sick Building Syndrome (SBS) as situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified. The complaints may be localized in a particular room or zone or may be widespread throughout the building. The characteristic symptoms of SBS that may occur singly or in combination with each other are headache, eye, nose, or throat irritation, dry cough, dry or itchy skin, dizziness and nausea, difficulty in concentrating, fatigue and sensitivity to odours (Redlich et al. 1997; ECA 1989; Burge et al. 1987). In contrast, the term Building-Related Illness (BRI) is used when symptoms of a diagnosable illness are identified and can be attributed directly to airborne building contaminants (EPA 1991). SBS does not include diseases caused by exposure to a specific cause in the environment (e.g., mould, spores or allergens) (Redlich et al. 1997). The main differences between SBS and BRI are presented in Table 2.1.

The syndrome first appeared in the 1970s with the development of energy-efficient buildings equipped with mechanical systems for heating, ventilation, and air-conditioning (HVAC). Some of the possible causes are the use of synthetic building materials, overcrowded workplaces, and stress in the workplace. Currently, none of the environmental factors has been identified as the sole cause of SBS, and the latter is likely to be a common consequence of biological, chemical and organic agents, as well as personal and individual factors (Redlich et al. 1997).

Table 2.1 Differences between Sick Building Syndromesick building syndrom (SBS) and Building-Related Illness (BRI) (Burge 2004; Redlich et al. 1997; EPA 1991)

| Indicators     | Description                                                                 | SBS                                                                 | BRI                                                                 |
|---------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------|
| Symptomatology| Building occupants complain of symptoms associated with acute discomfort, e.g., headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odours |                                                                      | Building occupants complain of symptoms, such as cough; chest tightness; fever, chills; and muscle aches |
| Diagnosis     | Non-diagnosable illness                                                      |                                                                      | Diagnosable illness                                                  |
| Aetiology (cause) | The cause of the symptoms is not known                                       |                                                                      | The symptoms can be clinically defined and have clearly identifiable causes |
| Duration      | Most complainants report relief soon after leaving the building             |                                                                      | Complainants may require prolonged recovery times after leaving the building |
Approximately 30% of new and renovated buildings worldwide may be affected by SBS (WHO 1983).

SBS symptoms may occur in residential and public buildings (Sahlberg et al. 2013; Takigawa et al. 2012; Araki et al. 2010; Engvall et al. 2001; Scheel et al. 2001). In studies on residential buildings in Japan (N = 871, Takigawa et al. 2012; N = 620, Araki et al. 2010), and residential buildings in three northern European cities (N = 159, Sahlberg et al. 2013), from 12% to 30.8% of occupants were identified as having SBS symptoms. Moreover, in the studies on public buildings in Canada (N = 1,390, Bourbeau et al. 1997), UK (N = 4,373, Burge et al. 1987), USA (N = 600, Woods et al. 1987) from 20% to 50% of workers experienced SBS symptoms.

A comprehensive study (Burge et al. 1987) performed in the UK on 4,373 office workers in 42 public buildings revealed that 29% of those studied experienced five or more of the characteristic SBS symptoms. An investigation carried out by Woods et al. (1987) on 600 office workers in the US concluded that 20% of the employees experienced SBS symptoms and most of them were convinced that this reduced their working efficiency. Additionally, a study on 1,390 workers in 5 public buildings in Quebec, Canada (Bourbeau et al. 1997) showed that 50% of workers experienced SBS symptoms. Moreover, much higher prevalence of SBS was demonstrated in hospital environment than in other public buildings. A review study by Kalender Smajlović et al. (2019) found that the prevalence of SBS was from 41% to 87%.

SBS is characterized by “non-specific symptoms, occurring while living/working in the building and not causing a specific disease or infection. Due to individual differences and non-specific symptoms, some experts do not define SBS as an independent syndrome. Currently there exist more than 50 possible symptoms of SBS that appear in different combinations and strengths” (Burge 2004, p. 185, Redlich et al. 1997, p. 1013).

