Sick Building Syndrome: Are We Doing Enough?

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ABSTRACT

Health and wellbeing is a vitally important aspect of people centric building design and is the root of productivity. Sick building syndrome (SBS) is a collection of factors that can negatively affect physical health in several ways. Besides physical health is also related to psychological wellbeing because the human body is one interactive biological system. This paper focuses on reviewing the current state of knowledge on building sickness syndrome which has been prevalent as a building illness since the 1970s especially in offices and schools. While the concepts of intelligent, smart and sustainable buildings have gained considerable attention during recent decades, there is now increasing attention being given to designing healthy buildings.

Exposure of occupants to unhealthy indoor conditions increases their risk of illness and this influences their well-being. The prevalence of SBS can result in a wide array of concerns which affect the occupants’ health and hence their work performance. This study endeavors to provide a holistic background knowledge about SBS symptoms. Several negative effects of SBS are identified and potential solutions are advocated. Finally, the study stresses the role of built environment and concludes that ongoing research towards tackling SBS and developing healthy indoor environments should not be limited to a single formula as any health-related building design approach is dependent on several interacting factors.

Keywords: Healthy Buildings; Sick Building Syndrome (SBS); Indoor Environments; Well-being; Sustainability

1. Introduction

Attitudes to well-being and healthy environments are beginning to change, both within the government and society, with a shift away from the idea that a flourishing life is primarily connected to material prosperity towards one that positions well-being as a significant goal for public policy (Barton, et.al, 2010; Barton, 2016; AlWaer and Illsley, 2017). This shift is being accompanied by a commitment to the design of healthy environments that would encourage productive workplaces, occupants’ health and improvement of natural environments/ecosystems. Together, these changes provide opportunities to secure healthier lifestyles, sustain urban development, safeguard ecological-integrity, promote greater equity and support more resilient places in the low carbon future (Barton, et.al, 2010; AlWaer and Illsley, 2017).

Recently, development of greener and smarter buildings, through the application of innovative technologies, has seen growing interests. Future buildings, embracing intelligent, smart, green and responsive attributes, have become a common topic of various academic debates, research investigations and practical implementations related to the architecture, engineering and construction industry. Besides, recent studies have focused on the sustainable dimension of buildings, their embodied intelligence, and responsive potentials as well as their contribution to smart cities {ADDIN EN.CITE <EndNote><Cite><Author>Ahvenniemi</Author><Year>2017</Year><RecNum>98</RecNum><DisplayText>(Ahvenniemi, 2017)</DisplayText></Cite></EndNote>
sustainable and smart cities? <title>Sustainable Cities and Society</title>

Biблиотека: <title>Journal of Cleaner Production</title>


Yang, B.; Xu, T.; & Shi, L., <title>Energy-Efficient House in the GCC Region</title>

Martos, A.; Pacheco-Ortiz, R.; Ordóñez, J., & Jabraque-Gago, E., <title>Energy-Efficient House in the GCC Region</title>

Martos, A., Pacheco-Ortiz, R., Ordóñez, J., & Jabraque-Gago, E., <title>Energy-Efficient House in the GCC Region</title>

Alalouch, Saleh, M. S. E.; & Al-Saadi, S. (2016), <title>Renewable and Sustainable Energy Reviews</title>


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Nonetheless, this study argues that; the majority of recent attempts, both in practice and academia, by architects, engineers and designers, are limited to the latter area of focus. Hence, less attention has been paid to evaluating the crucial impacts of SBS on occupants’ well-being, health status and productivity. Furthermore, for long, an ideal representation of future buildings was repeatedly shaped to embrace green and intelligent attributes while being intertwined with sophisticated automated and ICT-based technologies. Despite these common technology-oriented viewpoints, only a limited amount of studies (with limitation to indoor environmental quality) have attempted to define and envisage future buildings from the SBS perspective as being more responsive to occupants’ behavior, preferences, health, social and psychological well-being.

SBS is a particularly “hot topic”, not least because of the rise in cases of overheating, inadequate ventilation and poor indoor air quality, and growing global awareness of the role of the built environment on human health. This paper evaluates the state of knowledge on SBS by providing a holistic understanding of the impact of SBS on occupant health, wellbeing and productivity; the factors that contribute to these symptoms; and potential solutions. The paper provides useful synthesis and visualisation of research on SBS contributors, mitigation strategies, and the evolution of healthy building design (in light of recent technological advances), that will undoubtedly be of interest to researchers in the fields of public health, architecture, engineering, sustainability, and indoor performance of buildings.

Looking at the methodological approach, the study attempted to review and critically analyze the core SBS symptoms, contributors and their potential impacts through an exploratory review approach. We aim to begin a re-conceptualization of SBS that offers an analytic framework for more systematic enquiry. In this regard, using systematic literature review following preferred reporting items for systematic reviews (Moher, et al, 2009), a comprehensive literature search based on the ‘title/abstract/keyword’ components was carried out. The keywords used in the literature search were generally wide ranging and included terms related to ‘sick building syndrome (SBS)’, ‘healthy buildings’, ‘indoor environments’, ‘well-being’, and ‘sustainability’ based on the available academic journal databases including: Web of Science, Google Scholar, Scopus, Proquest, ACM digital library and Science Direct. Likewise, exploring the references of the already found articles, few papers not covered in the above databases, yet considerably important for the review, were identified. During this review approach, a collection of over 200 articles were identified and classified while through employing content analysis, all collected data were critically analyzed. This paper uses the issues identified to call for a future agenda based on improving professional practice, as well as preparing the ground for more detailed research work in this field. It does not present answers and solutions to all the downsides of trying to reconceptualise the practice of SBS. Nor does it test the proposed framework against real projects or case studies. This study was generally limited to the identification and demonstration of the crucial impacts
of SBS from built environment perspectives and the review aimed at providing new insights regarding the importance of healthy living environments from SBS angle.

2. Sick Building Syndrome

2.1 Introductory Overview

The concept of SBS was initially developed by the World Health Organization (WHO) in 1983 (WHO, 1983). The concept of SBS was first introduced by the WHO in a report titled “Sick Building Syndrome: A practical Guide” emphasizing the severity of the negative effects of the phenomenon. Later, the Commission of the European Communities published a report titled “Sick Building Syndrome: A practical Guide” emphasizing the severity of the negative effects of the phenomenon.

In the definition presented by WHO, SBS has been defined as ‘a collection of nonspecific symptoms including eye, nose and throat irritation, mental fatigue, headaches, nausea, dizziness and skin irritations, which seem to be linked with occupancy of certain workplaces’. Later, the Commission of the European Communities published a report titled “Sick Building Syndrome: A practical Guide” emphasizing the severity of the negative effects of the phenomenon.

Indoor air pollutants: exposure and health effects

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Sick building Syndrome: An Environmentally Related Condition with Increased Prevalence of Non-Specific Symptoms among the Population of Certain Buildings, Often without Clinical Signs and Objective Measures of Symptoms.

From another perspective, SBS has been defined as 'the density of workers' complaints', in which the WHO defined this density to be 20% of the building occupants presenting with the symptoms of SBS. From this perspective, SBS has been defined as 'a generic term used to describe common symptoms which, for no obvious reason, are associated with particular buildings'. Similarly, Transport Salaried Staffs’ Association (TSSA) defined SBS as 'the density of workers' complaints', in which the WHO defined this density to be 20% of the building occupants presenting with the symptoms of SBS. From another perspective, SBS has been defined as 'a generic term used to describe common symptoms which, for no obvious reason, are associated with particular buildings'. Similarly, Transport Salaried Staffs’ Association (TSSA) defined SBS as 'the density of workers' complaints', in which the WHO defined this density to be 20% of the building occupants presenting with the symptoms of SBS.
Similarly, other related studies stressed that there are two main criteria for the existence of SBS in a building: a) at least 20% of buildings users are concerned about an identical medical problem b) that identical medical problem is observed for at least 2 weeks (Abdul-Wahab, 2011; Clements-Croome, 2018). Table 1 demonstrates various definitions extracted from the literature.

Table 1. SBS definitions

<table>
<thead>
<tr>
<th>Reference</th>
<th>Definition</th>
<th>Key Attributes</th>
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</thead>
<tbody>
<tr>
<td>WHO (1983)</td>
<td>A collection of nonspecific symptoms including eye, nose and throat irritation, mental fatigue, headaches, nausea, dizziness and skin irritations, which seem to be linked with occupancy of certain workplaces.</td>
<td>SBS symptoms are nonspecific.</td>
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<tr>
<td>Rostron (2008)</td>
<td>SBS is a syndrome of complaints covering nonspecific feelings of malaise, the onset of which is associated with occupancy of certain modern buildings.</td>
<td>-Direct correlation with the occupancy in certain building.</td>
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<td>Molina, et al. (1990)</td>
<td>SBS is the name given to a set of varied symptoms experienced predominantly by people working in air conditioned buildings, although it has also been observed in naturally ventilated buildings.</td>
<td>-The recognized symptoms are similar amongst the group of people residing in a certain environment.</td>
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<tr>
<td>EPA (1991)</td>
<td>SBS is used to ‘describe 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’.</td>
<td>-The signs are nonspecific -Direct relationship with the occupancy in certain building. -The appearance of same acute symptoms amongst the residents of a certain building.</td>
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<tr>
<td>Goldman (1996)</td>
<td>SBS is where the occupants of a building are affected over an indefinite period, and is directly connected with the building itself.</td>
<td>-Building is the main source of SBS appearance.</td>
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<td></td>
<td>A group of non-specific symptoms with a temporal connection to a particular building, but with no specific or obvious cause.</td>
<td>-The causes are indefinite. -Symptoms are nonspecific and transient.</td>
</tr>
</tbody>
</table>
An environmentally related condition with increased prevalence of non-specific symptoms among the population of certain buildings, often without clinical signs and objective measures of symptoms.

- The symptoms are nonspecific.
- The signs are prevalent amongst the occupants residing in a certain building.
- Majority of these signs are not clinical.
Sick building syndrome. Do we live and work in unhealthy environment?
Passarelli (2009) SBS is a range of non-specific illnesses that are experienced by an occupant while inside a particular building or within a specific area of the inside environment. The symptoms experienced usually disappear hours, or in some cases days, after the occupant is away from the enclosed environment.

A generic term used to describe common symptoms which, for no obvious reason, are associated with particular buildings.

- The symptoms are nonspecific
- The environment is the main cause of appearing SBS.
- The symptoms will be improved once the occupants leave the place.
Crook and Burton (2010) SBS is a complex spectrum of ill health symptoms associated with the indoor environment. In broad terms, these signs are caused by the building itself.
symptoms can be divided into mucous membrane symptoms related to eyes, nose and throat; dry skin; general symptoms of headache and lethargy. These symptoms should improve within hours of leaving the problem building.

