5-15-2019

Ten Questions Concerning the Built Environment and Mental Health

Andrew J. Hoisington
Air Force Institute of Technology

Kelly A. Stearns-Yoder

Steven J. Schuldt
Air Force Institute of Technology

Cody J. Beemer

Kerry A. Kinney

See next page for additional authors

Recommended Citation

Hoisington, A. J., Stearns-Yoder, K. A., Schuldt, S. J., Beemer, C. J., Maestre, J. P., Kinney, K. A., … Brenner, L. A. (2019). Ten questions concerning the built environment and mental health. Building and Environment, 155(15 May), 58–69. https://doi.org/10.1016/j.buildenv.2019.03.036

Authors

Andrew J. Hoisington, Kelly A. Stearns-Yoder, Steven J. Schuldt, Cody J. Beemer, Kerry A. Kinney, Teodor T. Postolache, Christopher A. Lowry, and Lisa A. Brenner

Building and Environment 155 (2019) 58–69

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Ten questions concerning the built environment and mental health

Andrew J. Hoisington[a,b,c,*], Kelly A. Stearns-Yoder[b,c,d,e], Steven J. Schuldt[a], Cody J. Beemer[a], Juan P. Maestre[f], Kerry A. Kinney[f], Teodor T. Postolache[b,c,g,h], Christopher A. Lowry[b,c,e,i,j], Lisa A. Brenner[b,c,d,e,k]

[a] Department of Systems Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, OH 45433, USA
[b] Military and Veteran Microbiome: Consortium for Research and Education (MVM-CoRE), Aurora, CO 80045, USA
[c] Veterans Health Administration Rocky Mountain Mental Illness Research Education and Clinical Center (MIRECC), Denver Veterans Affairs Medical Center (VAMC), Aurora, CO, 80045 USA
[d] Marcus Institute for Brain Health, University of Colorado Anschutz Medical Campus, Aurora, CO 80045, USA
[e] Departments of Physical Medicine & Rehabilitation, Psychiatry, & Neurology, University of Colorado Anschutz Medical Campus, Aurora, CO 80045, USA
[f] Department of Civil, Environmental and Architectural Engineering, University of Texas Austin, Austin, TX 78712, USA
[g] Mood and Anxiety Program, University of Maryland School of Medicine, Baltimore, MD 21201, USA
[h] VISN 5 MIRECC, Department of Veterans Affairs, Baltimore, MD, 21201, USA
[i] Department of Integrative Physiology, University of Colorado Boulder, Boulder, CO 80309, USA
[j] Center for Neuroscience, University of Colorado Boulder, Boulder, CO 80309, USA
[k] Department of Psychiatry and Neurology, University of Colorado Anschutz Medical Campus, Aurora, CO 80045, USA

ARTICLE INFO

Keywords:
Built environment
Indoor air quality
Mental health
Microbiome

ABSTRACT

Most people spend the majority of their lives indoors. Research over the last thirty years has focused on investigating the mechanisms through which specific elements of the built environment, such as indoor air quality, influence the physical health of occupants. However, similar effort has not been expended in regard to mental health, a significant public health concern. One in five Americans has been diagnosed with a mental health disorder in the past year, and, in the United States, the number of suicide deaths are similar to the number of deaths due to breast cancer. Increases in mental health disorders in Western societies may be due, in part, to increased systemic inflammation, secondary to decreased exposures to a diverse microbial environment (i.e., the hygiene hypothesis, "Old Friends" hypothesis, "missing microbes" hypothesis, or biodiversity hypothesis), as well as increased environmental exposures that lead to chronic low-grade inflammation. In this review, we provide an assessment that integrates historical research across disciplines. We offer ten questions that highlight the importance of current lessons learned regarding the built environment and mental health, including a potential role for the microbiome of the built environment to influence mental health. Suggested areas for future investigation are also highlighted.

1. Introduction

In most cases, the built environment is designed, maintained, and operated in a manner that is intended to provide a safe and productive milieu for the occupant, while minimizing costs. While some elements of the built environment may include components that are beneficial to the occupant's physical and cognitive functioning, rarely is the built environment intentionally designed or operated with the goal of improving mental health. There are multiple reasons why this might be the case. The first is the lack of general understanding of how the built environment influences mental health. At present, causative research that ties elements of the built environment to mental health outcomes is lacking. A summary of research in the field, as described in the responses to the questions herein, has mostly been conducted by social scientists. Interdisciplinary collaborations that include social scientists, health researchers, architects, building scientists, and engineers, are scarce. Secondly, some effects of the design and operation of the built environment on mental health are likely to be specific to the individual. For example, set point temperature for an entire facility might be a source of irritation for some individuals while being acceptable for others. Finally, without evidence-based research, it is not possible for policymakers to develop clear guidance and incentives to promote built environments that may benefit the mental health of occupants. Here, we present and answer ten questions on the relationship between the

* Corresponding author. Department of Systems Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, OH 45433, USA.
E-mail address: andrew.hoisington@us.af.mil (A.J. Hoisington).

https://doi.org/10.1016/j.buildenv.2019.03.036
Received 18 January 2019; Received in revised form 13 March 2019; Accepted 18 March 2019
Available online 23 March 2019

built environment and mental health. The purpose of this paper is to promote discussion, and to provide a foundation for fostering collaborations among social scientists, health researchers, architects, building scientists, and engineers.

2. Ten questions

2.1. What is mental health and how is it assessed?

According to the World Health Organization (WHO), "Mental health is defined as a state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community" [1]. As with all areas of functioning, mental well-being should be viewed within the context of genetic, epigenetic, developmental, and contemporaneous environmental (i.e., biopsychosocial) influences. Moreover, as noted above mental health should not be understood as the absence of a mental health disorder or the absence of emotions that can be associated with mental health disorders, such as unhappiness, sadness, and anger. Mental health includes components of emotional and social well-being [2,3]. Social skills and cognitive functioning are components of mental health that impact engagement in basic tasks and social roles [4,5].

In the United States (US), 43.8 million adults have mental health conditions —approximately 1 in 5 (2016) [6], with an estimated $193.2 billion per year in lost earnings [7]. Mental health issues are not isolated to the US. The WHO reported that the tenth leading cause of disability-adjusted life years (DALYs) in Europe (2016) was depressive disorders, with 681 DALYs per 100,000 people [8]. Even in the absence of formal mental health conditions, individuals struggle to attain and maintain their mental health.

For research purposes, the assessment of mental health conditions/symptoms optimally occurs in settings where those administering the tools are trained and supervised by a licensed health care professional. For example, during a clinical research visit, the Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders (DSM-5)-TR Axis I Disorders, Research Version, Patient Edition with Psychotic Screen (SCID-5-I/P W/PSY SCREEN) may be administered as reliable and valid means to acquire information regarding current and lifetime psychiatric disorders [9]. The SCID-5-I/P W/PSY SCREEN takes approximately 30 min to administer. Other reliable and valid tools to evaluate mental health conditions and/or symptoms (presence/severity) are available. See Table 1 for a list of validated self-report measures in use among those participating in the United States-Veteran Microbiome Project (US-VMP) [10]. Although far from inclusive for all mental health outcomes, the list provides a starting point for investigators interested in evaluating mental health conditions or symptoms.

2.2. Do design- and occupant-controlled parameters in the built environment influence mental health?

Design choices made by architects and engineers can affect both the physical and mental health of occupants. Most research to date has focused on physical health implications of poor design and construction, but these choices can also negatively impact mental health. On a positive note, design and occupant choices can have positive health impacts (i.e., selection of low-emitting interior materials, controlled reduction of noise levels, access to clean fresh air, appropriate lighting, installation of mechanical systems to maintain desired indoor temperatures and appropriate air exchange rates) [22–24]. Temperature and light are two examples of engineered and occupant-controlled parameters that affect physical and mental health.