In general, we divide symptoms into five groups (ECA 1989):

- **Nasal manifestations**: nasal irritation, rhinorrhoea, nasal obstruction
- **Ocular manifestations**: dryness and irritation of the mucous membrane of the eye
- **Oropharyngeal manifestations**: dryness and irritation of the throat
- **Cutaneous manifestations**: dryness and irritation of the skin, occasionally associated with a rash on exposed skin surfaces
- **General manifestations**: headaches and generalized lethargy and tiredness leading to poor concentration.
Unlike SBS, BRI is usually grouped into four groups (ECA 1989):

- Allergy, asthma, rhinitis
- Hypersensitivity pneumonitis (extrinsic allergic alveolitis)
- Humidiﬁer fever
- Infections (bacterial, fungal, viral).

2.5 Health Outcomes Related to Unhealthy Built Environments

Health outcomes are “a change in the health status of an individual, group or population which is attributable to a planned intervention or series of interventions, regardless of whether such an intervention was intended to change health status” (WHO 1998, p. 10).

Findings from the relevant epidemiological studies and reports are mainly focused on European populations and are presented later in this book. A Pan-European study, Velux (2015) (N = 12,000, October 2014), demonstrated a clear correlation between unhealthy buildings and people who have rated the parameter of self-perceived health as “poor”. Today, one out of six Europeans—or the equivalent of Germany’s population—reports living in unhealthy buildings. More than one-and-a-half times as many people who live in unhealthy buildings have poor health compared to those who live in healthy buildings.

The most common indicators of inadequate indoor environments are (Velux 2015):

- building dampness,
- poor indoor air quality,
- uncomfortable thermal environment,
- excessive noise, and
- lack of daylight.

In addition, safety, space, accessibility, location, and immediate surroundings are significant influences of the internal environment (Lavin et al. 2006). They cause or affect health outcomes and result in diseases and injuries, such as respiratory, nervous system and cardiovascular diseases, and cancer (WHO 1992).

Global Health Observatory (GHO) data (WHO 2017c) revealed that in 2012, 12.6 million people died as a result of living or working in an unhealthy environment, representing 23% of all deaths. When accounting for both death and disability, the fraction of the global burden of disease due to the environment is 22%. In children under ﬁve years, up to 26% of all deaths could be prevented, if environmental risks were removed. For effective interventions, all indicators of
inadequate indoor environments must be eliminated. In the following subchapters, (Sects. 2.5.1 to 2.5.5), the most important ones will be more precisely defined.

### 2.5.1 Building Dampness

One of the most common indicators of an inadequate indoor environment is **building dampness**.

The term **building dampness** includes: “the increased indoor air humidity and/or damp construction complexes that often results in mould growth” (WHO 2009a; p. 2, Kukec et al. 2015, p. 36).

Building dampness most frequently results from inadequate ventilation, improper design of the building envelope and systems, inadequate damp-proof membrane, damaged plumbing systems, floods, occupants’ habits, and the position of furniture. In addition to inequalities in building and system design, activities and occupant behaviour are significant causes of dampness. Velux (2015) showed that 65% of all Europeans dry clothes indoors at least once a week, and only 28% ventilate rooms more than once a day during winter, which is needed to obtain optimal indoor air quality.

**Building dampness in the indoor built environment** may constitute a sub-standard living and working condition. It indicates the presence of water damage, a leaking roof, rot in window frames and floors, visible mould or condensation. Building dampness is associated with a broad array of detrimental health effects in adults and children (Fisk et al. 2010). The most common of these are related to the deterioration of the respiratory system (Mudarri and Fisk 2007), including a higher prevalence of respiratory symptoms, increased risk of asthma, wheezing, cough (Pirastu et al. 2009), bronchitis, common cold and rhinitis (Pirhonen et al. 1996).