-Signs will be improved once users leave the building.

SBS is the density of workers’ complaints’, in which the WHO defined this density to be 20% of the building occupants presenting with the symptoms of SBS

-The existence of SBS in a certain place can be quantified.
The common characteristic that is frequently repeated amongst the presented definitions is the ‘non-specific’ essence of SBS symptoms. This indicates that the signs of SBS can be highly variable, affecting diverse parts of human body in which correlating them to SBS could be challenging in the first place. Nonetheless, several health-related symptoms can be associated with SBS including: i) general symptoms (i.e. hoarseness of voice, allergies, flu-like symptoms, respiratory diseases, nausea, dizziness, headache, fatigue, and inability to concentrate), ii) mucous symptoms (i.e. eye, throat and nose irritations or coughing) and iii) dermal symptoms (i.e. itching skin, face, hands or scalp). The main cause of SBS symptoms is the building itself. The signs of SBS are nonspecific. The SBS symptoms may concern certain parts of the body. The extent of SBS signs cannot be limited. These symptoms are temporal.
Notwithstanding the various determinants contributing to the emergence of SBS symptoms, this study classified major causes of SBS under two general categories: individual-related factors and ambiance-related factors.

Individual-related factors can be gender, history of atopy (genetic tendency towards developing allergic diseases/allergic disorders, low status of individuals in an organization, working on more routine tasks and smoking status

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individually smoking and indoor painting as the two potential predictors of SBS symptoms through conducting an 8-year follow-up period to investigate the changes of SBS and different types of indoor exposures at home.

However, the prevalent complaints of SBS are more likely to be related to the ambient issues, including building dampness. Sahlberg, B., Mi, Y. H., & Norbäck, D. studied the association between SBS symptoms and physical and environmental conditions at both home and work through distributing postal questionnaire. Their findings confirmed the positive association existed between the perceptions of poor physical environmental conditions and emergence of common medical symptoms. They stated that atopy, poor air quality, and low social support were significantly associated with both SBS symptoms at work and home.

Building dampness is the presence of unwanted moisture in the building structure, which can be either the result of intrusion from outside or condensation within the structure. This phenomenon may stimulate the appearance of respiratory illness such as asthma in occupants. [ADDIN EN.CITE [ADDIN EN.CITE.DATA]]


Similarly, (Zhang, et al., 2012) identified dampness as one of the critical factors associated with SBS symptoms in newly built dwellings. In damp buildings, mold and bacteria grow by enjoying the hospitable environment existing in settled dust. In damp buildings, mold and bacteria grow by enjoying the hospitable environment existing in settled dust.

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SBSs were found across the world in different building types. Table 2 presents a summary of a selected set of studies from different countries that investigated SBS. Therefore, literature indicates the significant impacts of SBS on occupants. These symptoms may result in affecting the residents’ well-being or diminishing their productivity rates once they are working. Majority of these symptoms are found to be transient and their effects will be dissipated when the occupants leave the place such as work-related symptoms. Given these explanations, it can be inferred that the level of seriousness and the period of emerging symptoms once the occupants are exposed to sick environments can be highly variable. This mainly depends on the level of exposure and susceptibility of occupants to environmental contaminants.

Table 2. Studies addressed the impacts of SBS on human wellbeing

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Country</th>
<th>Type of Building</th>
<th>Identified Symptoms associated with SBS</th>
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<tbody>
<tr>
<td>Lim</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Zhang</td>
<td></td>
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<tr>
<td>Crook, B.</td>
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<tr>
<td>Burton, N.C.</td>
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</tbody>
</table>

{PAGE}
Work-related symptoms in indoor environments: a puzzling problem for the occupational physician

International archives of occupational and environmental health

Italy

Companies

Anxiety, depression, environmental discomfort and job strain
Iran Office buildings Malaise, headache, throat dryness, cough, sputum, wheezing, skin dryness and eye pain
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Journal Article</th>
<th>Title</th>
<th>Pages</th>
<th>Volume</th>
<th>Number</th>
<th>Date</th>
<th>URL</th>
<th>Countries</th>
<th>Schools</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhang et al.</td>
<td>2014</td>
<td>PloS one</td>
<td>A Longitudinal Study of Sick Building Syndrome (SBS) among Pupils in</td>
<td>e112933</td>
<td>9</td>
<td>11</td>
<td>2014</td>
<td>/</td>
<td>China</td>
<td>Schools</td>
<td>Skin symptoms, mucosal symptoms</td>
</tr>
<tr>
<td>Shan et al.</td>
<td>2016</td>
<td>PloS one</td>
<td>Head and eye related issues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>/</td>
<td>Singapore</td>
<td>Schools</td>
<td></td>
</tr>
</tbody>
</table>
Comparing mixing and displacement ventilation in tutorial rooms: Students' thermal comfort, sick building syndromes, and short-term performance.

Malaysia Schools

Ocular, rhinitis, throat symptoms, headache and tiredness, dermal symptoms.
Endotoxin, ergosterol, muramic acid and fungal DNA in dust from schools in Johor Bahru, Malaysia—Associations with rhinitis and sick building syndrome (SBS) in junior high school students

Science of the Total Environment

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Pages: 95-103


Lim

Malaysia University Dermal, mucosal and general symptoms
Dry skin, runny nose, dry eyes, blocked/stuffy nose, tiredness and flu-like symptoms
Architectural Evaluation of Thermal Comfort: Sick Building Syndrome Symptoms in Engineering Education Laboratories

Effects of gender and dormitory environment on sick building syndrome symptoms among college students in Tianjin, China.


Sweden/Estonia/Iceland
Residential Building
General signs of sick building (i.e. mucosal symptoms)
(Takigawa, et al., 2010)
Taiwan Office building Eye irritation and upper respiratory symptoms

USA Office building Asthma and allergic disease
Indoor environmental and air quality characteristics, building-related health symptoms, and worker productivity in a federal government building complex

Croatia

Office buildings

Fatigue, sore and dry eyes, and headache
Thorn Gomzi et al. (2007) reported that sick building syndrome involves psychological, somatic, and environmental determinants. The syndrome includes headache, tiredness, nausea, and sensation of a cold.
Sick building syndrome (SBS) and sick house syndrome (SHS) in relation to psychosocial stress at work in the Swedish workforce.
2.2 SBS Contributors

According to WHO, up to 30% of new and remodeled buildings worldwide were recognized to be potential carriers of SBS. Boubekri (2008) and Wong, et al. (2009) highlighted that the appearance of symptoms associated with SBS may result in a decrease in performance rates of individuals. The prevalence of SBS is challenging to substantiate or single out the main source(s) responsible for stimulating the appearance of a particular symptom. Reviewing the research investigations about SBS in buildings, the study draws attention to the major contributors of SBS as highlighted below:

- **Physical contributors**: These factors are associated with the physical attributes of buildings that can stimulate the appearance of SBS signs. These contributors can significantly affect the health status, well-being, and comfort. In fact, the provision of physical comfort in a workplace is essential in enhancing the occupants’ performances through a healthier and more productive workplace.

  - **Temperature**: Deviation from the thermal comfort threshold for buildings’ indoor environment may result in occurrence of SBS. Humphreys, Nicol, Roaf, & Sykes (2015) highlighted Standards for Thermal Comfort: Indoor Air Temperature Standards for the 21st Century while subsequently affecting the performance rates of individuals.

  - **Relative Humidity**: This factor is considered one of the major contributors of SBS. Chua, et al. (2016) reviewed the effects of relative humidity on office employee’s performance.

In MATEC Web of Conferences. EDP Sciences. In MATEC Web of Conferences. EDP Sciences.
found a strong correlation existing between room temperature, lighting and relative humidity and human health. They concluded that an increased concentration of temperature and humidity was directly linked to affected the workers’ productivity. 

A 24 research paper on the effect of thermal comfort on productivity, showed that the performance increased with temperature up to 21-22°C and decreased with temperature above 23-24°C. In a review of a wide array of variables such as temperature, radiation, wind, and humidity, though it is often treated as a sole product of temperature, it is shown that the performance of office workers is basically dependent upon interactions of a wide array of variables such as temperature, radiation, wind, and humidity, though it is often treated as a sole product of temperature. 

The mechanism by which heat affects human performance is basically dependent upon interactions of a wide array of variables such as temperature, radiation, wind, and humidity, though it is often treated as a sole product of temperature. 

Although there is no agreement on what constitutes the ideal range of relative humidity, environments with temperature above 32°C and relative humidity above 60% are considered as...
The existence of humidity can potentially provide a hospitable environment for microscopic organisms such as mildews and molds to be grown up indoor and pose a serious danger upon the health status of residents. Additionally, humidity exposure can cause muscle cramps, fainting, heat stroke, and even exacerbate the underlying medical conditions, such as lung or heart disease. Ventilation; The current ventilation standards and guidelines investigated the prevalent perceptions of odors and sensations of air humidity and SBS symptoms in domestic environments through questionnaire. The findings confirmed the significance of humid air’s role in symptomizing general signs as well as mucosal and skin sicknesses in children. The combined effect of temperature, relative humidity and work intensity on human strain in hot and humid environments.
to tackle the SBS. Ideally, the air movement induced by buoyancy is capable of transferring heat and pollutants away from the occupied zone, promoting stratification, creating a warmed indoor environment without cold drafts.

Good indoor air quality contributes to causing symptoms such as inflammation, respiratory infections, asthma symptoms and short-term sick leave. Additionally, sufficient use of natural ventilation (NV) systems can be also considered as a key factor in improving indoor air quality and reducing health issues.

Indoor air quality standards such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1e2007, Ventilation for Acceptable Indoor Air Quality. Atlanta, GA, USA: ASHRAE; 2007; have been established to ensure that indoor environments are free from pollutants and bio-effluents, and to maintain a high level of indoor air quality.

Indoor air quality has been found to have a significant impact on the health and performance of occupants. Poor ventilation can potentially trigger the emergence of SBS symptoms such as nose and throat irritation, headaches, fatigue, asthma, rhinitis and increased susceptibility to colds and flu. Actions have been proposed to include adequate outdoor ventilation, control of moisture, and avoidance of indoor exposures to pollutants such as microbiological particles, allergens and chemical substances which are considered likely to have adverse effects.