Proper indoor temperatures are necessary to ensure thermal comfort, protect human health, and improve quality of life [25]. Unfortunately, there is no universal optimal measure of thermal comfort; rather, it varies from individual to individual and is influenced by: (1) environmental parameters, including air temperature, mean radiant temperature, air relative humidity, and air velocity; (2) personal factors, including human metabolic rates and clothing insulation; and (3) thermal adaptation of the individual occupant, which is correlated with factors such as geographic location, climate, time of year, gender, race, and age [26,27]. A large percentage of the low-income population lives below minimum acceptable temperatures, which would be expected to negatively impacts their physical and mental health [25]. Low indoor temperatures are associated with various conditions, including pneumonia, increased blood pressure, asthma, bronchitis, and migraine [25], and stress-related psychiatric disorders, such as depression and anxiety disorders [28], as well as mortality; resulting in 30,000 to 60,000 excess winter deaths annually in the United Kingdom alone [29]. Lower temperatures are also associated with a reduction in relative humidity, which can result in respiratory tract infections [30]. At the opposite extreme, working or living at uncomfortably warm temperatures and humidity levels can lead to moisture damage and fungal growth [31–34], which have been found to be associated with increased absenteeism, reduced worker productivity [35,36], and mortality

Table 1
Potential self-report measures relevant to mental health.

Measure	Description	Condition(s)/Factor(s) of Interest	Time to Administer (minutes)
Beck Depression Inventory (BDI-II)	Psychometrically-sound 21-item measure to assess depressive symptoms [11,12]	Depression-related symptoms	5
Insomnia Severity Index (ISI)	Reliable and valid 7-item instrument assessing the nature and severity of insomnia symptoms [13]	Insomnia symptoms	5
International Physical Activity Questionnaire (IPAQ) Short Form	Reliable and valid 7-item measure of physical activity [14]	Physical activity	5
36-Item Short Form Health Survey (SF-36)	36-item multi-purpose health survey that yields an 8-scale profile of functional health and well-being scores [15]	Perceived health (general, physical/mental health)	10
National Health Interview Survey (NHIS) – Chronic Conditions	Chronic conditions [16] are used to query chronic health conditions [17]	Chronic health conditions	5
Outcome Questionnaire-45 (OQ-45)	45-item questionnaire designed to measure distress associated with key areas of functioning (e.g., interpersonal functioning, social role) [18]	Psychological distress	10
Patient Health Questionnaire-9 (PHQ)-9	Frequently used and psychometrically-sound measure of depression [19,20]	Depression-related symptoms	5
PTSD Checklist for DSM-5 (PCL-5)	20-item self-report measure used to assess PTSD symptom severity, based on DSM-5 diagnostic criteria [9]	Posttraumatic symptoms	5
Seasonality Pattern Assessment Questionnaire (SPAQ)	Screening tool extensively used in studies of seasonality of mood and behavior, and of Seasonal Affective Disorder [21]	Seasonality of mood and behavior; Seasonal Affective Disorder	5

[37,38]. Since the ideal thermal comfort can widely vary for individuals, it is crucial that buildings are designed in order to afford occupants the maximum feasible control over their thermal environment.

Light is another example of a building parameter that influences physical and mental health. It has been established that building occupants prefer: (1) natural over artificial light [39,40]; (2) windows within their work space [40–42]; and, (3) natural views over built or urban ones [43–46]. These preferences are directly tied to mental health. Data from a WHO survey suggested that inadequate daylighting or bad window views increased the probability of depression by 60% and 40%, respectively [47]. Well-designed lighting is directly and indirectly associated with positive physical, physiological, and psychological health outcomes [48], as demonstrated by empirical studies across a number of building types, including schools [49], offices [50–53], hospitals [54,55], and retail stores [56]. These positive outcomes include higher test scores, improved health, reduced absenteeism, and increased worker productivity [57]. Conversely, poorly designed lighting can cause glare and thermal discomfort or a loss of privacy, leading to reduced productivity, increased absenteeism, and self-selected reduction of daylight exposure by moving offices or using window coverings [57,58]. Recent research has even connected light exposure in the built environment to the bacterial communities observed in indoor areas [59].

Light primarily influences mental health outcomes by two primary mechanisms: (1) a direct arousing effect, driven by activating the neurocircuitry of alertness and arousal; and, (2) a delayed effect, via impacting circadian rhythms and, secondarily, sleep duration and sleep quality [8]. It is relevant that sleep and circadian rhythm disruptions are frequently observed in patients with neurodegenerative diseases and psychiatric disorders, including bipolar disorder, schizophrenia, and autism spectrum disorder [60–63], and that correction of circadian abnormalities result in an improved therapeutic control of these conditions. The quantity and timing of light exposure can therefore positively or negatively impact occupant mental health. Studies have shown that health benefits of quality building lighting can be attributed to improved sleep quality and beneficial effects of circadian rhythm realignments, while prolonged exposure to cool white fluorescent lights at the wrong time of day may induce circadian dysrhythmia [57]. Quality lighting with natural views has also been linked to reduced stress, decreased anxiety, and improved mood [64]. Additionally, more than 70 therapeutic trials and two meta-analyses [65,66] have demonstrated that bright-light therapy (BLT) is an effective first-line treatment for seasonal affective disorder (SAD) [67]. There is also evidence that BLT may be effective in treating non-seasonal depression disorders, such as chronic depression, antepartum depression, and bipolar disorder [68].

2.3. What impact does ventilation have on the built environment?

Ventilation in the built environment is strongly influenced by the type of ventilation system present (e.g., mechanical versus natural), the design and condition of the building, and occupant behavior. Of particular importance to the health of building occupants is the amount of outdoor air supplied to the indoor environment (ventilation air). Ventilation air is a function of several factors including, for instance, the characteristics of the heating and air conditioning system present, penetration of outdoor air across the building envelope, opening of doors or windows by occupants and the use of dedicated outdoor fans found in many kitchens and bathrooms. The impact of ventilation on the physical health and cognitive function of occupants has been extensively studied (for review, see Refs. [69–72]). Of interest to the current discussion is how both high and low outdoor ventilation rates influence the concentration of pollutants indoors that may be associated with negative mental health outcomes.

For pollutants whose primary source is indoors, low ventilation rates that reduce the supply of fresh outdoor air into the built environment can increase the indoor concentrations of these pollutants [73]. Indoor air pollution can be derived from multiple sources including, but not limited to, composite-wood materials, flooring, furnishings, cleaning products, electronic equipment, air fresheners, combustion processes, and cooking activities [73]. Common pollutants generated indoors include particulate matter, bioaerosols, volatile organic compounds (VOCs; i.e., any of thousands of organic [carbon-containing] chemicals that are present mostly as gases at room temperature), and semi-volatile organic compounds [SVOCs], a subgroup of VOCs that tend to have a higher molecular weight and higher boiling point temperature than other VOCs). Indoor air pollution can be derived from multiple sources, to include, but not limited to, composite-wood, flooring, furnishings, cleaning products, electronic equipment, air fresheners, combustion processes, and cooking activities [73]. Many indoor pollutants are known to cause adverse health effects ranging from respiratory illnesses [74,75] to cognitive effects [76–78] and others are known irritants (e.g. odors). Low ventilation rates in occupied spaces can also increase indoor carbon dioxide concentrations from exhaled breath, a potential health risk in itself [79], and a surrogate for high concentrations of pollutants sourced indoors [80]. Additionally, an increase of moisture leading to mold growth occurs with low ventilation [81], an effect that can be exacerbated by an occupant's behavior, most notably in kitchens and bathrooms.

Improving ventilation systems to increase the supply of fresh air can reduce the indoor concentration of some indoor pollutants such as carbon dioxide and VOCs [35,70,82,83]. However, high ventilation rates that increase the supply of outdoor air into buildings can also increase the levels of airborne pollutants that have a primary source outdoors [84]. Such outdoor pollutants include particulate matter, carbon monoxide, ozone, nitrogen oxides, sulfur oxides, and ozone. In one study of an urban environment, residents with higher ventilation rates with potentially increased outdoor pollutants were more likely to report negative health effects like chronic cough, asthma, and asthma-like symptoms [85]. High ventilation rates that are due to poor quality or compromised building envelopes can also lead to moisture and pest intrusion [86], as well as poor thermal comfort [87,88]. Finally, high ventilation rates in the absence of efficient filters can result in increased concentrations of outdoor allergens in the built environment [89].

2.4. What is the impact of indoor air pollution, or outdoor air pollution that accesses the indoor environment, on mental health?