Epidemiologic studies and cost-effect analysis in the US and the EU have revealed that building dampness has a substantial **public health and economic impact** (Fisk et al. 2010). Researchers from the U.S. Department of Energy’s Lawrence Berkeley National Laboratory (Berkeley Lab), concluded that building dampness and mould raised the risk of a variety of respiratory and asthma-related health outcomes in the U.S. by 30–50%. The public health and economic impact of dampness and mould was assessed by Mudarri and Fisk (2007), who determined that of the 21.8 million people reported to have asthma in the U.S., approximately 4.6 million cases are estimated to be attributable to dampness and mould exposure at home. They estimated that in the US national annual cost of asthma that is attributable to dampness and mould exposure at home was $3.5 billion (Mudarri and Fisk 2007).
A pan-European study, Velux (2015) (N = 12,000, October 2014), revealed that **80 million Europeans live in damp and unhealthy buildings**, which nearly doubles the risk of developing asthma. The cost to European societies of asthma and chronic obstructive pulmonary disease is €82 billion per year (Velux 2017). In fact, people are 40% more likely to have asthma when living in a damp or mouldy home, and today, 2.2 million Europeans have asthma as a result of their living conditions. Half of that amount goes to direct costs such as medicine and care. The other half is calculated as indirect costs due to loss of work productivity (Velux 2017).

### 2.5.2 Uncomfortable Thermal Environment

**Uncomfortable thermal environment** in a building is directly related to the building and systems efficiency on the specific location. Additionally, family income plays a key role in ensuring a comfortable thermal environment. This means that household’s ability to keep the home adequately warm or cold is dependent on the indicator of fuel poverty (a person is to be regarded as living “in fuel poverty” if he is a member of a household living on a lower income in a home which cannot be kept warm at reasonable cost) (WHECA 2000). In Europe, between 50 and 125 million people are estimated to suffer from fuel poverty and the Epee Project reveals that this number will inevitably rise in the future as global energy prices increase (BPIE 2014).

It is important to recognize that a **household’s inability** to keep the home adequately warm or cold has serious health consequences. In a European cross-country analysis (Healy 2003), a statistically significant association between poor housing thermal efficiency and high levels of winter mortality was found. According to the recent Marmot Review Team report (2011) on the health impacts of cold housing and fuel poverty, excess winter deaths (EWDs) in England, are associated with thermal efficiency of housing and low indoor temperatures. About 40% and 33% of excess winter deaths are attributable to cardiovascular and respiratory diseases respectively, the risk of excess winter death being almost three times higher in the quartile of houses with the coldest indoor temperatures than in the warmest quartile. European studies on the burden of disease of inadequate housing quantified as 30% the proportion of excess winter deaths attributable to cold housing (Braubach et al. 2011). Results of the pan-European study, Velux (2017) showed that forty-five percent of people keep their temperatures down in order to lower their energy bills. Twice as many Europeans report poor health when they are unable to keep their dwelling at a comfortable temperature in the winter; 20% of Europeans report poor health when they are living in cold home, and 9% of Europeans report poor health when they are living in a comfortably warm home.

Climate change is expected to cause increases in heat-related mortality, especially from respiratory and cardiovascular diseases (Basagaña et al. 2011). Children and the elderly are the most vulnerable groups. The effects of heat on morbidity
across all age groups and across a wider range of temperatures in Rhode Island were clarified by Kingsley et al. (2016). Their findings suggest that the current population of Rhode Island would experience substantially higher morbidity and mortality if maximum daily temperatures increase further as projected.

2.5.3 Poor Indoor Air Quality

Indoor air is often more seriously polluted than outdoor air even in the largest and most industrialized cities (EPA 2017). Indoor air may contain over 900 chemicals, particles and biological materials with potential health effects (EC 2007).