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mixed layer in the upper part of the room. Studies also reported promising results for improving the health status of occupants where DV system was installed. However, the usage of this system is involved in certain limitation. First, light influences the secretion of melatonin, through the eye and the retinohypothalamic tract. Second, light inhibits the visual comforts. First, light influences the suprachiasmatic nucleus (SCN), a region in the hypothalamus that controls circadian rhythms, through the eye and the retinohypothalamic tract. Second, light inhibits the secretion of melatonin and result in disrupting of sleep pattern. Third, light is found to have alerting effects through indirect projections on the ascending arousal system, which in turn, facilitates thalamic and cortical connections. Illuminance level: The poor quality of light can directly influence human health by affecting the occupants’ visual comforts. First, light influences the suprachiasmatic nucleus (SCN), a region in the hypothalamus that controls circadian rhythms, through the eye and the retinohypothalamic tract. Second, light inhibits the secretion of melatonin and result in disrupting of sleep pattern. Third, light is found to have alerting effects through indirect projections on the ascending arousal system, which in turn, facilitates thalamic and cortical connections.
The importance of indoor illuminance was highlighted by a study where they investigated the effects of indoor lighting on occupants' visual comfort and eye health in a green building. Indoor and Built Environment's research indicated that daylight can potentially improve the occupants' psychological health and productivity. Illumination level at 1000lux were found to improve productivity, performance and occupant’s health in office buildings.

Noise: Noise is a pervasive and influential source of stress with great potentials to distract occupants engaged in undertaking a particular performance. Noise effects are generally categorized into two broad groups; auditory (behavioral and physiological effects) and non-auditory (behavioral and physiological effects).
Behavioral problems and cardiovascular effects result in increasing the possibility for respiratory diseases, namely asthma. It is more likely that low frequency noise (20-100 Hz) which is found in buildings with industrial machines or ventilation machinery may cause health problems.

Noise exposure during night can lead to serious health effects on long-term, such as behavioral problems and cardio vascular effects. Moreover, it may affect the occupants' hearing abilities, increased systolic blood pressure and chronic headaches. This can provide a hospitable environment for growing airborne bacteria and fungi, and subsequently, results in increasing the possibility for respiratory diseases, namely asthma.


Electromagnetic radiation (ER): The electromagnetic spectrum refers to a group of distinct forms of energies emanating from multiple sources with various frequencies (Genuis, 2008). The high frequencies are gamma rays, X-rays and ultraviolet light; the lower frequencies of the spectrum include microwaves; medium frequencies include radio waves and light wave emission that provide the possibility to perceive the vision and the light and infrared energy which allows perceiving the heat (Genuis, 2008). Ionizing radiation is a term to describe the human exposure to the sources of energy with high frequencies which result in causing serious health issues (Christensen, et al. 2014; Azzam, et al. 2012). This phenomenon may intrigue the risk of malignancy or cell death by altering the atomic composition of cell structures, breaking the chemical bonds and inducing free radical formation (Genuis, 2008; Azzam, et al. 2012). Fife (2017) mentioned that 'electromagnetic energy surrounds and penetrates our homes, our work environment and every place in-between'. In this regards, Zamanian and Hardiman (2005) stated that human beings are constantly exposed to low levels of ionizing radiation from natural sources such as sunlight, radioactive materials on the earth's surface, radioactive gases leaking from the earth, cosmic rays from outer space entering the earth's atmosphere through the ionosphere and natural radioactivity.

The natural radioactivity has been around since the beginning of universe due to the found radioelement in the earth's crust. The radionuclides of $^{226}$Ra, $^{232}$Th and $^{40}$K can be almost found in all types of rocks, granite, sand, cement and gypsum, from which majority of building materials are produced (Mavi and Akkurt, 2010). As such, materials obtained from the earth's crust contain traces of $^{238}$U and $^{232}$Th (Bavarnegin, et al. 2013). In the $^{238}$U series, $^{226}$Ra decays to radon ($^{222}$Rn), which is a radioactive gas with a half-life of 3.82 days (Bavarnegin, et al. 2013; Lu, et al. 2012; Baykara, et al. 2011). Prolonged exposure of occupants to the indoor radon causes pathological effects and functional respiratory alterations, by which consequently lead to serious risks of developing lung cancer (Bavarnegin, et al. 2013; Saad, et al. 2014). The severity of this risk depends on the concentration of radon indoors, the duration of exposure, and the degree of ventilation in the houses (Saad, et al. 2014). To this extent, the significance of addressing the exposure of human beings originating from the building materials has been underlined by several initiatives. For instance, the article 75 of the Euratom basic safety standards (EU-BSS) (Council directive 2013/59/Euratom) stipulated that, 'the reference level applying to indoor external exposure to gamma radiation emitted by building materials, in addition to outdoor external exposure, shall be 1 MilliSievert (mSv) per year' (European Council, 2014). EU-BSS is expected to be transposed to national law by EU Member States before February 2018, aiming to establish a basic standard adoptable by the EU members to protect the public against the exposure of ionising radiation (Croymans, et al. 2018; Schroeyers, et al. 2018). Studies have widely addressed the issue associated with the emission of natural radioactivity from building materials (Mavi and Akkurt, 2010; Chen, et al. 2010; Saad, et al. 2014; Bavarnegin, et al. 2013; Lu, et al. 2012; Ravisankar, et al. 2012). In one attempt, Mavi and Akkurt (2010) measured the radioactivity of commonly-used building materials, namely brick, cement, limestone, ytong, limra, gypsum, ceramic tile and gravel existing in Ispartacity of Turkey. They conclusively stated that the levels of natural radioactivity in these materials were below the acceptable limits. Saad, et al. (2014) also assessed the rates of radon exhalation concerned with 37 samples of different building materials which were being utilized for the purposes of construction and decoration in Libyan market. The results identified two materials, Indian granite and Italian marble, with high values of radon concentration, in which have been recommended to be substituted by alternatives.

- Biological contributors; IAQ can be affected by development of moulds, fungi and mites inside the buildings and endanger the occupants’ wellbeing and health status. Several contributors can be mentioned with the association to the growth of biological factors inside the buildings namely, building’s structural failure, poor air ventilation or improper maintenance of building
Consistent exposure of residents with these infected environments can result in occurring health-related issues such as respiratory and allergic diseases [Singh, 2005; Singh, et al., 2010]. They carried out a research to investigate the dorm environment and college students' health in Tianjin, China. Since 2004, the development of quantitative polymerase chain reaction (QPCR) analysis of molds (US. Patent 6,387,652) has dramatically improved fungal speciation and quantification, resulting in a highly standardized process for describing the indoor fungal population [Johansson, et al., 2013; Vereecken &amp; Roels, 2012].

\[\text{...}\]

26/03/2017/ &lt;title&gt;ExcluderateAuth="1" &lt;Author&gt;Vesper&lt;/Author&gt; &lt;Year&gt;2004 &lt;/Year&gt; &lt;RecNum&gt;173 &lt;/RecNum&gt; &lt;Prefix&gt;Vesper &amp; Vesper' &lt;/Prefix&gt; &lt;rec-number&gt;173 &lt;/rec-number&gt; &lt;foreign-keys&gt; &lt;key app="EN" db-id="z2wa9ws2tvf000ex5fps95kxxe2pdszv22" timestamp="1490635519">173&lt;/key&gt; &lt;/foreign-keys&gt; &lt;ref-type name="Journal Article">17&lt;/ref-type&gt; &lt;contributors&gt; &lt;authors&gt;&lt;author&gt;Vesper, S. J. &amp; Vesper, M. J.&lt;/author&gt; &lt;/authors&gt; &lt;/contributors&gt; &lt;/title&gt; Possible role of fungal hemolysins in sick building syndrome &lt;/title&gt; &lt;secondary-title&gt;Advances in microbiology &lt;/secondary-title&gt; &lt;/titles&gt; &lt;/periodical&gt; &lt;/url&gt; &lt;/periodical&gt; &lt;/pages&gt;191-213 &lt;/volume&gt;55 &lt;/volume&gt; &lt;/year&gt;2004 &lt;/year&gt; &lt;/url&gt; &lt;/periodical&gt; &lt;/EndNote&gt; }. Recently, studies are focused on identifying the significance of biological attributes, namely fungi that can potentially contribute to SBS. In one attempt, { ADDIN EN.CITE &lt;EndNote&gt;&lt;Cite ExcludeAuth="1" &lt;Author&gt;Boechat&lt;/Author&gt; &lt;Year&gt;2011 &lt;/Year&gt; &lt;RecNum&gt;171 &lt;/RecNum&gt; &lt;Prefix&gt;Boechat', et al. &lt;/Prefix&gt; &lt;DisplayText&gt;Boechat, et al. 2011 &lt;/DisplayText&gt; &lt;rec-number&gt;171 &lt;/rec-number&gt; &lt;foreign-keys&gt; &lt;key app="EN" db-id="z2wa9ws2tvf000ex5fps95kxxe2pdszv22" timestamp="1490629573">171&lt;/key&gt; &lt;/foreign-keys&gt; &lt;ref-type name="Article">17&lt;/ref-type&gt; &lt;contributors&gt; &lt;authors&gt;&lt;author&gt;Boechat, J. L., Rios, J. L., Ramos, M. C., Luiz, R. R., Neto, F. A., &amp;amp; e Silva, J. L.&lt;/author&gt; &lt;/authors&gt; &lt;/contributors&gt; &lt;title&gt; Sick Building Syndrome (SBS) Among Office Workers and Exposure to Indoor Fungal Allergens in Rio de Janeiro, Brazil &lt;/title&gt; &lt;secondary-title&gt;Journal of Allergy and Clinical Immunology &lt;/secondary-title&gt; &lt;/titles&gt; &lt;/periodical&gt; &lt;/url&gt; &lt;/periodical&gt; &lt;/pages&gt;AB178 &lt;/pages&gt;127 &lt;/volume&gt; &lt;/number&gt;2 &lt;/number&gt; &lt;/year&gt;2011 &lt;/year&gt; &lt;/url&gt; &lt;/periodical&gt; &lt;/EndNote&gt; } investigated the prevalence of SBS in workers of two buildings and its relationship with fungal exposure in the workplace in Rio de Janeiro, Brazil. Based on the medical examination and a score-based questionnaire, they evaluated the SBS diagnosis of 160 full-time workers of a sealed building, and 164 employers from a naturally ventilated building. The results indicated that the prevalence of SBS in the sealed building and non-sealed buildings were 44.8% and 48.6%, respectively. They stated that, fungal exposure was the unique significant risk factor for SBS in the non-sealed building, whilst no significant exposure to fungi in the indoor environment of the sealed building was found. { ADDIN EN.CITE &lt;EndNote&gt;&lt;Cite ExcludeAuth="1" &lt;Author&gt;Polizzi&lt;/Author&gt; &lt;Year&gt;2011 &lt;/Year&gt; &lt;RecNum&gt;180 &lt;/RecNum&gt; &lt;Prefix&gt;Polizzi', et al. &lt;/Prefix&gt; &lt;DisplayText&gt;Polizzi, et al. 2011 &lt;/DisplayText&gt; &lt;rec-number&gt;180 &lt;/rec-number&gt; &lt;foreign-keys&gt; &lt;key app="EN" db-id="z2wa9ws2tvf000ex5fps95kxxe2pdszv22" timestamp="1490785374">180&lt;/key&gt; &lt;/foreign-keys&gt; &lt;ref-type name="Article">17&lt;/ref-type&gt; &lt;contributors&gt; &lt;authors&gt;&lt;author&gt;Polizzi, V., Adams, A., Picco, A. M., Adriaens, E., Lenoir, J., Van Peteghem, C., ... &amp;amp; De Kimpe, N.&lt;/author&gt; &lt;/authors&gt; &lt;/contributors&gt; &lt;title&gt; Influence of environmental conditions on production of volatiles by Trichoderma atroviride in relation with the sick building syndrome &lt;/title&gt; &lt;secondary-title&gt;Building and Environment &lt;/secondary-title&gt; &lt;/titles&gt; &lt;/periodical&gt; &lt;/full-title&gt; &lt;/periodical&gt; &lt;/pages&gt;945-954 &lt;/volume&gt;46 &lt;/volume&gt; &lt;/number&gt;4 &lt;/number&gt; &lt;/year&gt;2011 &lt;/year&gt; &lt;/url&gt; &lt;/periodical&gt; &lt;/EndNote&gt; } also announced that the 6-pentyl-2-pyrene produced by T. atroviride, a mold present in damp dwellings, can result in the appearance of SBS symptoms. The 6-pentyl-2-pyrene is a compound emitted on common building materials that could give irritation and damage to mucosal membranes.