Research on the influence of air pollutants in the built environment on mental health is limited (a PubMed search on 25 Feb 2019 returned 13 articles). However, multiple large-scale mental health studies have utilized outdoor air pollutant information in attempts to relate ambient air pollutant concentrations to mental health outcomes. These include commonly measured air pollutants found in the Clean Air Act, such as particulate matter, nitrogen dioxide, carbon dioxide, and sulfur dioxide. This methodology is strengthened through the use of sizeable cohorts, but suffers from faulty assumptions that indoor/outdoor concentrations are always correlated [90,91] and air pollution from one source in an area adequately represents air pollution within the entire study boundary [92]. Of course, correlation should not be associated with causality. Nevertheless, the outdoor air pollution results provide an initial starting point for future indoor air studies.

Air pollutants measured outdoors have been shown in multiple studies to have a negative influence on mental health outcomes, even when using multi-parameter adjustments (Table 2). For examples, a rise of 10 $\mu g/m^3$ of particle matter under 10-μm in size (PM_{10}) and sulfur dioxide (SO_2) in a 2-day period increased mental disorder hospitalization rates by 1.27% and 6.88%, respectively [93]. A gender bias was also observed in a mouse model on prenatal air pollution where male offspring of prenatally-exposed dams displayed both increased anxiety and impaired cognition during adulthood, at 60 days postnatal [94].

Air pollutant effects on mental health conditions may be from acute

Table 2
Select odds ratios for effects of outdoor air pollutants on mental health.

Study	Cohort Size	Location	Mental Health Outcome	PM10	PM2.5	SO2	NO2	CO	Note
Bakian et al., 2015 [96]	1210 (Men)	United States	Suicide deaths		1.06		1.19		Pollutants measured 3 days prior. Developed from increase in interquartile range
	336 (Women)				0.95		1.04		Pollutants measured 3 days prior. Developed from increase in interquartile range
Lin et al., 2016 [95]	1550	China	Suicide deaths	1.13		1.12	1.15		PM10 & SO2 measured at 2 days prior, NO2 measured at 1 day prior. Developed from increase in interquartile range
Pun et al., 2017 [97]	4008	United States	Anxiety		1.54				Pollutant measured 30-day rolling average. Developed from increase in 5 μg/m^3
			Depression		1.22				
Shin et al., 2018 [98]	61,978 (Men)	South Korea	Depression	1.34		1.15	1.71	1.54	Pollutant daily avg. concentration of hourly measurements. Developed in fourth quartile of pollutant concentrations
			Depression (Doctor diagnosed)	0.98		1.15	1.28	1.20	
			Suicidal ideation	1.21		0.88	1.32	1.32	
	62,227 (Women)		Depression	1.39		0.99	1.39	1.52	Pollutant daily avg. concentration of hourly measurements. Developed in fourth quartile of pollutant concentrations
			Depression (Doctor diagnosed)	1.02		0.80	1.22	1.10	
			Suicidal ideation	1.26		0.86	1.40	1.16	

PM_{10} = particulate matter less than 10-μm in size, $PM_{2.5}$ = particulate matter less than 2.5-μm in size, SO_2 = sulfur dioxide, NO_2 = nitrogen dioxide, CO = carbon monoxide.

or chronic exposures, with some studies using lag periods, or rolling weekly or monthly averages as environmental sampling times prior to a discrete event (e.g., fatal suicidal self-directed violence). Kim et al. (2015) found a statistically significant higher percentage of suicides in South Korea with ozone concentrations over one standard deviation over mean levels for up to four weeks [99]. In that same study, similar results were observed for PM but not nitrogen dioxide (NO_2), carbon monoxide (CO), or SO_2. In an indoor air study, children during their first three months of life exposed to gas stoves and gas fireplaces producing higher NO_2 than the control condition (i.e., electric stoves) had an odds ratio of 2.72 of developing attention deficient disorder, measured at 4 years of age [100].

A better understanding of the biological mechanisms of adverse mental health responses to air pollution (see preliminary discussion in question 2.6) might assist in explaining these trends. Also, still eluding researchers are the specific influences of other indoor air pollutants, including VOCs, SVOCs, fungal spores, allergens, and other indoor air constituents on mental health outcomes. The actual influence of those pollutants may be important, since concentrations of such VOCs sourced in the indoor environment can be significantly higher than in outdoor air [101–103]. Similarly, SVOCs such as flame retardants and plasticizers are ubiquitous in the indoor environment and several are known to cause adverse neurologic effects [104,105].

Measuring mental health outcomes in relation to indoor air pollutants is challenging and future studies are unlikely to be as highly powered as the national studies of outdoor air pollutants. Despite those issues, it is feasible for future researchers to include mental health outcomes in existing indoor air research. In an editorial on the future of indoor air research, Corsi [106] called for social scientists to be involved in built environment research. One potential area for social scientists and building scientists to work together is the implementation of monitoring of indoor air quality. For example, low-cost air pollution sensors are becoming more readily available [107–109], including networks of sensors that automatically send the information through the internet to a secured central server [110].

2.5. Does the microbiome of the built environment influence mental health?

Microbiota-gut-brain (MGB) axis models have gained attention for mental health outcomes, including conditions like anxiety and depression [111–113]. The biological mechanisms responsible for MGB axis signaling have been extensively reviewed by others [114–117]. Recent research has also developed a microbiome-lung-brain model with bidirectional signaling [118], either directly to the brain or indirectly through the gut [119]. However, the extent to which the microbial communities that surround occupants in the built environment can influence mental health is not clear.

The microbiome of the built environment (MoBE) has been increasingly studied in the past decade, recently summarized in a report by the National Academy of Sciences, Engineering, and Medicine [120] and included as another Ten Questions article series [121]. Transmission of the MoBE to and from human occupants is a complex with transition modes through air, water, surfaces, and resuspension of settled dust containing microorganisms. Sources include, but are not limited to, outdoor environments [122–124], occupants [125–127], premise plumbing [128,129], and pets [130,131]. The study of transmission of the MoBE to occupants in the built environment has historically focused on infectious disease airborne routes [69,132], although the direct transfer of MoBE to occupants has been shown in neonatal intensive care units [133]. Even when the pathways connecting the MoBE to occupants have been identified, it will be important to determine if the microorganisms are viable or just passively accumulating in the built environment, particularly if no moisture is present [134]. That being said, even heat-killed environmental bacteria have potential to impact immune signaling and emotional behavior [135–139].

Further characterization of mechanisms underlying transmission of microorganisms from the MoBE to occupants would remove one barrier in a bioinformed design of the built environment [140]. Potentially more difficult though is determining what features of the MoBE would best support overall occupant health. This could be immunomodulatory bacteria that we listed in a review [141] based on potential probiotics, or microbial diversity and antimicrobial resistance [142]. Alternatively, the biodesigned MoBE might be based on those outdoor microbiomes that have been shown to have beneficial effects for human health outcomes, like those seen in Amish farms [143]. The timing of the exposure has been shown to be important, being probably most beneficial during early childhood, when the immune response system is developing [144,145]. Likewise, during the early years of life, the human microbiome is likely more adaptable in ways that can influence health outcomes [146]. Relevant to mental health in early years of life, differences in the gut microbiome were associated with temperament in a observational study of 77 toddlers (18–27 months) [147]. Altogether, determining which microbiome community structures are beneficial for overall mental health, and the mechanisms through which environmental microorganisms influence mental health, appears to be a potential next step in the MoBE research field.

2.6. What are the known biological mechanisms for indoor air pollution, or outdoor air pollution that accesses the indoor environment, to influence mental health?

Chronic low-grade inflammation is thought to be a risk factor for stress-related psychiatric disorders, such as depression [148], and has even been identified as a risk factor for trauma- and stressor-related disorders, such as posttraumatic stress disorder [149]. The biological mechanisms underlying the link between inflammation and stress-related psychiatric disorders have been extensively reviewed and will not be outlined in detail here [150–155]. In the context of the built environment, elements of the built environment with potential to induce chronic low-grade inflammation (such as indoor air pollution, or outdoor air pollution that is actively or passively transferred to the indoor environment) are likely to increase risk for negative mental health outcomes.