Problems of indoor air quality are recognized as important risk factors for human health in low-, middle- and high-income countries. WHO (2016) reported:

- Globally, 4.3 million people a year die from exposure to household air pollution.
- Over 4 million people die prematurely from illness attributable to the household air pollution from cooking with solid fuels.
- More than 50% of premature deaths due to pneumonia among children under 5 are caused by particulate matter (soot) inhaled from household air pollution.
- 3.8 million premature deaths annually from noncommunicable diseases including stroke, ischaemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer are attributed to exposure to household air pollution.

Hazardous substances emitted from buildings, construction materials and indoor equipment or due to human activities indoors, such as combustion of fuels for cooking or heating, lead to a broad range of health problems and may even be fatal. World Health Organization (WHO 2010) identified five important hazardous substances which have been linked to respiratory diseases including asthma, lung cancer and mesothelioma by the:

- radon
- environmental tobacco smoke (ETS)
- cooking pollutants
- volatile organic compounds and
- asbestos.

A pan-European study, Velux (2015) revealed that unhealthy indoor air quality is a concern for Europeans; 24% of Europeans are very concerned, and 59% have above average concern. They rank this concern at the same level as financial and job insecurity. A total of 35% of Europeans rank both indoor air quality of the highest importance if moving to a new house. If they were to choose a new home, 42% would give the highest importance to the indoor air; 89% would give it above average importance, resulting in an indicator score of 6. A total of 28% have made changes within the last five years to improve indoor air quality. Moreover, 55% of
Europeans aged 60 to 65 assign indoor air quality the highest importance, compared to 31% of the 18–29-year olds.

### 2.5.4 Excessive Noise

Noise pollution is considered not only an environmental nuisance but also a threat to public health (WHO 2011). In indoor environments, we are exposed to numerous noise sources emitted from outdoor to indoor environments. Sound protection of buildings provides protection against the following sources of noise:

- **external noise** (e.g., traffic noise, noise from industrial facilities),
- **airborne noise** (i.e., transmitted by air and atmosphere),
- **structure-borne noise** from other spaces (i.e., transmitted when sound arises from the impact of an object on a building element such as a wall, floor, or ceiling),
- **noise of operating equipment** (e.g., HVAC), and
- **reverberation noise** (i.e., collection of reflected sounds from the surfaces in an enclosure).

The results of the classification of buildings by sound protection in the EU show that the large majority of the buildings are classified into Class D (poor sound insulation of the building envelope, internal constructional complexes) (Rasmussen 2010). Inadequate sound protection of buildings consequently results in increased occupant exposure. Epidemiological studies indicate that those chronically exposed to high levels of environmental noise have an increased risk of cardiovascular diseases, such as myocardial infarction. The evidence from epidemiological studies on the association between exposure to road traffic and aircraft noise and hypertension and ischaemic heart disease has increased in recent years. Night-time noise is thought to be particularly problematic as it can affect sleep with subsequent impacts on health (WHO 2009b).

One of the negative effects of exposure to noise is **tinnitus** (i.e., the sensation of sound in the absence of an external sound source). In some people, tinnitus can cause sleep disturbance, cognitive effects, anxiety, psychological distress, depression, communication problems, frustration, irritability, tension, inability to work, reduced efficiency and restricted participation in social life. Globally, tinnitus caused by excessive noise exposure has long been described; 50–90% of patients with chronic noise trauma report tinnitus (WHO 2011).

To estimate the environmental burden of disease (EBD) due to environmental noise, a quantitative risk assessment was performed by WHO (2011). The EBD is expressed as disability-adjusted life years (DALYs). DALYs are the sum of the potential years of life lost due to premature death and the equivalent years of “healthy” life lost by virtue of being in states of poor health or disability. The burden of disease due to environmental noise has been recently estimated for
western European countries with a range of 1.0–1.6 million DALYs lost across all health outcomes (WHO 2011). The estimates are 61,000 DALYs for ischaemic heart disease, 45,000 for cognitive impairment of children, 903,000 for sleep disturbance, 22,000 for tinnitus, and 587,000 for annoyance.