- Chemical contributors: Certain chemical substances and dust could lead to developing SBS. For example, { ADDIN EN.CITE &lt;EndNote&gt;&lt;Cite ExcludeAuth="1" &lt;Author&gt;Sahlberg&lt;/Author&gt; &lt;Year&gt;2013 &lt;/Year&gt; &lt;RecNum&gt;53 &lt;/RecNum&gt; &lt;Prefix&gt;Sahlberg', et al. &lt;/Prefix&gt; &lt;DisplayText&gt;Sahlberg, et al., 2013 &lt;/DisplayText&gt; &lt;rec-number&gt;53 &lt;/rec-number&gt; &lt;foreign-keys&gt; &lt;key app="EN" db-id="z2wa9ws2tvf000ex5fps95kxxe2pdszv22" timestamp="1447025222">53&lt;/key&gt; &lt;/foreign-keys&gt; &lt;ref-type name="Article">17&lt;/ref-type&gt; &lt;contributors&gt; &lt;authors&gt;&lt;author&gt;Sahlberg, B., Gunnbjörnsdottir, M., Soon, A., Jogi, R., Gislason, T., Wieslander, G., ... &amp; Norback, D.&lt;/author&gt; &lt;/authors&gt; &lt;/contributors&gt; &lt;title&gt; Airborne molds and bacteria, microbial volatile organic compounds (MVOs), plasticizers and formaldehyde in dwellings in three North European cities in relation to sick building syndrome (SBS) &lt;/title&gt; &lt;secondary-title&gt;Science of the total environment &lt;/secondary-title&gt; &lt;/titles&gt; &lt;/periodical&gt; &lt;/full-title&gt; &lt;/periodical&gt; &lt;/pages&gt;433-
symptoms of sick buildings, namely mucosal symptoms. On the other hand, different types of indoor exposures at home for the Swedish population: a longitudinal cohort study from 1989 to 1997. They concluded that indoor painting is one of the major to SBS. In another study, the association between volatile organic compounds (VOCs) of possible microbial origin (MVOCs), and airborne levels of bacteria, molds, formaldehyde, and two plasticizers in dwellings with the prevalence of SBS. This study was conducted with participation of 159 adults selected from three cities in Sweden, Iceland and Estonia. The conclusion confirmed the existence of a positive association between MVOCs, formaldehyde and the plasticizer texanol with appearance of symptoms of sick buildings, namely mucosal symptoms. On the other hand, Japan newly built houses tend to increase the risk of subjective symptoms in residents suffering from SBS. They found that chemicals detected in Japanese newly built houses tend to increase the risk of subjective symptoms in subjects suffering from SBS. In another study, the association between volatile organic compounds (VOCs) and aldehydes with optical, nasal, and gular symptoms. They concluded that chemicals detected in Japanese newly built houses tend to increase the risk of subjective symptoms in residents suffering from SBS. In another study, the association between volatile organic compounds (VOCs) and aldehydes with optical, nasal, and gular symptoms. They concluded that chemicals detected in Japanese newly built houses tend to increase the risk of subjective symptoms in residents suffering from SBS. In another study, the association between volatile organic compounds (VOCs) and aldehydes with optical, nasal, and gular symptoms. They concluded that chemicals detected in Japanese newly built houses tend to increase the risk of subjective symptoms in residents suffering from SBS.
103.pages объем 545 даты 2016 год даты ссылки ссылки record record @] investigated the appearance of SBS among 462 students at secondary schools in Johor Bahru, Malaysia. The results confirmed a positive association between the existence of fine dust in the classroom and appearing of some symptoms of sick buildings i.e. ocular symptoms and rhinitis. Furthermore, there were positive associations between C14 3-OH and rhinitis and between C18 3-OH and dermal symptoms.

- Psychosocial contributors: SBS can pose serious threats on occupants’ psychosocial status through subjecting them with anxiety, depression, environmental discomfort, job strain and reducing the occupants’ performances. One of the psychosocial factors that is believed to be effective in the development of SBS is monotonous work environment. Monotous work refers to the state that the employees are obligated to constantly repeating activities or tasks { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"><Author>Gül</Author><Year>2011</Year><RecNum>188</RecNum><Prefix>Gül</Prefix><DisplayText>(Gül, 2011)</DisplayText><record><rec-number>188</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1491058525">188</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Gül, H</author></authors></contributors><titles><title>Sick Building Syndrome from the Perspective of Occupational and Public Health. In Sick Building Syndrome</title><secondary title><periodical><full title>Springer Berlin Heidelberg</full title><pages>89-104</pages><dates><year>2011</year></dates><urls></urls></periodical></secondary></titles><url></url></record></Cite></EndNote>}. This can result in degrading the productivity rate of employees as they may become mentally disengaged with their tasks. Additionally, { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"><Author>Crawford</Author><Year>1996</Year><RecNum>167</RecNum><Prefix>Crawford &amp; Bolas</Prefix><DisplayText>(Crawford &amp; Bolas, 1996)</DisplayText><record><rec-number>167</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1486195696">167</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Crawford, J. O.</author><author>Bolas, S. M</author></authors></contributors><titles><title>Sick building syndrome, work factors and occupational stress</title><secondary title><periodical><full title>Scandinavian journal of work, environment &amp; health</full title><pages>243-250</pages><dates><year>1996</year></dates><urls></urls></periodical></secondary></titles><url></url></record></Cite></EndNote> underlined the role of occupational stress to be closely correlated with appearance of SBS symptoms. Nevertheless, it should be argued that despite the significant impact of psychosocial contributor, the number of existing studies with focus on examining its impacts is relatively limited.

- Individual contributors: Personal characteristics of individual’s might amplify the effect of SBSs on occupants. To explain, gender, genetic tendency to develop allergy, smoking status and psychological state were found to be associated with SBS { ADDIN EN.CITE { ADDIN EN.CITE.DATA }}. In one study, { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"><Author>Lim, et al</Author><Year>2015</Year><RecNum>3</RecNum><Prefix>Lim’, et al’</Prefix><DisplayText>(Lim, et al., 2015)</DisplayText><record><rec-number>3</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1469624878">3</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Lim, F. L.</author><author>Hashim, Z.</author><author>Said, S. M.</author><author>Than, L. T. L.</author><author>Hashim, J. H.</author><author>Norbäck, D.</author></authors></contributors><titles><title>Sick Building Syndrome from the Perspective of Occupational and Public Health. In Sick Building Syndrome</title><secondary title><periodical><full title>Science of The Total Environment</full title><pages>535-361</pages><dates><year>2015</year></dates><urls></urls></periodical></secondary></titles><url></url></record></Cite></EndNote> investigated the associations between SBS symptoms, selected personal factors, office characteristics and indoor office exposures among office workers from a university in Malaysia. It was concluded that a combination of allergy to cat or house dust mites is a risk factor for SBS. On the other hand, { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"><Author>Zhang</Author><Year>2011</Year><RecNum>58</RecNum><Prefix>Zhang’, et al’.</Prefix><DisplayText>(Zhang, et al., 2011)</DisplayText><record><rec-number>58</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1474181393">58</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Zhang, et al.</author></authors></contributors><titles><title>Sick Building Syndrome, work factors and occupational stress</title><secondary title><periodical><full title>Springer Berlin Heidelberg</full title><pages>25-35</pages><dates><year>2011</year></dates><urls></urls></periodical></secondary></titles><url></url></record></Cite></EndNote> confirmed a positive association between the existence of fine dust in the classroom and appearing of some symptoms of sick buildings i.e. ocular symptoms and rhinitis. Furthermore, there were positive associations between C14 3-OH and rhinitis and between C18 3-OH and dermal symptoms.
The attributes causing SBS will not be limited to the mentioned contributors, other factors such as ‘building materials’, ‘poor sanitation’, ‘availability of ozone, organic solvents and formaldehyde in the atmosphere’, ‘office equipment, furnishings and other materials and products located or used in the building with potentials to produce fumes or contact dermatitis’, ‘air borne chemical fumes or gasses from any components in the building’ and ‘vermin (i.e., mice, rats and cockroaches) infestation’ can also play a significant role towards the unhealthy status of a building. 

Table 3 summarizes the major effects of each contributor on the occupants’ well-being. It can be conclusively mentioned that attributes pertaining to the physical features of buildings may have a more determinative influence in stimulating the emergence of SBS’ symptoms. The negative impacts of physical contributors on occupants’ health during the operational phase of building can be initially neutralized through considering health-related design principles during the building’s design phase. The building’s orientation { ADDIN EN.CITE <EndNote><Cite><Author>Jansz</Author><Year>2011</Year><RecNum>128</RecNum><DisplayText>(Jansz, 2011b)</DisplayText></Cite><EndNote><Cite><Author>Abanda</Author><Year>2016</Year><RecNum>128</RecNum><Prefix>Abanda &amp; Byers</Prefix>, <DisplayText>(Abanda &amp; Byers, 2016; Mangkuto, et al., 2016)</DisplayText></Cite></Cite> conducted a two-year study investigating changes of SBS symptoms in Chinese pupils pertaining to the parental asthma/allergy, own atopy, classroom temperature, relative and absolute humidity, crowdedness, IAQ (i.e. CO₂, NO₂, and SO₂). It was found that parental asthma/allergy and atopy were correlated with incidence of SBS.