Maternal exposure to environmental air pollutants during the late second trimester, extending into the early third trimester, of pregnancy is associated with increased risk of autism spectrum disorder (ASD) in the offspring [156,157]. This window of vulnerability for ASD risk due to environmental pollutants coincides with a critical window for development of a type of immune cell, the regulatory T cell (Treg) in the fetus, including the emergence, seeding, and expansion of Treg populations and Th17 cells (a type of immune cell that mediates inflammatory responses that have been implicated in ASD development [158]) from 12 weeks of gestation until early postnatal development, with some continued development out to 2 years of age [159]. Increased risk of mental health conditions is not necessarily limited to early childhood exposures. Recent studies have also identified an increased risk of history of depressive disorders and suicide during adulthood with increasing air pollution [95,160–162].

Although the mechanisms underlying these associations are not clear, studies in animals have shown that air pollution impairs cognitive function and increases depressive-like behaviors in association with neuroinflammation in the hippocampus [163], an important brain region controlling cognitive and affective functioning. Furthermore, we have argued that a lack of exposure to environmental microorganisms in modern urban societies leads to a failure of immunoregulation, a reduction in Treg, inappropriate levels of inflammation, and increased risk for psychiatric disorders [164]. Thus, modern urban societies increase exposure to environmental pollutants and inadequate exposure to microorganisms that can induce immunoregulation and limit inappropriate inflammation [95,160–174].

Apart from air pollutants or other factors leading to chronic low-grade inflammation, additional features of indoor air quality may also influence mental health outcomes. For example, Spengler and colleagues demonstrated that, in an office environment, VOCs and carbon dioxide levels were independently associated with cognitive scores [79]. A subset of brainstem serotonergic neurons, which are thought to play an important role in stress-related psychiatric disorders, is CO_2-sensitive [175–178]. Hypoxemia/hypoxia may also be an important factor; serotonergic cells in the periphery and brain have been identified as "hypoxia sensors" [179], while living at high altitude has been associated with increased risk of depression and death by suicide [180]. Furthermore, oxidative stress in response to air pollution or other features of indoor air may be an important mediator [181]. The mechanisms described above that result in oxidative stress and inflammation may activate enzymatic pathways that redirect tryptophan metabolism from the synthesis of serotonin towards the synthesis of kynurenines, with certain excitotoxic metabolites, such as quinolinic acid, implicated in depression and suicide [182,183]. A final potential mechanism through which indoor air pollution, including household allergens, may influence mental health involves indirect mechanisms, (i.e., through exacerbation of underlying medical conditions). For example, features of the built environment may lead to exacerbation of underlying medical conditions (e.g., respiratory disease or cardiovascular disease) which in turn lead to worsening mental health outcomes [184,185].

A common denominator underlying the effects of indoor air pollution on mental health may be microglial priming. In the context of neuroinflammatory priming, priming is defined as a process whereby a previous condition or prior exposure to a stimulus potentiates the immune response to a subsequent condition or stimulus [186], Air pollution activates brain microglia and induces microglial priming [187,188], which in turn has been implicated in anxiety-like defensive behavioral responses and cognitive impairment, processes that can be exacerbated by stress and aging [186].

2.7. Does an increase in urbanization influence mental health?

Psychiatric disorders are more prevalent in urban versus rural areas [189–192]. For example, a number of studies have demonstrated that an urban birth or upbringing increases schizophrenia risk [192–195]. Overall, these studies demonstrate that birth in an urban environment is associated with an increased risk for mental illness in general and for a broad range of specific psychiatric disorders. Although the mechanisms underlying these urban versus rural differences in psychiatric disorders are not clear, the hygiene hypothesis or "old friends" hypothesis offers a useful starting point. Immunoregulation, indicated by a balanced expansion of effector T-cell populations (which induce inflammatory responses) and Treg (which induce immunoregulatory and anti-inflammatory responses), is known to be driven by microbial signals, mainly by organisms with which mammals coevolved, including: (1) the commensal microbiota, which have been altered by the Western lifestyle, including a diet that is commonly low in microbiota-accessible carbohydrates [196,197]; (2), pathogens associated with the "old infections" that were present throughout life in evolving human hunter-gatherer populations [198]; and (3) organisms from the natural environment with which humans were inevitably in daily contact (and so had to be tolerated by the immune system) [166]. Immunoregulation is thought to be compromised in modern high-income settings, due to reduced contact with these three categories of organisms [166,199,200]. A failure of immunoregulation, attributable to reduced exposure to the microbial environment within which the mammalian immune system evolved, is thought to be one factor contributing to recent increases in chronic inflammatory disorders and stress-related psychiatric disorders in high-income countries [166,197,198].

In a recent study designed to test this hypothesis, Böbel et al. (2018) compared healthy young individuals that either: (1) were raised in a rural farming environment (in the presence of farm animals); or (2) were raised in an urban environment (in the absence of pets). As adults, individuals were exposed to a psychosocial stress paradigm, the Trier Social Stress Test. Although individuals raised in a rural environment reported experiencing higher levels of stress and anxiety and had higher glucocorticoid stress hormones, individuals raised in an urban environment had an exaggerated immune response to the stressor, as evidenced by increased peripheral blood mononuclear cells in the blood and increased release of proinflammatory cytokines (i.e., interleukin 6) [201]. Given that chronic low-grade inflammation in response to psychosocial stress is thought to be a risk factor for development of stress-related psychiatric disorders [202], an urban upbringing may confer increased risk. Other elements of urban upbringing and urban living, relative to rural upbringing and rural living, apart from microbial exposures, are also likely to be important in determining risk for stress-related psychiatric disorders, including access to green spaces [203], exposures to air pollutants, access to quality health care, and other factors.

2.8. Does socioeconomic status change the built environment to influence mental health?

Socioeconomic status (SES), one of the most widely studied constructs in social science, is the combination of social and economic status, measured via income, occupation, and education [204]. Originally designed for individual and family units, the SES concept has been broadened in scope to also apply at the neighborhood level [205]. Positive connections between SES and health outcomes are vast and previously reviewed by others [206,207]. Due to the connection between SES and health conditions, studies often use SES as one controlled variable, neglecting the issue that it is measured as a continuous scale [208]. The measurement of SES directly relates to housing quality and noise exposures in residential built environments.

The quality of housing can affect the mental health of the building occupants. For instance, housing quality (e.g., as assessed by structural quality, crowding, clutter) for low and middle income families in rural areas was found to be more highly correlated to poor psychological health in children than neighborhood quality [209]. Similarly, in an urban setting, women experiencing housing disarray (e.g., crowding, noise, dark conditions) and housing instability (i.e., moving often) were more likely to be at risk for depression and generalized anxiety disorder [210]. Poor housing quality also contributes to pest (e.g., cockroach, rat, mouse) infestations that can affect the mental health of occupants. In a sample of public housing residents, for instance, current cockroach infestations increased the odds of experiencing high depressive symptoms by threefold and dual infestations (mouse and cockroach) led to a five-fold increase [211]. Similarly, exposure to rats can result in negative mental health consequences for residences [212,213].

Noise can also be exaggerated in low-quality housing that has limited insulation and poor-quality windows [25]. In lower SES neighborhoods, additional noise exposure may come from proximity to roadways [214], railways, industrial sites, or airfields. High levels of noise have been associated with depression and anxiety [215]. One factor where noise might represent a problem is proximity to airports, which has been associated with both positive [216] and negative [6] mental health findings. Studies that consider noise as an annoyance, rather than just an increase in decibels, have found a negative impact of noise on mental health [217–219]. For example, noise annoyance from neighbors in high-density residential units results in 2.3 times higher odds of an individual having poor mental health [219]. Noise and noise annoyance have non-standard effects on individuals that might depend on previous experiences or biological susceptibility. When individuals do not have control over the noise, as experienced with noise annoyance, individuals might suffer from learned helplessness and biological signatures of chronic stress, including overproduction of cortisol [220].

In addition to considering the quality of housing, it is important to understand how financial stresses associated with unaffordable built environments impact the mental health of occupants, particularly for low-income communities. For instance, Bentley et al. [221] "found that entering unaffordable housing is detrimental to the mental health of individuals residing in low-to-moderate income households." This negative effect of residing in unaffordable housing may be more pronounced for those with insecure employment than those with secure employment [222]. It is likely that the effects of lower SES are cumulative. That is, those individuals in lower SES have limited ability in housing selection and neighborhoods resulting in a decline in access to green spaces and built environment features that could provide protection from mental health disorders. Therefore, providing higher quality affordable housing is particularly important for promoting positive mental health in vulnerable communities.