Exposure to noise in living and working environments might cause both auditory and non-auditory adverse health effects (Basner et al. 2014).

Adverse effects of noise on the human body depend on sound intensity, frequency, impulsiveness, duration of exposure (acute, chronic) and the individual’s sensitivity. Impairment might be temporary or permanent and is a result of cumulative effects of noise exposure over the course of a lifetime.

Noise-induced hearing loss can be caused by a one-time exposure to an intense impulse sound, or by steady long-term exposure with sound pressure levels higher than 75–85 dB, in occupational and industrial settings. Hearing loss is increasingly caused by social noise exposure (Basner et al. 2014).

A review study by Basner et al. (2014) found that the non-auditory effects of environmental noise exposure on public health are growing. The most investigated non-auditory health endpoints for noise exposure are perceived disturbance and annoyance, cognitive impairment (mainly in children), sleep disturbance, and cardiovascular health (Basner et al. 2014). They can be caused by an exposure with lower sound pressure levels compared to levels that caused auditory adverse health effects. For example, maximum sound pressure levels as low as 33 dB can induce physiological reactions during sleep including autonomic, motor, and cortical arousals (e.g., tachycardia, body movements, and awakenings) (WHO 2009b).

Additionally, infrasound might have adverse health effects. Jeffery (2013) highlighted that people who live or work in proximity to industrial wind turbines have experienced symptoms that include decreased quality of life, annoyance, stress, sleep disturbance, headache, anxiety, depression, and cognitive dysfunction. Causes of symptoms include a combination of wind turbine noise, infrasound, electricity, ground current, and shadow flicker. Environmental noise exposure must be regulated by holistic actions, including sound prevention measures in buildings.

Beside building dampness and noise, lack of daylight also contributes to the inadequate environmental quality of the built environment.

2.5.5 Lack of Daylight

Positive influences of daylighting on well-being have been researched since the 1950s.
Daylighting in a built environment has two important effects on the human body: visual and non-visual (Robbins 1986; Berson et al. 2002).

First studies were concerned with visual effects (i.e., reduced eyestrain) (Robbins 1986) and the psychological benefits of daylight (i.e., improved mood) (Heerwagen 1986). The physiological mechanisms of non-visual effects were fully explained with the discovery of the third photoreceptor cells by David Berson (Berson et al. 2002). Since 2002, studies have been focused mainly on non-visual effects of daylight, which include direct or non-circadian effects, indirect or circadian effects, effects on skin (vitamin D synthesis, skin tanning, and dissociation of bilirubin) and other unexplored effects. Current studies demonstrate the positive impact of daylight in office environments, educational institutions, retail environments, health-care facilities, and in prisons. In addition to health benefits, daylight in built environments also has social, economic and environmental benefits. The social benefits have been associated with improved mood and enhanced morale (Robbins 1986), increased social interactions among employees, and reduced absenteeism rates (Clark and Watson 1988). The economic benefits of daylighting were analysed especially in office environments and were increased productivity. The environmental benefits of daylighting include lower CO₂ emissions and annual energy savings for lighting due to changes in a typical six-storey office building (Jenkins and Newborough 2007).

A lack of daylight in built environments has adverse health effects on human health and their determinants. One of them presents Seasonal Affective Disorder (SAD).

SAD characterized by “fall/winter major depression with spring/summer remission, is a prevalent mental health problem. SAD etiology is not certain, but available models focus on neurotransmitters, hormones, circadian rhythm dysregulation, genetic polymorphisms, and psychological factors” (Roehlklein and Rohan 2005, p. 20).