In a study, Lee, et al. (2001) employed a test chamber to characterize the rate of pollutants introduced from certain office equipment, namely fax machines, laser printers, ink-jet printers, scanners and photocopying machines. They measured the concentrations of VOCs, total VOC (TVOC), ozone, respirable particles (PM10) and temperature associated with the usage of these equipment. The results indicated that the highest emission rates of VOCs compounds were toluene, ethylbenzene, m,p-xylene, and styrene. Also, the emissions of ozone and VOC produced through the laser printers were significantly higher than ink-jet printers. In another study, Kowalska, et al. (2015) analyzed the indoor emissions of volatile halogenated organic compounds (VHOCs) produced through office printers and copiers by taking samples in laboratory conditions during the operation of these appliances. The tests of VHOCs were performed by dint of utilizing a simulated environment (test chamber). The results showed that, the operation of these devices can significantly lead to producing VOCs in typical office indoor air. Furthermore, the chlorinated organic compounds were the only determinants found amongst the examined VHOCs, which may possibly contribute to carcinogenic.
{PAGE }
The occurrence of SBS can be recognized in various environments such as office spaces, residential environments, schools, universities, or hospitals. The core symptoms of SBS may concern with the health status of occupants, either physically or mentally. These symptoms can potentially incur many negative effects on the occupants. Majority of these negative effects are interrelated, in which the occurrence of one effect may trigger the emergence of another (Vural and Balanlı, 2011; Abdul-Wahab, 2011).

2.2.1 Symptomatology
Recent studies suggested several symptoms for SBS, affecting different parts of human body ranging from headache, fatigue and irritation in upper respiratory tract to nose, throat, eyes, and dermal abnormalities. These signs can be categorized into eight main groups (See Table 4):

<table>
<thead>
<tr>
<th>Category</th>
<th>Symptoms</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>Allergic Rhinitis (repetitive sneezing and a runny nose), Sinus congestion, Influenza like symptoms, Dry Cough, Throat irritation, Wheezing when breathing, Shortness of breath, Sensation of having dry mucus membranes, Houneseness of the voice due to inflammation of the throat and larynx, Sensitivity to odors, Increased incidences of building related asthma attacks, Asthma</td>
<td>It refers to the symptoms that concern the respiratory system of patients.</td>
</tr>
<tr>
<td>Air quality</td>
<td>Poor quality of indoor air, CO2, SO2, O3, PM10</td>
<td>hearing issues, headaches, increasing blood pressure, Respiratory diseases, lowering the rate of productivity, tiredness, decision-making</td>
</tr>
<tr>
<td>Electromagnetic radiation (ER)</td>
<td>Protracted exposure to the building materials emitting</td>
<td>Respiratory diseases and lung cancer</td>
</tr>
<tr>
<td>Biological</td>
<td>Moulds, fungi and mites, 6-pentyl-2-pyrone</td>
<td>Respiratory and allergic diseases, mucosal and skin problems, nose irritation</td>
</tr>
<tr>
<td>Chemical</td>
<td>Building materials, MVOCs, formaldehyde, plasticizer texanol, fine dust, C14 3-OH, C18 3-OH CO2 concentrations</td>
<td>Mucosal, optical, nasal, gular, ocular and rhinitis symptoms, respiratory issues</td>
</tr>
<tr>
<td>Psychosocial</td>
<td>Monotonous work environment, occupational stress</td>
<td>Anxiety, depression, environmental discomfort, job strainer and reduction in performances</td>
</tr>
<tr>
<td>Individual</td>
<td>Gender, genetic tendency to develop allergy, atopy, parental asthma/allergy, smoking status and psychological state</td>
<td>Individual with these characteristics are more likely to experience different types of SBSs.</td>
</tr>
</tbody>
</table>
Nasal\hspace{1cm}Runny nose, Sneezing, Blocked nose, Nose bleeding

One of the most frequent symptoms that inhabitants of sick buildings suffer is the nasal irritation with rhinorrhea and nasal obstruction. This symptom which is
usually considered as ‘nasal stuffiness’ may appear alongside the other factors {ADDIN EN.CITE {ADDIN EN.CITE.DATA}]. It refers to the presence of issues related to the dryness and irritation of mucous membrane of eye and swollen eyelids {ADDIN EN.CITE {ADDIN EN.CITE.DATA}].

Ocular Eye dryness, Itching of the eyes, Watering of the eyes, Gritty eyes, Eye Burning, Visual disturbances, Light sensitivity, Swollen eyelids

Oropharyngeal Dryness and irritation of the throat, Dry sore throat

Cutaneous Skin rashes, Itchy skin, Dry skin, Erythema (Redness or inflammation due to congestion in, and dilation of, the superficial capillaries of the skin.), Irritation and dryness of the lips, Seborrheic dermatitis, Periorbital eczema, Rosacea, Urticaria, Itching folliculitis

This is related to the appearance of dryness and irritation of skin, which occasionally associated with rashes exposed on the skin surfaces {ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"><Author>Maoz-Segal</Author><Year>2015</Year><RecNum>16</RecNum><Prefix>Maoz-Segal`, et al.`</Prefix><DisplayText>Lu, et al., 2016; Maoz-Segal, et al., 2015</DisplayText><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5fps95kxxe2pdsvt22" timestamp="1469958717">16</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Maoz-Segal, R., Agmon-Levin, N., Israeli, E., &amp; Shoenfeld, Y.</author></contributors><titles><title>The sick building syndrome as a part of&Apos;ASIA&Apos; autoimmune/auto-inflammatory syndrome induced by adjuvants</title><secondary-title>Harefuah</secondary-title></titles><pages><pages><volume>154</volume><number>2</number><dates><year>2015</year><urls /></pages></pages></titles></Cite><Cite ExcludeAuth="1"><Author>Lu</Author><Year>2016</Year><RecNum>2</RecNum><Prefix>Lu`, et al.`</Prefix><record><rec-number>2</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5fps95kxxe2pdsvt22" timestamp="1469624654">2</key></foreign-keys><ref-type name="Journal
Lethargy, Difficulty in concentrating, Mental fatigue, General fatigue, Unable to think clearly, Drowsy
Cognitive Functional headache that affect a person’s performance, but which fail to reveal evidence of physiological or structural abnormalities, Migraine headache, Tension headache, Sinus headache due to swelling of the mucus membranes, Mental confusion

General Nausea, Dizziness, Unspecified hypersensitivity reactions, deteriorating the pre-existing illnesses i.e., asthma, sinusitis or eczema.

2.2.2 Psychological well-being and satisfaction
Sick buildings can induce the appearance of psychological symptoms such as stress, anxiety and aggression in occupants.
These psychological disorders may further result in increasing people’s susceptibilities toward other environmental factors, lowering workers’ performances and increase absenteeism. 

Productivity and Absenteeism 

2.3 Productivity and Associated Costs
The negative effects of sick buildings can be also regarded in terms of costs imposing upon occupants. These expenses may appear in various forms, namely absence from work, lower productivity, remedial expenses, or increasing the building energy consumption. Fisk, et al. found that natural ventilation or mixed-mode conditioning could achieve 0.8 - 1.3% savings on health costs, 3 - 18% productivity gains, and 47 - 79% in HVAC energy savings. (Fisk, et al., 2011; Fisk, et al., 2012). Bekö, G., Clausen, G., & Weschler, C. J. in another study, suggested that financial benefits resulting from improved occupant health and productivity from more efficient air filter upgrades, may exceed the incremental costs of the new filters by a factor of twenty. In fact, the cost of SBS was point out earlier by WHO in their influential 1986 report. WHO Regional Office for Europe, Copenhagen (1986).
added, ‘The added cost to society of the increased sensory irritation, the increased discomfort and the fear of more serious, persistent health effects among the occupants is likely to exceed any of the gains that can be made on the margins of energy savings’.

Lowering the productivity rates of occupants’ performances is a crucial adverse effect of SBS. This is particularly relevant to those occupants who are continuously exposed to sick environments (i.e. employees or pupils) [ADDIN EN.CITE { ADDIN EN.CITE.DATA }]. The predominant exposure of SBSs can potentially compel the occupants to have lower performance compared to their usual productivity [ADDIN EN.CITE { ADDIN EN.CITE.DATA }] and schools [ADDIN EN.CITE { ADDIN EN.CITE.DATA }].

Sick buildings can affect occupants’ performances through different ways. Decreasing the quality of indoor environments is one of the key issues contributing to discomfort conditions of occupants. In a study, [ADDIN EN.CITE ExcludeAuth="1"><Author> Singh </Author><Year>2010</Year><RecNum>60</RecNum><Prefix>Singh`, et al.</Prefix><DisplayText>(Singh, et al., 2010)</DisplayText><record><rec-number>60</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfp95kxxe2pdszvt22" dbid="17"><foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><author> Singh, A., Syal, M., Grady, S. C., \&amp; Korkmaz, S.</author><authors></author></contributors><titles><title>Effects of green buildings on employee health and productivity</title><secondary-title>American journal of public health</secondary-title><full-title>American journal of public health</full-title><periodical><full-title>International Journal of Occupational Hygiene</full-title><pages>376</pages><volume>6</volume><number>4</number><dates><year>2015</year></dates><urls></urls></periodical></titles></record></ExcludeAuth> investigated the effects of improved IEQ on perceived health and productivity in occupants in office buildings. The results demonstrated that improved IEQ contributed to the reductions of absenteeism and work hours affected by asthma, respiratory allergies, depression, and stress and to self-reported improvements in productivity. They also mentioned that green buildings may positively be considered as an effective strategy for enhancing the public health. In this line, Baird et al (2012) compared the performance of sustainable buildings versus conventional buildings from users’ viewpoint. Their analysis concluded that sustainable buildings not only provide generally higher level of operation but as well, they result in an increased level of users’ satisfaction.