2.9. What are actions that can be taken in the design and operation of built environments to improve mental health?

Recommendations to promote mental health wellness include reducing indoor exposure to harmful particulates and chemicals, and improving built environment conditions. To achieve these objectives, measures can be taken at each stage of the building lifespan, from its conception stage through its continuous usage. Furthermore, additional research on the connections between the built environment and mental health, as well as the mechanisms involved, is also a first-order recommendation.

Given that pollutant exposures are implicated in poor mental health outcomes, one approach to protect mental health is to reduce exposures to pollutants inside the built environment. In the case of indoor pollutants, lowering concentrations can be accomplished through indoor cleaners with: (1) media filtration units placed in building ventilation systems to reduce particulate matter concentrations; (2) ultraviolet C irradiation (UVC) units to reduce bioaerosol concentrations; or (3) portable high efficiency particulate air (HEPA) filters intended to reduce particulate matter or VOC concentrations. The effectiveness of indoor air cleaners is a function of a wide variety of factors such as air cleaner design (e.g., clean air delivery rate), and it is important to realize that unintended secondary pollutant releases can occur in some systems [223]. Also, many studies examining the effectiveness of indoor air cleaner technologies for protecting occupant health have focused on quantifying the potential respiratory or cardiovascular health benefits of decreasing indoor pollutant exposures to $PM_{2.5}$, ozone and VOCs [224,225]. The effects of specific air cleaning interventions on mental health have generally not been studied in a rigorous manner.

An alternate approach to improve indoor air quality and protect occupant mental health is to reduce the introduction of materials and products into homes and other buildings that are sources for the pollutants of concern. For instance, SVOCs are now ubiquitous within the built environment, due to their widespread use in consumer products, building materials, and furnishings. Several SVOCs, such as organophosphates (found in pesticides) and polybrominated diphenyl ethers (flame retardant found in electronics, foam, textiles, etc.), have been identified as neurotoxic and are associated with negative behavioral outcomes [104,105]. Thus, it would be beneficial to identify which SVOCs and other pollutants negatively affect the mental health of occupants and reduce their use in building and consumer products.

Improving the condition of the built environment would likely lead to improved mental health outcomes. Buildings that are damaged by moisture have an increased microbial diversity [226] that is unique from non-damaged facilities [227]. In one study, moisture damage in schools was shown to increase systemic inflammation in children at six years of age [228]. However, inflammation was not increased from early life exposures to moisture damage (under 1 year), measured later at 6 years of age [229]. It appears multiple biotoxins from moisture-damaged buildings have a cumulative influence on inflammation [230]. Renovation after moisture damage can be successful for health improvements [231,232], but is expensive and might not be undertaken in residences of low incoming housing. While there is evidence of dampness and mold being relevant to health, is difficult to quantify the specific dose-responses due to challenges related to measuring moisture (for review, see Ref. [233]); yet associations between mold exposures and mental health outcomes can be observed. For example, Shenassa et al. [234] surveyed 5882 adults in eight European cities and found rates of depression for none, minimal, moderate, or extensive dampness or mold in home of 6.5%, 9.7%, 11.6%, and 15.8%, respectively. Foundational research, like a recent study characterizing water activity in gypsum board by Adams et al. [235], may assist to better quantify water that is available to support growth of microorganisms, including mold, in the built environment.

2.10. What are future research directions needed for science, health, and policy?

Joint efforts by policymakers, social scientists, health researchers, architects, and engineers (i.e., interdisciplinary team science) will be required to facilitate meaningful research to define the relationship between the built environment and mental health. Moreover, challenges associated with this work are likely associated with the cumulative and dynamic nature of exposures to elements that are either health- or disease-promoting [236]. Similarly, it is likely that exploration of the complex nature regarding relationships between the built environment and mental health will require large-scale prospective studies.

A challenge associated with determining built environment elements that influence mental health outcomes is that there are multiple external interacting factors that are known to influence mental health. For example, social determinates of health are complex connections of social structures and economic conditions that can result in health inequalities that vary across a population [237]. As noted above, increases in the occurrence of mental health conditions are associated with decreases in SES [3,238], though the specific causations are unclear [239]. Rates of mental health conditions have also been reported based on gender [240,241], race [206], sexual orientation [242], adverse early life experiences [243–245] and family status [246]. These factors should be considered in mental health research aimed at exploring how the built environment influences psychological functioning.

Another future research need is a more rigorous approach to assessing housing quality [247]. Often, social science researchers investigating the effects of housing on physical and mental health outcomes do not conduct detailed or direct assessments of home quality. Standardized and validated measures should be developed by engineers with in-depth knowledge of built design. Detailed and longitudinal data are often necessary in order to accurately determine impacts of housing characteristics on mental health. The advent of low-cost sensors and increases in built environment data collection should have a positive impact on future research studies.

Finally, future research should investigate the influence of architectural features and facility design that can contribute to the occupants' mental health. Moore et al. [248] completed a full systematic review on "the effects of changes to the built environment on mental health". The review was comprehensive, but did not include review of studies that discussed interventional actions at the facility level. Individuals integral to communities, but actually live and work in facilities. Additional research is needed to inform facility design and operation to maximize mental health outcomes.

Currently, policy in the US does not specifically address the ties between the built environment and mental health. Understanding regarding the physical and cognitive performance on existing standards is on the rise. Standards outlined by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), and the U.S. Green Building Council (USGBC), have facilitated advances. Nonetheless, the lack of standards regarding mental health outcomes should not be viewed as a deficiency on the part of any of these or other organizations; rather, policy to date has not supported the conclusion that mental health outcomes might be important considerations in the design of the built environment. However, policy is just one avenue for change. Even if policy is adopted, it will be unlikely to include changes to the built environment in previously constructed building. With evidence-based research on the effects of the built environment on mental health, engineers and social scientists can provide recommendations for improvements to the built environment that improve mental health.

3. Conclusion

There is a great need to improve our understanding of the effects of the built environment on the occurrence, severity, and persistence of mental illness, as well as the factors that promote mental health and human performance. Given that we spend the majority of our time within homes, schools, offices and other spaces, it is critical to explore the mental health consequences of how we design, operate and maintain buildings. Building factors that merit further investigation in a mental health context include ventilation, lighting, temperature as well as indoor microbial, chemical and pest exposures. While there is a growing awareness that many of these factors affect human performance such as asthma, allergies, and cognitive function, most research to date has not incorporated explicitly assessed mental health outcomes into the study designs. An interdisciplinary approach that integrates social scientists, health researchers, architects, building scientists, and engineers coupled with controlled experiments and interventions to isolate the effect of individual building factors on specific mental health outcomes is needed. Also, a focus on understanding how external factors such as SES, gender, affects mental health should be incorporated into mental health outcome research in the built environment. Negative mental health impacts many daily lives throughout the world and it is time to consider not only physical health but also mental health in the built environment.

Acknowledgements

We are grateful to Zachary D. Barger for proofreading the manuscript. The views expressed in this article are those of the authors and do not reflect the official policy or position of the US Air Force, Department of Defense, US Department of Veterans Affairs, or the US government. C.A.L. serves on the Scientific Advisory Board of Immodulon Therapeutics, Ltd. L.A.B. consults for a professional sports team.