SAD has a seasonal pattern, usually beginning in fall and continuing into the winter months. Those who live in northern latitudes are most at risk. An estimated 10–20% of recurrent depression cases follow a seasonal pattern (Magnusson 2000). Although a summer pattern of recurrence is possible, the predominant pattern involves fall/winter depression with spring/summer remission. In U.S. community surveys, SAD prevalence ranges from 9.7% in New Hampshire to 1.4% in Florida (Rosen et al. 1990). In North America, SAD prevalence increases with latitude, but the correlation is nonsignificant in other parts of the world (Mersch et al. 1999). In the United Kingdom, 20% experience “winter blues” and 2% experience SAD (UK SAD). Light therapy is established as the best available treatment for SAD.
A study by Espiritu et al. (1994) on 104 subjects aged 40–64 years in San Diego, CA. The median subject was exposed to illumination greater than or equal to 1000 lux for only 4% of the time observed, that is, only about 58 min per day were spent in daylight. Exposure to that amount of daylight does not provide adequate efficiency in the surroundings for the regulation of the circadian rhythm.

Additionally, every one of us is aware that the daylighting has an important contribution to our health and well-being due to the improved quality of our environment. A pan-European (Velux 2015) survey determined that the Europeans living in dark buildings are more likely to report poor health compared to those who do not live in dark homes. One of the findings of the survey is that Europeans value daylight in the home. If they were to choose a new home, 47% would give the highest importance to the amount of daylight, 92% would give it above average importance, resulting in an indicator score of 6.1 out of 7. With greater age comes a greater appreciation of daylight in the home. Europeans also invest in improving daylight. More than one in four Europeans 27% have made changes within the last five years aimed at improving the amount of daylight in their home.

2.6 Population Groups and Priority Environments

National renovation strategies often define the priority built environments for renovation. Selection of the priority environment for renovation is often based on the cost-effective approach, which identifies the energy performance of the existing buildings and energy improvements. Selection explicitly on the health status of a building is almost never the primary criteria for decision making. Interestingly, the owners guiding factor for the renovation of an apartment building is first comfort and second energy efficiency.

Studies on unhealthy buildings and the adverse health effects (Sahlberg et al. 2013; Takigawa et al. 2012; Araki et al. 2010; Engvall et al. 2001; Scheel et al. 2001) revealed that the most problematic environments among public buildings are:

- health-care facilities,
- schools, and
- kindergartens.

Vulnerable population groups are always present in all built environments, also general ones. Because of the sensitivity of these groups and public health protection, all built environments should have the same priority.
According to WHO (2017d), the particularly vulnerable are:

- children,
- pregnant women,
- elderly people,
- malnourished people, and
- people who are ill or immunocompromised.

The numbers of these vulnerable populations are increasing, not only as the proportion of the uninsured grows but as the population ages. The health domains of vulnerable populations can be divided into 3 categories regarding (Aday 1994):

- physical
- psychological, and
- social.

According to the categories, specific needs are defined that has to be fulfilled in a specific priority environment (Table 2.2).

**Children** are one example of a vulnerable population group. They are more susceptible to environmental hazards than healthy adults are for several reasons (ATSDR 2016; WHO 2017d):

- Children have disproportionately heavy exposures to environmental toxicants.
- In relation to body weight, children drink more water, eat more food, and breathe more air than adults. Children in the first 6 months of life drink seven times as much water per kg of body weight, and 1–5-year-old children eat 3–4 times more food per kg than the average adult.
- The air intake of a resting infant is proportionally twice that of an adult. As a result, children will have substantially heavier exposures than adults to any toxicants that are present in water, food, or air.
- Two additional characteristics of children further magnify their exposures: their hand-to-mouth behaviour, and the fact that they live and play close to the ground.
- Children’s metabolic pathways, especially in the first months after birth, are immature.
- Children’s ability to metabolize, detoxify, and excrete many toxicants is different from that of adults. Commonly, however, they are less well able to deal with toxic chemicals and thus are more vulnerable to them.