In another study, [ADDIN EN.CITE ExcludeAuth="1"><Author>Ahmadi</Author><Year>2015</Year><RecNum>61</RecNum><Prefix>Ahmadi`, et al.</Prefix><DisplayText>(Ahmadi, et al., 2015)</DisplayText><record><rec-number>61</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfp95kxxe2pdszvt22" dbid="17"><foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><author>Ahmadi, M., Golbabaei, F., Behzadi, M.</author><authors></author></contributors><titles><title>The effect of sick building syndrome (SBS) on the productivity of administrative staff</title><secondary-title>International Journal of Occupational Hygiene</secondary-title><full-title>International Journal of Occupational Hygiene</full-title><periodical><full-title>International Journal of Occupational Hygiene</full-title><pages>210-219</pages><volume>6</volume><number>4</number><dates><year>2015</year></dates><urls></urls></periodical></titles></record></ExcludeAuth> investigated the effect of SBS on the productivity of 105 staff working in an office building through distribution of questionnaire survey. The findings showed that the mental SBS symptoms such as irritability, depression, mental fatigue can have a negative impact on productivity. Similarly, findings of [ADDIN EN.CITE ExcludeAuth="1"><Author>Singh</Author><Year>2010</Year><RecNum>62</RecNum><Prefix>Singh`, et al.</Prefix><DisplayText>(Singh, et al., 2010)</DisplayText><record><rec-number>62</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfp95kxxe2pdszvt22" dbid="17"><foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><author>Singh`, et al.</author><authors></author></contributors><titles><title>Indoor Air</title><secondary-title>International Journal of Occupational Hygiene</secondary-title><full-title>International Journal of Occupational Hygiene</full-title><periodical><full-title>Indoor Air</full-title><pages>376-390</pages><volume>21</volume><number>5</number><dates><year>2011</year></dates><urls></urls></periodical></titles></record></ExcludeAuth> ’s investigation confirmed the negative effects of SBS symptoms on people’s productivity rates. They studied the impacts of thermal discomfort on health and occupants’ performance in an office to elucidate the physiological mechanisms involved. The results revealed that productivity of performing tasks decreased once residents detected signs of SBS (high temperature). Also, Wargorcki et al (2006) argued that staff performance in

"
office environments is highly correlated with indoor temperature levels. On the other hand, Karakolis and Callaghan (2014) examined the recent studies focusing on the influence of sit-stand office workstations. Among the existing 14 studies, they identified that six of these studies show lower level of discomfort upon use of sit-stand office workstations while eight studies presented an increase in staff productivity. Also, Etemadinezhad, et al. (2017) explored the existence of SBS and its impacts on bank staff in Iran and their findings indicated that the satisfaction level of staff is significantly correlated with the prevalence of SBS.

Apart from the IAQ and thermal concerns, improper properties of buildings envelope, such as wall can be also counted as a factor causing discomfort for occupants. (USDAW, 2006). The existence of such conditions led to the difference in productivity levels among employees, as people felt more comfortable to be working in the individual and shared room offices. Combi offices and flex offices, on the other hand, provide the expected office productivity benefits due to the increased autonomy and flexibility for employees. In another study, (De Been & Beijer, 2014) reported the results of a questionnaire survey conducted to investigate the impacts of sound on office productivity and assessing the relationship between changes in office productivity and noise sources. They also studied the effects of five environmental and office design factors, namely temperature, air quality, office layout, sound and lighting on people’s productivities. The outcomes yielded that among the factors examined, sound and temperature were the principal factors affecting office productivity. In another study, (Mak & Lui, 2011) examined the recent studies focusing on the influence of sit-stand office workstations.

Shan, et al (2016) explored the existence of SBS and its impacts on bank staff in Iran and their findings indicated that the satisfaction level of staff is significantly correlated with the prevalence of SBS. Also, (De Been & Beijer, 2014) reported the results of a questionnaire survey conducted to investigate the impacts of sound on office productivity and assessing the relationship between changes in office productivity and noise sources. They also studied the effects of five environmental and office design factors, namely temperature, air quality, office layout, sound and lighting on people’s productivities. The outcomes yielded that among the factors examined, sound and temperature were the principal factors affecting office productivity. In another study, (Mak & Lui, 2011) examined the recent studies focusing on the influence of sit-stand office workstations. Among the existing 14 studies, they identified that six of these studies show lower level of discomfort upon use of sit-stand office workstations while eight studies presented an increase in staff productivity. Also, (Etemadinezhad, et al. 2017) explored the existence of SBS and its impacts on bank staff in Iran and their findings indicated that the satisfaction level of staff is significantly correlated with the prevalence of SBS.

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Additionally, (Shan & Yang, 2016) found that the presence of SBS results from high CO2 concentration and low RH level in indoor space with high temperature. They also studying the effects of utilizing mixing and displacement ventilation on human subjects' thermal comfort, SBS, and short-term performance. The experimental results indicated that higher CO2 concentration contributed to causing SBS related to head, while both higher CO2 concentration and lower relative humidity (RH) associated to SBS related to eyes. Consequently, they concluded that SBS resulted from high CO2 concentration and low RH could lead to the increase in short-term performance. Furthermore, according to a study in the UK, over 80% of office staff express being in an indoor space with high temperature does now allow them to easily concentrate; approximately 60% believe in such hot indoor environment, they need 25% more time to complete their given tasks and lastly, 78% think their office environment partially kills their creativity for completing their job (UDSAW, 2006).
In summary, SBS can negatively affect occupants’ performances and productivity due to a number of factors, which can be conclusively summarized as the unsatisfactory IAQ; the existence of unacceptable level of humidity, CO₂, and temperature in indoor environment; building layout; sound and lighting status. However, the list of factors leading to undermining the occupants’ productivity can be further expanded to include more determinants such as psychological or social parameters. Figure 1 provides a comprehensive summary of the factors that contributes to SBS and their negative effects on occupants as per the reviewed studies.

**Figure 1.** An overview of SBS contributors and their negative impact on occupants

### 3. Review of studies mitigating SBS

This section reviews recent studies conducted with the aim of addressing issues germane to SBS. The outcome of this section helps developing practical guidelines through discussing the recent strategies examined in the literature.

In order to address the issues related to SBS, improvement of ventilation systems has been a key strategy. Shan et al. (2016) suggested that proper design of ventilation system, besides efficient room layout including thoughtful arrangement of seating can be helpful to defuse the symptoms of SBS in tutorial rooms. These proposed strategies could be...
promising in facilitating the air circulation throughout the building layout and result in enhancement of IAQ. These measures can be further coupled by application of frequent cleaning and improvement of indoor hygiene status, as recommended by ... by 2.2°C at ambient temperature of 35.7 °C. Additionally, simulation results indicated a superior saving due to the application of EREEC. The inlet temperature was reduced by 2.2°C at ambient temperature of 24.4 °C and by 7.5°C at highest ambient temperature of 35.7 °C. Additionally, simulation results showed that the base cooling load can be reduced up to 13.38%. Moreover, the payback period of EREEC from annual energy saving occurred is around 8 years. More background on employment of active ventilation systems for increasing the IAQ may associate with the increase of building energy usage. This can further trigger the emergence of new concerns, namely environmental issues. As such, there is a demand from professional engineers for application of an optimized ventilation system which can maintain the internal air temperature at a comfortable range, while meeting the concerns toward energy consumption and environmental issues.

Investigation of energy recovery with exhaust air evaporative cooling in ventilation system

proposed a model of Energy Recovery with Exhaust air Evaporative Cooling (EREEC) in ventilation to theoretically and experimentally test the thermal performance in Mediterranean climate. The experimental results indicated a superior saving due to the application of EREEC. The inlet temperature was reduced by 2.2°C at ambient temperature of 24.4 °C and by 7.5°C at highest ambient temperature of 35.7 °C. Additionally, simulation results showed that the base cooling load can be reduced up to 13.38%. Moreover, the payback period of EREEC from annual energy saving occurred is around 8 years.
...replacement of the air filters and cleaning all screens of the outdoor air intakes of the building. They suggested a number of measures to eliminate the symptoms and improve the poor IAQ, including: i) restriction of smoking in indoor spaces, ii) opening the building’s windows and doors to supplement the room ventilation, iii) cleaning and regulating inlet and outlet openings (diffusers) of the HVAC systems inside the building, iv) cleaning the plenum, floor, carpet and all equipment and furniture, v) opening the building’s windows and doors to supplement the room ventilation, vi) cleaning the outdoor areas around the building, which are close to the air intakes of the HVAC systems. Notwithstanding the promising results achieved to improve the occupants’ well-being, these conducted studies paid no or considerably limited attention to the energy performance of buildings. Building sector has already performed a considerable role in consuming a large portion of global energy. Application of passive wall systems for improving the energy efficiency in buildings: A comprehensive review.

From another side, Ghashghai et al. (2017) examined the impacts of cool colours in indoor environments on the sensation of elderslies in high-rise condominiums in Malaysia. They realized that cool colours can significantly alter the levels of blood pressure, heart beat rate and skin temperature. Their analysis concluded that use of particular cool colours can result in relaxation feeling. Moving on, from a psychological point of view, a visual and/or physical access to nature is likely to improve people’s wellbeing in buildings. While this notion has been around since at least 1976 (Ludlow, 1976), it is recently known as Biophilic design (Cramer and Browning, 2008). ADDIN EN.CITE <EndNote><Cite><Author>Kellert</Author> <Year>2012</Year> <RecNum>209</RecNum> <Prefix>Kellert</Prefix> <DisplayText>Kellert, (2012)</DisplayText> <foreign-keys>key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1509186483">209</key> <foreign-keys>ref-type name="Journal Article">17</ref-type> <contributors><authors><author>Kellert, R</author></authors></contributors><titles><title>Birthright: People and Nature in the Modern World</title><secondary-title>Yale University Press</secondary-title><full-title>Yale University Press</full-title></titles><periodical><full-title>Yale University Press</full-title><volume>In Press</volume><dates><year>2012</year></dates><urls></urls></periodical></Cite></EndNote> The term Biophilia might be first used in this context by the socio-biologist Edward Wilson to describe his connection to nature (Wilson, 1984). It was later assumed that humankind’s connection to nature is innate and hence our physiological responses to experiencing being in nature is genetically programed (Kellert and Wilson, 1993). This hypothesis has been widely tested at different levels and in different contexts. Evidences that support the positive impact of nature on people’s physiological wellbeing are not scarce (HYPERLINK \"_ENREF_76\" ^ "Kellert, (2012) #209") and scientifically tested (Ryan et. al., 2014). Examples include improved mental health (Ulrich, 1979; Tyrväinen et al., 2014), reduced stress (Berman et al., 2008; Matsunaga et al., 2011), increased well-being (Ulrich et al., 1991; Ikei et al., 2014), attention restoration (Kaplan, 1995; Raanaas et al. 2011) and faster healing rates (Ulrich, 1984; Park and Mattson, 2008). Providing a window with a view to a pleasing nature scene or indoor planning allows...
the eye to adjust and re-focus, which reduces fatigue, headaches resulting in better health, less frustration, and better overall performance in work places. 