References

[1] W.H. Organization, Promoting mental health : concepts, emerging evidence, practice : summary report/a report from the World Health Organization, D.o.M.H.a.S.A.i.c.w.t.V.H.P.F.a.t.U.o.M.G.W.H. Organization (Ed.), World Health Organization, Geneva, Switzerland, 2004.
[2] C.L.M. Keyes, C.C. Martin, The complete state model of mental health, in: A. Jarden, L. Oades, M. Slade (Eds.), Wellbeing, Recovery and Mental Health, Cambridge University Press, Cambridge, 2017, pp. 86–98.
[3] K.A. McLaughlin, E.J. Costello, W. Leblanc, N.A. Sampson, R.C. Kessler, Socioeconomic status and adolescent mental disorders, Am. J. Public Health 102 (9) (2012) 1742–1750.
[4] B. Winblad, K. Palmer, M. Kivipelto, V. Jelic, L. Fratiglioni, L.-O. Wahlund, A. Nordberg, L. Bäckman, M. Albert, O. Almkvist, H. Arai, H. Basun, K. Blennow, M. De Leon, C. DeCarli, T. Erkinjuntti, E. Giacobini, C. Graff, J. Hardy, C. Jack, A. Jorm, K. Ritchie, C. Van Duijn, P. Visser, R.C. Petersen, Mild cognitive impairment – beyond controversies, towards a consensus: report of the international working group on mild cognitive impairment, J. Intern. Med. 256 (3) (2004) 240–246.
[5] S. Larrieu, L. Letenneur, J.M. Orgogozo, C. Fabrigoule, H. Amieva, N. Le Carret, P. Barberger–Gateau, J.F. Dartigues, Incidence and outcome of mild cognitive impairment in a population-based prospective cohort, Neurology 59 (10) (2002) 1594.
[6] C. Baudin, M. Lefèvre, P. Champelovier, J. Lambert, B. Laumon, A.-S. Evrard, Aircraft noise and psychological ill-health: the results of a cross-sectional study in France, Int. J. Environ. Res. Public Health 15 (8) (2018) 1642.