Another vulnerable group is the **elderly**. Both internal and external factors can contribute to the vulnerability of the elderly (Lachs and Pillemer 1995).
Internal risk factors include: increasing age, female gender, medical comorbidities, substance abuse, mental illness, cognitive impairment, sensory impairment, impairment in activities of daily living (ADL), malnutrition.

External risk factors include: lack of social network, dependence on a care provider, living alone, lack of community resources, inadequate housing, unsanitary living conditions, high-crime neighbourhood, adverse life events, poverty.

In the United States, 87% of those 65 years and older have one or more chronic conditions, and 67% of this population has two or more chronic illnesses (Partnership for Solutions 2002). Major chronic conditions affecting older people worldwide are cardiovascular disease, hypertension, stroke, diabetes, cancer, chronic obstructive pulmonary disease, musculoskeletal conditions, mental health condition, blindness and visual impairments (WHO 2002).

Globally, between 1970 and 2025, an increase in older persons of some 694 million or 223% is expected (WHO 2002). In Europe, the shift in the age pyramid is more dramatic: almost one third of people will be elderly in 2050. Due to dramatic demographic changes, the significant burden of dementia, chronically ill and
immobile persons is expected. The Survey of Health, Ageing and Retirement in Europe (SHARE) showed that living conditions before and after retirement vary considerably across Europe and are not fully adjusted to the needs of the elderly (Börsch-Supan 2016). Therefore, the built environment must be adapted and designed for the future of society.

Each vulnerable group, as well as each individual in the group, has specific needs and requirements. If certain requirements and needs of users in a specific environment are not fulfilled, it can be severely debilitating or life-threatening.

For example, a ward for severe burn injuries should have temperature controls that permit adjusting room air temperature up to 32 °C and relative air humidity up to 95% (ASHRAE Handbook 2007). The reason is that patients with large burn injuries have higher risks of hypermetabolism, hypothermia, higher evaporative water losses, progressive weight loss, increased susceptibility to infection, and poor wound healing (Corallo et al. 2007; Herndon and Tompkins 2004; Ramos et al. 2002; Herndon 1996, 1981; Kelemen 1996; Wallace et al. 1994; Caldwell et al. 1992; Carlson et al. 1992; Martin et al. 1992; Wilmore et al. 1975). To decrease energy demands, minimize metabolic expenditure and decrease the hypermetabolic response to thermal injury and evaporative water losses, room air temperature and relative air humidity should be maintained at 28–33 °C and 80%, respectively. In this way, optimal healing and comfort conditions are created (Dovjak 2012) and consequently mortality, morbidity, and hospitalization can be significantly decreased (Herndon 1996; Wilmore et al. 1975).

In current planning, it often happens that these needs tend to be underestimated. Current built environments are not meeting the needs of these vulnerable populations. The environment must be designed to take into account the rationales and requirements of a specific population group. The design of built environments following the concept of active aging or age-friendly environment is a good example.

An age-friendly environment allows people to realize their potential for physical, social and mental well-being throughout the life course and to participate in society according to their needs, desires and capacities, while providing them with adequate protection, security and care when they require assistance (WHO 2002, p. 12).

A series of pan-European surveys, Velux (2017) determined that the link between adverse health effects and the indoor climate does not appear to be well known amongst Europeans, nor does the importance of correct behaviour.
Therefore, health promotion with public awareness is a key to the successful prevention of adverse health effects.

Public health is the science and art of preventing disease, prolonging life and promoting health through the organized efforts and informed choices of society, organizations, public and private, communities and individuals (Fink 2013, p. 2).

To summarize, various health outcomes are related to unhealthy built environments. SBS is one of the most researched health outcomes related to such environments. It is a consequence of exposure to numerous health risk factors and their parameters. The identification of health hazards and their parameters is the key step in the process of effective control and prevention. Therefore, on the basis of a comprehensive literature review, health risk factors and their parameters are systematically presented and classified in Chap. 3.

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