On the other hand, Largo Wight et al. (2011) presented that in working environments, there is a significant negative correlation between nature contact and productivity. In a study, they found that the presence of real trees and plants, or roof gardens makes sense. In fact, research has shown a reasonable awareness of the importance of providing view to nature in hospital among designers. For example, a recent substantial report found that providing patients with views of nature could save the US healthcare authorities up to $93 million/year.


In the healthcare sector, a recent substantial report found that providing patients with views of nature could save the US healthcare authorities up to $93 million/year. Nevertheless, viewing nature can be provided if aiming atriums, courtyards, communal sky gardens with real trees and plants, or roof gardens. 


Arlington, Va.: Timber Press.</primary_language
and stress as well as nature contact and health-related complaints. More recently, another study indicated that in office spaces that are exposed to natural daylight and vegetation, staff are 15% more creative and 6% more productive (Human spaces report, 2015).

Biophilic design is not limited to providing visual/physical access to nature. Söderlund and Newman (2017) categorized the key elements of biophilic design into three categories based on the works of Cramer and Browning (2008) and Ryan, et al (2014).

1) ‘Nature in the space’; incorporating plants, water, animals and movement into the built environment.
2) ‘Natural analogues’; suggesting patterns/materials that evoke the nature.
3) ‘Nature of the space’; referring to different spatial configurations and associated physiological/psychological responses they engender such as prospect, refuge, mystery and risk/peril.

These studies (Cramer and Browning, 2008; Ryan et. al. 2014) support the proposition that biophilic design is likely to mitigate the effect of SBS, improve the overall wellbeing of the occupants, and contribute positively to their satisfactions, productivity and performances.

In conclusion, a number of strategies and methodologies are put forward and suggested in the relative literature in order to tackle the issues concerned with SBS. Table 5 provides a comprehensive summary of these strategies, whereas Figure 2 separates these strategies according to their effectiveness and ease of implementation in existing buildings as assessed in literature.

<table>
<thead>
<tr>
<th>Table 5. Strategies to tackle the SBS</th>
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<td>Author(s)</td>
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<td>Shan, et al., 2016</td>
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</tbody>
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Proper design of ventilation system and careful arrangement of room layout
Improvement of cleaning in schools

Schools

Imbalance of ventilation system, and frequent cleaning

Office environment, University
Amin, et al. (2015) used a functioning control system to control the indoor air temperature.
Reduction of mold/dampness, control air pollution emissions from home renovations, and enhancement of building ventilation

Regulation of indoor temperature, Sun shield, use of sufficient ventilation system

Classroom
Sick building syndrome in relation to air exchange rate, CO2, room temperature and relative air humidity in university computer classrooms: an experimental study

International archives of occupational and environmental health

Zhang `et al`. (Zhang, et al., 2011)

A longitudinal study of sick building syndrome among pupils in relation to microbial components in dust in schools in China

Frequent cleaning and improving hygiene

School
environment</secondary-title></titles><periodical><full-title>Science of The Total Environment</full-title></periodical><pages>5253-5259</pages><volume>409</volume><number>24</number><dates><year>2011</year></dates><urls></urls></record></Cite></EndNote>} { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"><Author>MacNaughton</Author><Year>2016</Year><RecNum>65</RecNum><Prefix>MacNaughton`, et al.`,</Prefix><DisplayText>(MacNaughton, et al., 2016)</DisplayText><record><rec-number>65</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5ppps95kxe2pdszvt22" timestamp="1474694918">65</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>MacNaughton, P., Spengler, J., Vallarino, J., Santanam, S., Satish, U., & Allen, J</author></authors></contributors><titles><title>Environmental perceptions and health before and after relocation to a green building</title><secondary-title>Building and Environment</secondary-title></titles><periodical><full-title>Building and Environment</full-title></periodical><pages>138-144</pages><volume>104</volume><dates><year>2016</year></dates><urls></urls></record></Cite></EndNote> { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"><Author>MacNaughton</Author><Year>2017</Year><RecNum>170</RecNum><Prefix>MacNaughton`, et al.`,</Prefix><DisplayText>(MacNaughton, et al., 2017)</DisplayText><record><rec-number>170</rec-number><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5ppps95kxe2pdszvt22" timestamp="1474694918">170</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>MacNaughton, P., Spengler, J., Vallarino, J., Santanam, S., Satish, U., & Allen, J</author></authors></contributors><titles><title>Population-based study of in-home air quality before and after relocation to a green building</title><secondary-title>Building and Environment</secondary-title></titles><periodical><full-title>Building and Environment</full-title></periodical><pages>138-144</pages><volume>104</volume><dates><year>2017</year></dates><urls></urls></record></Cite></EndNote>
hton, et al., 2017; Singh, et al., 2010)</DisplayText><record><recordnumber>170</recordnumber><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfs95kxe2pdszvt22" timestamp="1490627434"/>170</key><foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>MacNaughton, P., Satish, U., Laurent, J. G. C., Flanigan, S., Vallarino, J., Coull, B., ... & Allen, J. G</author></authors></contributors><titles><title>The impact of working in a green certified building on cognitive function and health</title><secondary-title>Building and Environment</secondary-title></titles><periodical><full-title>Building and Environment</full-title></periodical><pages>178-186</pages><volume>114</volume><years>2017</years></record></Cite><Cite ExcludeAuth="1"><Author>Singh</Author><Year>2010</Year><RecNum>60</RecNum><Prefix>Sin</Prefix><Prefix>gh`, et al.`</Prefix><record><recordnumber>60</recordnumber><foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfs95kxe2pdszvt22" timestamp="1474320042"/>60</key><foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Singh, A., Syal, M., Grady, S. C., & Korkmaz, S</author></authors></contributors><titles><title>Effects of green buildings on employee health and productivity</title><secondary-title>American journal of public health</secondary-title></titles><periodical><full-title>American journal of public health</full-title></periodical></record></Cite>
American journal of public health


Thatcher & Milner, 2016.
Is a green building really better for building occupants? A longitudinal evaluation.

Biophilic design (view/access to nature); indoor plants; nature patterns, colors, and materials; spatial configurations that are provided by nature.

Prison building, Elderly house, Office building
Accordingly, the most prevalent measure claimed to address the SBS symptoms is associated with application of proper ventilation systems in buildings. These reviewed strategies can be generally classified into two major groups; first group refers to those measures that do not require major considerations such as physical modification in buildings structure in order to rectify the SBS symptoms such as frequent cleaning procedures or maintaining the hygiene in buildings. Second group refers to those measures that require considering the physical alterations such as usage of greeneries in building or improvement of mechanical ventilation systems. Apart from these measures, it is believed that SBS can be categorized as a pollution-related illness. Therefore, national governments must also attempt to solve these problems by making building regulations that prevent the use of toxic materials in living environments and/or providing financial support for SBS patients to take radical measures to solve their problems. Yet, there is a dearth of attempts performed to address the SBS related issues with consideration of all potential strategies altogether.
Based on the review of recent studies (Abdul-Wahab, 2011; Vural and Balanlı, 2011; Clements-Croome, 2018), it can be deduced that in order to effectively tackle SBS and achieve a healthy indoor environment, the following key attributes should be taken into account:

- **Fresh and clean air and proper (natural) ventilation while maintaining indoor air quality (i.e. cross ventilation provides the most ventilation)**
- **Thermally comfortable environment (i.e. acceptable level of temperature, humidity, PMV)**
- **Adequate acoustic level and minimized level of external noise**
- **Acceptable level of CO₂ and minimized level of indoor pollutants (i.e. NO₂)**
- **Control moisture levels (i.e. too much moisture can increase growth of bacteria, and mould)**
- **Sufficient daylight and no glare (i.e. window sizes should be carefully considered and be fit for purpose)**
- **Solar gain control (i.e. Too much glass can lead to internal overheating).**
- **Acceptable material usage with no issues of toxicity, microbe, dampness, mold, and similar challenges**
- **External views, and determines the window height required for views**
- **Appropriate landscape allocation and possibly nature contact**
- **Proper colour use relevant to the function of spaces**
- **Proper segregation of spaces for sense of privacy once required**
- **Efficient plan layout and furniture arrangement to promote flexibility and collaboration**
- **Ergonomic indoor layout**
- **Adequate use of digital technology once required**
4. Future Directions of Buildings from SBS Perspective

Well-being, embracing health and comfort, is a critical parameter for determining the quality of life of an occupant. In late 1980s and during the 1990s, WHO concept of health, became significant for identifying the concept of a ‘healthy building’ in terms of building performances (i.e., IAQ, thermal comfort, lighting quality and acoustics) { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"> <Author>Bluyssen</Author>/ <Year>2010</Year>/ <RecNum>66</RecNum>/ <Prefix>Bluyssen</Prefix>, <DisplayText>(Bluyssen, 2010)/ </DisplayText> <record> <rec-number>66</rec-number>/ <foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1474724844"/> </foreign-keys><ref-type name="Journal Article">17</ref-type>/ <contributors><authors><author>Bluyssen, P.M</author></authors></contributors>/ </title> </periodical>/ </full-title>/ </periodical>/ </volume>/ <number>3/4</number>/ <dates><year>2010</year></dates>/ </urls>/ </record>/ </Cite></EndNote> ]. A healthy building is defined as ‘built environment that encourages positive well-being of human beings’ { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"> <Author>Mohtashami</Author>/ <Year>2016</Year>/ <RecNum>69</RecNum>/ <Prefix>Mohtashami</Prefix>, et al., </Prefix><DisplayText>(Ho, et al., 2004; Mohtashami, et al., 2016)/ </DisplayText> <record> <rec-number>69</rec-number>/ <foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1474802070"/> </foreign-keys><ref-type name="Journal Article">17</ref-type>/ <contributors><authors><author>Mohtashami, N., Mahdavinejad, M., &amp; Bemanian, M</author></authors></contributors>/ </title> </periodical>/ </full-title>/ </periodical>/ </volume>/ <number>3</number>/ <dates><year>2016</year></dates>/ </urls>/ </record>/ </Cite></EndNote> Moreover, a broader definition is proposed by { ADDIN EN.CITE <EndNote><Cite ExcludeAuth="1"> <Author>Ho</Author>/ <Year>2004</Year>/ <RecNum>70</RecNum>/ <Prefix>Ho` et al.`/ </Prefix><DisplayText>(Ho, et al., 2004; Mohtashami, et al., 2016)/ </DisplayText> <record> <rec-number>70</rec-number>/ <foreign-keys><key app="EN" db-id="z2wa9ws2tvf000ex5pfps95kxxe2pdszvt22" timestamp="1474802994"/> </foreign-keys><ref-type name="Journal Article">17</ref-type>/ <contributors><authors><author>Ho, D. C., Leung, H. F., Wong, S. K., Cheung, A. K. C., Lau, S. S. Y., Wong, W. S., ... &amp; Chau, K. W</author></authors></contributors>/ </title> </periodical>/ </full-title>/ </periodical>/ </volume>/ <number>3/4</number>/ <dates><year>2004</year></dates>/ </urls>/ </record>/ </Cite></EndNote>], in which the health of its occupants nor the larger environment’. From a generic outlook, a healthy building is free of hazardous materials (e.g. lead and asbestos) and capable of fostering health and comfort of the occupants during its entire building life cycle, while supporting social needs and enhancing productivity. While Levin aspiration calls for ‘treads lightly on the earth’, this brings in other dimensions— such as the total amounts of materials used in the construction and operation of a building and the environmental impact of the mining/production/transportation to site and subsequent disposal of waste. In short, this would require lifecycle analysis of the wider environmental impact of buildings. This reveals the ‘health’ and ‘well-being’ approaches as being flawed because they are entirely species-centric and lacking regard for other flora and fauna.
This study critically argues that there is a gradual shift from the current predominant focus on ‘sustainable and intelligent design’ to ‘healthy design’ as a fundamental basis of future buildings. This healthy design vision should not only be observed at building-scale level as its urban and city-scale image allows effectively contributing to the eventual goals of smart and intelligent cities.