[7] M.D. Thomas, R. Insel, Assessing the economic costs of serious mental illness, Am. J. Psychiatry 165 (6) (2008) 663–665.
[8] T.T. Postolache, D.A. Oren, Circadian phase shifting, alerting, and antidepressant effects of bright light treatment, Clin. Sports Med. 24 (2) (2005) 381–413 (xii).
[9] American Psychiatric Association, Diagnostic and Statistical Manual of Mental Disorders, fifth ed., (2013) Washington, DC.
[10] L.A. Brenner, A.J. Hoisington, K.A. Stearns-Yoder, C.E. Stamper, J.D. Heinze, T.T. Postolache, D.A. Hadidi, C.A. Hoffmire, M.A. Stanislawski, C.A. Lowry, Military-related exposures, social determinants of health, and dysbiosis: the United States-veteran microbiome Project (US-VMP), Frontiers in Cellular and Infection Microbiology 8 (400) (2018).
[11] A.T. Beck, C.H. Ward, M. Mendelson, J. Mock, J. Erbaugh, An inventory for measuring depression, Arch. Gen. Psychiatr. 4 (1961) 561–571.
[12] Y.P. Wang, C. Gorenstein, Assessment of depression in medical patients: a systematic review of the utility of the Beck Depression Inventory-II, Clinics 68 (9) (2013) 1274–1287.
[13] C.M. Morin, Insomnia: Psychological Assessment and Management, Guilford Press, 1993.
[14] C.L. Craig, A.L. Marshall, M. Sjostrom, A.E. Bauman, M.L. Booth, B.E. Ainsworth, M. Pratt, U. Ekelund, A. Yngve, J.F. Sallis, P. Oja, International physical activity questionnaire: 12-country reliability and validity, Med. Sci. Sports Exerc. 35 (8) (2003) 1381–1395.
[15] J.E. Brazier, R. Harper, N.M. Jones, A. O'Cathain, K.J. Thomas, T. Usherwood, L. Westlake, Validating the SF-36 health survey questionnaire: new outcome measure for primary care, BMJ 305 (6846) (1992) 160–164.
[16] M.G.P. Kovar, Gail Scott the National Interview Survey Design, 1973-84, and Procedures, 1975-1983, (1985) Available online at: https://www.cdc.gov/nchs/data/series/sr_01/sr01_018acc.pdf.
[17] B.W. Ward, J.S. Schiller, Prevalence of multiple chronic conditions among US adults: estimates from the National Health Interview Survey, 2010, Prev. Chronic Dis. 10 (2013) E65.
[18] M.J. Lambert, G.M. Burlingame, V. Umphress, N.B. Hansen, D.A. Vermeersch, G.C. Clouse, S.C. Yanchar, The reliability and validity of the outcome questionnaire, clinical psychology & psychotherapy, An International Journal of Theory and Practice 3 (4) (1996) 249–258.
[19] K. Kroenke, R.L. Spitzer, J.B. Williams, The PHQ-15: validity of a new measure for evaluating the severity of somatic symptoms, Psychosom. Med. 64 (2) (2002) 258–266.
[20] A. Pinto-Meza, A. Serrano-Blanco, M.T. Penarrubia, E. Blanco, J.M. Haro, Assessing depression in primary care with the PHQ-9: can it be carried out over the telephone? J. Gen. Intern. Med. 20 (8) (2005) 738–742.
[21] N.E. Rosenthal, R.G. Skwerer, D.A. Sack, C.C. Duncan, F.M. Jacobsen, L. Tamarkin, T.A. Wehr, Biological effects of morning-plus-evening bright light treatment of seasonal affective disorder, Psychopharmacol. Bull. 23 (3) (1987) 364–369.
[22] G.W. Evans, The built environment and mental health, J. Urban Health : Bull. N. Y. Acad. Med. 80 (4) (2003) 536–555.
[23] J. Krieger, D.L. Higgins, Housing and health: time again for public health action, Am. J. Public Health 92 (5) (2002) 758–768.
[24] G.W. Evans, J.M. McCoy, WHEN BUILDINGS DON'T WORK: THE ROLE OF ARCHITECTURE IN HUMAN HEALTH, J. Environ. Psychol. 18 (1) (1998) 85–94.
[25] M. Santamouris, S.M. Alevizos, L. Aslanoglou, D. Mantzios, P. Milonas, I. Sarelli, S. Karatasou, K. Cartalis, J.A. Paravantis, Freezing the poor—indoor environmental quality in low and very low income households during the winter period in Athens, Energy Build. 70 (2014) 61–70.
[26] M.C. Katafygiotou, D.K. Serghides, Bioclimatic chart analysis in three climate zones in Cyprus, Indoor Built Environ. 24 (6) (2015) 746–760.
[27] T.N. Quang, C. He, L.D. Knibbs, R. de Dear, L. Morawska, Co-optimisation of indoor environmental quality and energy consumption within urban office buildings, Energy Build. 85 (2014) 225–234.
[28] H. Thomson, C. Snell, Quantifying the prevalence of fuel poverty across the European Union, Energy Policy 52 (2013) 563–572.
[29] J.P. Clinch, J.D. Healy, Housing standards and excess winter mortality, J. Epidemiol. Community Health 54 (9) (2000) 719–720.
[30] T.M. Mäkinen, R. Juvonen, J. Jokelainen, T.H. Harju, A. Peitso, A. Bloigu, S. Silvennoinen-Kassinen, M. Leinonen, J. Hassi, Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections, Respir. Med. 103 (3) (2009) 456–462.
[31] C.J. Simonson, M. Salonvaara, T. Ojanen, The effect of structures on indoor humidity–possibility to improve comfort and perceived air quality, Indoor Air 12 (4) (2002) 243–251.
[32] D.P. Wyon, The effects of indoor air quality on performance and productivity, Indoor Air 14 (Suppl 7) (2004) 92–101.
[33] P. Wolkoff, S.K. Kjærgaard, The dichotomy of relative humidity on indoor air quality, Environ. Int. 33 (6) (2007) 850–857.
[34] K.C. Dannemiller, C.J. Weschler, J. Peccia, Fungal and bacterial growth in floor dust at elevated relative humidity levels, Indoor Air 27 (2) (2017) 354–363.
[35] P. Wargocki, D.P. Wyon, J. Sundell, G. Clausen, P.O. Fanger, The effects of outdoor air supply rate in an office on perceived air quality, Sick Building Syndrome (SBS) symptoms and productivity, Indoor Air-International Journal of Indoor Air Quality and Climate 10 (4) (2000) 222–236.
[36] J. Singh, Impact of indoor air pollution on health, comfort and productivity of the occupants, Aerobiologia 12 (1) (1996) 121–127.
[37] M.A. McGeehin, M. Mirabelli, The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States, Environ. Health Perspect. 109 (Suppl 2) (2001) 185–189.
[38] M. Stafoggia, F. Forastiere, D. Agostini, A. Biggeri, L. Bisanti, E. Cadum, N. Caranci, F. de' Donato, S. De Lisio, M. De Maria, P. Michelozzi, R. Miglio, P. Pandolfi, S. Picciotto, M. Rognoni, A. Russo, C. Scarnato, C.A. Perucci, Vulnerability to heat-related mortality: a multicity, population-based, case-crossover analysis, Epidemiology 17 (3) (2006) 315–323.
[39] J.A. Veitch, D.W. Hine, R. Gifford, END users' knowledge, beliefs, and preferences for lighting, J. Inter. Des. 19 (2) (1993) 15–26.
[40] J.H.H. Heerwagen, Lighting and psychological comfort, Light. Des. Appl. 6 (1986) 47.
[41] M.C. Finnegan, L.Z. Solomon, Work attitudes in windowed vs. Windowless environments, J. Soc. Psychol. 115 (2) (1981) 291–292.
[42] J.A.F. Veitch, M.J. Kelly, A Room with a View: A Review of the Effects of Windows on Working and Well-Being, National Research Council Canada, Ottowa, ON, Canada, 2001.
[43] C.-Y. Chang, P.-K. Chen, Human response to window views and indoor plants in the workplace, Hortscience 40 (5) (2005) 1354–1359.
[44] T. Hartig, G.W. Evans, L.D. Jamner, D.S. Davis, T. Gärling, Tracking restoration in natural and urban field settings, J. Environ. Psychol. 23 (2) (2003) 109–123.
[45] C.M. Tennessen, B. Cimprich, Views to nature: effects on attention, J. Environ. Psychol. 15 (1) (1995) 77–85.
[46] R. Ulrich, View through a window may influence recovery from surgery, Science 224 (4647) (1984) 420–421.
[47] W.H. Organization, Large Analysis and Review of European Housing and Health Status (LARES), World Health Organization, Copenhagen, Denmark, 2007.
[48] R. Codinhoto, P. Tzortzopoulos, M. Kagioglou, G. Aouad, R. Cooper, The impacts of the built environment on health outcomes, Facilities 27 (3/4) (2009) 138–151.
[49] R. Küller, C. Lindsten, Health and behavior of children in classrooms with and without windows, J. Environ. Psychol. 12 (4) (1992) 305–317.
[50] E. Ne'eman, A comprehensive approach to the integration of daylight and electric light in buildings, Energy Build. 6 (2) (1984) 97–108.
[51] D.L. Butler, P.M. Biner, Effects of setting on window preferences and factors associated with those preferences, Environ. Behav. 21 (1) (1989) 17–31.
[52] J.H. Heerwagen, G.H. Orians, Adaptations to windowlessness:A study of the use of visual decor in windowed and windowless offices, Environ. Behav. 18 (5) (1986) 623–639.
[53] P. Leather, M. Pyrgas, D. Beale, C. Lawrence, Windows in the workplace:sunlight, View, and Occupational Stress, Environment and Behavior 30 (6) (1998) 739–762.
[54] K.M. Beauchemin, P. Hays, Sunny hospital rooms expedite recovery from severe and refractory depressions, J. Affect. Disord. 40 (1) (1996) 49–51.
[55] F. Benedetti, C. Colombo, B. Barbini, E. Campori, E. Smeraldi, Morning sunlight reduces length of hospitalization in bipolar depression, J. Affect. Disord. 62 (3) (2001) 221–223.
[56] L. Heschong, R.L. Wright, S. Okura, Daylighting impacts on retail sales performance, J. Illum. Eng. Soc. 31 (2) (2002) 21–25.
[57] L. Edwards, P. Torcellini, Golden, CO. (US), Literature Review of the Effects of Natural Light on Building Occupants, National Renewable Energy Lab, 2002Medium: ED; Size: 58 pages.
[58] M.B.C. Aries, J.A. Veitch, G.R. Newsham, Windows, view, and office characteristics predict physical and psychological discomfort, J. Environ. Psychol. 30 (4) (2010) 533–541.
[59] A.K. Fahimipour, E.M. Hartmann, A. Siemens, J. Kline, D.A. Levin, H. Wilson, C.M. Betancourt-Román, G. Brown, M. Fretz, D. Northcutt, K.N. Siemens, C. Huttenhower, J.L. Green, K. Van Den Wymelenberg, Daylight exposure modulates bacterial communities associated with household dust, Microbiome 6 (1) (2018) 175.
[60] K. Wulff, S. Gatti, J.G. Wettstein, R.G. Foster, Sleep and circadian rhythm disruption in psychiatric and neurodegenerative disease, Nat. Rev. Neurosci. 11 (8) (2010) 589–599.
[61] K. Wulff, D.-J. Dijk, B. Middleton, R.G. Foster, E.M. Joyce, Sleep and circadian rhythm disruption in schizophrenia, Br. J. Psychiatry 200 (4) (2012) 308–316.
[62] G. Glickman, Circadian rhythms and sleep in children with autism, Neurosci. Biobehav. Rev. 34 (5) (2010) 755–768.
[63] R. Carr, M.B. Wasdell, D. Hamilton, M.D. Weiss, R.D. Freeman, J. Tai, W.J. Rietveld, J.E. Jan, Long-term effectiveness outcome of melatonin therapy in children with treatment-resistant circadian rhythm sleep disorders, J. Pineal Res. 43 (4) (2007) 351–359.
[64] R.S. Ulrich, Natural versus urban scenes:some psychophysiological effects, Environ. Behav. 13 (5) (1981) 523–556.
[65] T.M.C. Lee, C.C.H. Chan, Dose-response relationship of phototherapy for seasonal affective disorder: a meta-analysis, Acta Psychiatr. Scand. 99 (5) (1999) 315–323.
[66] M. Terman, J.S. Terman, F.M. Quitkin, P.J. McGrath, J.W. Stewart, B. Rafferty, Light therapy for seasonal affective disorder, A review of efficacy, Neuropsychopharmacology : official publication of the American College of Neuropsychopharmacology 2 (1) (1989) 1–22.
[67] C. Even, C.M. Schroder, S. Friedman, F. Rouillon, Efficacy of light therapy in nonseasonal depression: a systematic review, J. Affect. Disord. 108 (1–2) (2008) 11–23.
[68] G. Pail, W. Huf, E. Pjrek, D. Winkler, M. Willeit, N. Praschak-Rieder, S. Kasper, Bright-light therapy in the treatment of mood disorders, Neuropsychobiology 64 (3) (2011) 152–162.
[69] Y. Li, G.M. Leung, J.W. Tang, X. Yang, C.Y. Chao, J.Z. Lin, J.W. Lu, P.V. Nielsen, J. Niu, H. Qian, A.C. Sleigh, H.J. Su, J. Sundell, T.W. Wong, P.L. Yuen, Role of ventilation in airborne transmission of infectious agents in the built environment - a multidisciplinary systematic review, Indoor Air 17 (1) (2007) 2–18.
[70] J. Sundell, H. Levin, W.W. Nazaroff, W.S. Cain, W.J. Fisk, D.T. Grimsrud, F. Gyntelberg, Y. Li, A.K. Persily, A.C. Pickering, J.M. Samet, J.D. Spengler, S.T. Taylor, C.J. Weschler, Ventilation rates and health: multidisciplinary review