Do current standards go far enough? A healthy building recognizes the human health needs, and responds to the occupants’ comfort requirement as the top priority. But beside these tangible benefits, there is a need to consistently draw attention to its potentials for intangible output ranging from stress reduction to mental calmness and happiness. Likewise, a healthy building should be ready and capable to respond to future needs, adaptable to ‘new drivers’ such as climate change, and responsive to the changes towards a multifunctional and diverse society, the increasing individualization and the ever-changing needs and preferences of occupants (See Figure 3).

Figure 3. The role of SBS: Evolution of building design and development from sustainable, intelligent and healthy design perspectives

In principle, healthy buildings should be developed based on successful fulfillment of various technical requirements such as being in line with proper design and construction principles of buildings and their satisfactory performance with view to providing sufficient IAQ, visual comfort, daylight and natural ventilation without compromising the occupants’ health and satisfaction. Rees (1999) would argue that this focus solely on occupants (building end users) – and not on ‘distant elsewhere’ is a continual failing of the design and construction industries which ‘draw on resources and dump their garbage all over the world’. This ecological reality underscores the urgency of ‘healthier factors’ in the building industry.

Overall, the result of reviewed studies reveals the significant impact of buildings’ health-related parameters not only on occupants but in many different ways, take into account the health and well-being of those involved in producing the materials or constructing buildings or servicing their operation. This can be deemed as a convincing reason to justify more rigorous consideration of both objective and subjective healthy principles during the design, construction and operational phases of buildings towards tackling SBS (See Figures 4). The following paragraphs discuss the major principles to be taken into account towards future healthy buildings.
5. Conclusions
The exposure of occupants to unhealthy indoor environments can potentially trigger the emergence of SBS symptoms. This paper attempted to advocate the crucial role of healthy buildings, based on their significant impacts on occupants’ health and well-being, through exploring the negative effects of sick buildings. The review critically showed that sick buildings are likely to endanger the occupants’ health status while negatively affecting the level of productivity. On the contrary, the concept of healthy building has been discussed through highlighting its major promising principles including the maintenance of IAQ and thermal control, maximizing the use of daylight, providing a workplace in compliance with the occupants’ ergonomics and creating opportunities for occupants to access nature. Additionally, this study redefines the concept of healthy building through including the importance of energy management in its scope, besides its capability to procure flourishing environments and assuring the occupants’ health (Clements-Croome 2018).

This study has identified physical, biological, chemical, psychosocial and individual parameters as the major contributors to SBS. These factors facilitate the emergence of SBS symptoms, in which they result in bringing several negative effects for occupants. The analysis categorized these effects into four major groups. The first one is the symptomatology that refers to nasal, ocular, oropharyngeal, cutaneous and general manifestations. The second one is the psychological effect of SBS such as stress and anxiety; as well as the impact of SBS on occupants’ satisfaction. The third effect refers to the costs associated with occurrence of SBS such as the absence from work, lower productivity, remedial expenses, or increasing the building energy consumption. The fourth effect refers to compromising the productivity of occupants in sick buildings. Although the reviewed points cover majority of

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**Figure 4.** Flourish Model for healthy buildings, source: Clements-Croome 2018

- **Qualitative**
  - Greenery/Nature
  - Views
  - Decor/Aesthetics
  - Colour
  - Character
  - Layout/Functionality
  - Space

- **Perceptual**
  - Perceived Health and Well-being
  - Happiness and Satisfaction
  - Security
  - Empowerment
  - Achievement
  - Relationships
  - Community

- **Physical**
  - Daylight
  - Air Quality
  - Noise
  - Dampness
  - Pollution
  - Temperature
  - Neighbourhood Design

- **Quantitative**
  - Economic
    - Decreased Public Health Costs
    - (illness, injuries, therapies)
  - Developers
    - Increased Asset Value/Sale Price
  - Landlords
    - Higher Rental Rates
    - Better Occupancy Rates/Tenant Longevity
  - Occupants
    - Productivity
    - Performance
    - Prosperity
    - Social Capital

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negative effects attributed to the SBS, but these effects can go beyond that, namely social effects of SBS. Therefore, future studies will be required to address new aspects of SBS.

Reviewing recent studies has revealed that the physical features of buildings can be influential in appearing SBS symptoms. The adverse effects of physical contributors on occupants’ health during the operational phase of building can be initially neutralized through practicing a careful architecture during the building’s design phase. It can be stated that the accurate consideration of building’s orientation, felicitous selection of building materials in accordance with local climate, application of passive techniques in building envelope such as passive walls can be efficacious in avoidance of occurring the physical contributors. These design principles may potentially facilitate the air circulation throughout the building, manage recipient of a sufficient amount of solar radiations and providing a required measure of illuminance for occupants. The control of physical contributors can be further promising in minimization of biological and psychosocial contributors.

It should be stressed that healthy buildings are beyond SBS and embrace many other interrelated aspects such as stress, physical mental, musculoskeletal impacts, social well-being and others health-related attributes (Clements-Croome, 2018). Indeed, healthy building is a better conceptualization than what we have today but requires consistent in-depth exploration to unleash new potentials. This study identifies a number of strategies to improve the issues concerned with SBS namely; proper design of ventilation systems, careful arrangement of room layouts, sanitizing frequency, reduction of mold/dampness, installation of external devices on openings such as sun shades, development of green buildings and providing visual/physical access to nature. Despite the stand-alone influences of the abovementioned factors, further investigations to address their interrelated effects are essential. Lastly, from the professional practice perspective, while the main focus of this research was on the identification of SBS indicators and their impacts, highlighting the current needs to pave the way for healthier buildings, it is vital to continue this debate regarding the role of professionals and professionalism in this context. Without a doubt, more in-depth explorations should be carried out to dictate the role of architects, engineers, and building technology experts towards creating healthier indoor environments.

Building for health and wellbeing is presented in this paper as a moving target where there is neither a ‘state to be reached’ nor a ‘one-size-fits-all’ solution. This implies creating a secure sense of long term vitality, with sustainable thinking influencing all aspects of development, from the built form to financial, technological, economic and social policies and delivery mechanism. Healthy/ well-being approach does not happen as an outcome in a ‘predetermined way’. It requires to be carefully discussed, openly debated and even centrally planned. The concept will need to be translated into real and tangible design solutions if the built environments are to avoid serious problems and costs in the future (Trained, 2011). This may move the design for health and well-being debate away from ‘best practice’ and towards ‘next practice’, focusing on innovation in the design of housing, workplaces, schools, public spaces and transport (Trained, 2011).

Meeting the objectives and apprehensions described above confront professional bodies and individuals with a major challenge on how to become more responsible for healthier places. Unlike the deterministic conventional physical-led approach to green/sustainable building design, many contemporary thinkers emphasize the inter-relationship between people’s lives and their environment and advocate taking a more strategic and holistic approach. Therefore, any search concerning healthier places must consider the built environment as a complex system. Thus, multi-level, multi-sectorial policymaking challenges along this way must be coordinately addressed to materialize desired healthier outcomes. Realizing this goal may require investigations on a ‘new professionalism’ which must span all across the built environment, planning, engineering and design professions based on their interconnectivity and collective responsibilities, including fully appraising desired healthier outcomes (Cooper, 2009; Hill and Lorenz, 2011). Indeed, such approach is a necessity if our health, wellbeing and quality of life are to be enhanced, and thus GHG emissions to be seriously mitigated. Roberts (2009) argued that placing emphasis on applying (subject-specific) specialist skills can result in the full or partial exclusion of wider generic competences (Roberts 2009): over dependence on discipline skills may be redressed by expanding professionals’ knowledge and skills toward the social and cognitive competences required for sharing experience and insights. Achieving this would require paying detailed attention to understanding the patterns of relationships between the wish-list of desires voiced by academics in this paper in order to provide clues for understanding how effective outcomes emerge. Successful building design process would thus require explicitly managing for integration and harmonisation across disciplines and phases, as well as between and among team members and local stakeholders from a wide range of disciplines and constituencies - including the interface of
private and public exchange. This would be needed to ensure the effective capture and integration of both explicit/professional and tacit/lay forms of knowledge into more deliberative forms of practice (Cooper, 2009).

To sum up, the following research-based future actions are recommended for further exploring the SBS impacts, enhancing the capacity of healthy buildings and contributing to the overall well-being and health status of inhabitants:

- To present a more holistic and inclusive definition of healthy buildings with no limit to SBS but moving beyond the current boundaries
- To expand the technical studies on the evaluation of buildings from health perspective (soft and hard issues) to demonstrate the most crucial obstacles and future direction
- To move beyond sustainable buildings and interconnect the sustainable design principles to healthy design attributes
- To similarly explore the weaknesses, challenges and drawbacks of healthy design rather than predominantly concentrating on its benefits
- To clarify the role of industry professionals for promoting healthy buildings during the implementation and application phases based on an explicit understanding of SBS impacts and other health-related parameters
- To increase the public awareness regarding the impacts of buildings on health and well-being
- To develop incentivized programs and policies to encourage the professionals as well as building owners to move towards the proliferation of healthy buildings
- To strike an urban-scale vision towards the possible impacts and potentials of SBS versus healthy buildings at city level

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