of the scientific literature, Indoor Air 21 (3) (2011) 191–204.
[71] O.A. Seppänen, W.J. Fisk, M.J. Mendell, Association of ventilation rates and CO2 concentrations with health and Other responses in commercial and institutional buildings, Indoor Air 9 (4) (1999) 226–252.
[72] P. Carrer, P. Wargocki, A. Fanetti, W. Bischof, E. De Oliveira Fernandes, T. Hartmann, S. Kephalopoulos, S. Palkonen, O. Seppänen, What does the scientific literature tell us about the ventilation–health relationship in public and residential buildings? Build. Environ. 94 (2015) 273–286.
[73] C.J. Weschler, Changes in indoor pollutants since the 1950s, Atmos. Environ. 43 (1) (2009) 153–169.
[74] J. Madureira, I. Paciência, J. Rufo, E. Ramos, H. Barros, J.P. Teixeira, E. de Oliveira Fernandes, Indoor air quality in schools and its relationship with children's respiratory symptoms, Atmos. Environ. 118 (2015) 145–156.
[75] S.J. Campbell, P. Kauffman, N. Parinandi, S. Kotha, T. Gurney, S. Varikuti, A. Satoskar, Indoor airborne dust/particulate matter causes occupational respiratory disease: novel lipidocentric mechanism of airway inflammation, B60, Environmental Dust and Particulates in Airway Disease, American Thoracic Society, 2017, p. A3893.
[76] D.A. Cory-Slechta, J.L. Allen, K. Conrad, E. Marvin, M. Sobolewski, Developmental exposure to low level ambient ultrafine particle air pollution and cognitive dysfunction, Neurotoxicology 69 (December 2018) 217–231.
[77] U. Ranft, T. Schikowski, D. Sugiri, J. Krutmann, U. Krämer, Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly, Environ. Res. 109 (8) (2009) 1004–1011.
[78] J.-C. Chen, J. Schwartz, Neurobehavioral effects of ambient air pollution on cognitive performance in US adults, Neurotoxicology 30 (2) (2009) 231–239.
[79] J.G. Allen, P. MacNaughton, U. Satish, S. Santanam, J. Vallarino, J.D. Spengler, Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: a controlled exposure study of green and conventional office environments, Environ. Health Perspect. 124 (6) (2016) 805–812.
[80] O. Ramalho, G. Wyart, C. Mandin, P. Blondeau, P.-A. Cabanes, N. Leclerc, J.-U. Mullot, G. Boulanger, M. Redaelli, Association of carbon dioxide with indoor air pollutants and exceedance of health guideline values, Build. Environ. 93 (2015) 115–124.
[81] L.H.E, T.S, I.S, J.S, S.J, C.G. Bornehag, Low home ventilation rate in combination with moldy odor from the building structure increase the risk for allergic symptoms in children, Indoor Air 19 (3) (2009) 184–192.
[82] J. Sundell, On the history of indoor air quality and health, Indoor Air 14 (2004) 51–58.
[83] P. Wargocki, J. Sundell, W. Bischof, G. Brundrett, P.O. Fanger, F. Gyntelberg, S.O. Hanssen, P. Harrison, A. Pickering, O. Seppänen, P. Wouters, Ventilation and health in non-industrial indoor environments: report from a european multidisciplinary scientific consensus meeting (EUROVEN), Indoor Air 12 (2) (2002) 113–128.
[84] T. Ben-David, M.S. Waring, Interplay of ventilation and filtration: differential analysis of cost function combining energy use and indoor exposure to PM2.5 and ozone, Build. Environ. 128 (2018) 320–335.
[85] E.J. Carlton, K. Barton, P.M. Shrestha, J. Humphrey, L.S. Newman, J.L. Adgate, E. Root, S. Miller, Relationships between home ventilation rates and respiratory health in the Colorado Home Energy Efficiency and Respiratory Health (CHEER) study, Environ. Res. 169 (2019) 297–307.
[86] J. Krieger, D.E. Jacobs, Healthy homes, in: A.L. Dannenberg, H. Frumkin, R.J. Jackson (Eds.), Making Healthy Places: Designing and Building for Health, Well-Being, and Sustainability, Island Press/Center for Resource Economics, Washington, DC, 2011, pp. 170–187.
[87] S. Mirrahimi, M.F. Mohamed, L.C. Haw, N.L.N. Ibrahim, W.F.M. Yusoff, A. Aflaki, The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate, Renew. Sustain. Energy Rev. 53 (2016) 1508–1519.
[88] F. Ascione, N. Bianco, R.F. De Masi, G.M. Mauro, G.P. Vanoli, Design of the building envelope: a novel multi-objective approach for the optimization of energy performance and thermal comfort, Sustainability 7 (8) (2015) 10809.
[89] A. Menzel, M. Matiu, R. Michaelis, S. Jochner, Indoor birch pollen concentrations differ with ventilation scheme, room location, and meteorological factors, Indoor Air 27 (3) (2017) 539–550.
[90] A. Challoner, L. Gill, Indoor/outdoor air pollution relationships in ten commercial buildings: PM2.5 and NO2, Build. Environ. 80 (2014) 159–173.
[91] S.-O. Baek, Y.-S. Kim, R. Perry, Indoor air quality in homes, offices and restaurants in Korean urban areas—indoor/outdoor relationships, Atmos. Environ. 31 (4) (1997) 529–544.
[92] J.S. Apte, K.P. Messier, S. Gani, M. Brauer, T.W. Kirchstetter, M.M. Lunden, J.D. Marshall, C.J. Portier, R.C.H. Vermeulen, S.P. Hamburg, High-resolution air pollution mapping with google street view cars: exploiting big data, Environ. Sci. Technol. 51 (12) (2017) 6999–7008.
[93] C. Chen, C. Liu, R. Chen, W. Wang, W. Li, H. Kan, C. Fu, Ambient air pollution and daily hospital admissions for mental disorders in Shanghai, China, Sci. Total Environ. 613–614 (2018) 324–330.
[94] J.L. Bolton, N.C. Huff, S.H. Smith, S.N. Mason, W.M. Foster, R.L. Auten, S.D. Bilbo, Maternal stress and effects of prenatal air pollution on offspring mental health outcomes in mice, Environ. Health Perspect. 121 (9) (2013) 1075–1082.
[95] G.Z. Lin, L. Li, Y.F. Song, Y.X. Zhou, S.Q. Shen, C.Q. Ou, The impact of ambient air pollution on suicide mortality: a case-crossover study in Guangzhou, China, Environ. Health : a global access science source 15 (1) (2016) 90.
[96] A.V. Bakian, R.S. Huber, H. Coon, D. Gray, P. Wilson, W.M. McMahon, P.F. Renshaw, Acute air pollution exposure and risk of suicide completion, Am. J. Epidemiol. 181 (5) (2015) 295–303.
[97] V.C. Pun, J. Manjourides, H. Suh, Association of ambient air pollution with depressive and anxiety symptoms in older adults: results from the NSHAP study, Environ. Health Perspect. 125 (3) (2017) 342–348.
[98] J. Shin, J.Y. Park, J. Choi, Long-term exposure to ambient air pollutants and mental health status: a nationwide population-based cross-sectional study, PLoS One 13 (4) (2018) e0195607.
[99] Y. Kim, W. Myung, H.-H. Won, S. Shim, H.J. Jeon, J. Choi, B.J. Carroll, D.K. Kim, Association between air pollution and suicide in South Korea: a nationwide study, PLoS One 10 (2) (2015) e0117929.
[100] E. Morales, J. Julvez, M. Torrent, R. de Cid, M. Guxens, M. Bustamante, N. Künzli, J. Sunyer, Association of early-life exposure to household gas appliances and indoor nitrogen dioxide with cognition and attention behavior in preschoolers, Am. J. Epidemiol. 169 (11) (2009) 1327–1336.
[101] F. Villanueva, A. Tapia, S. Lara, M. Amo-Salas, Indoor and outdoor air concentrations of volatile organic compounds and NO2 in schools of urban, industrial and rural areas in Central-Southern Spain, Sci. Total Environ. 622–623 (2018) 222–235.
[102] J.A. Siegel, J. Srebric, N. Crain, E. Nirlo, M. Zaatari, A. Hoisington, J. Urquidi, S. Shu, Y. Kim, D. Jereemit, Ventilation and Indoor Air Quality in Retail Stores, ASHRAE Research Project RP-1596, University of Texas at Austin and Pennsylvania State University, 2013.
[103] M.A. Cohen, P.B. Ryan, Y. Yanagisawa, J.D. Spengler, H. Ozkaynak, P.S. Epstein, Indoor/outdoor measurements of volatile organic compounds in the Kanawha Valley of West Virginia, JAPCA 39 (8) (1989) 1086–1093.
[104] M. Pelletier, P. Glorennec, C. Mandin, B. Le Bot, O. Ramalho, F. Mercier, N. Bonvallot, Chemical-by-chemical and cumulative risk assessment of residential indoor exposure to semivolatile organic compounds in France, Environ. Int. 117 (2018) 22–32.
[105] K. Fournier, E. Baumont, P. Glorennec, N. Bonvallot, Relative toxicity for indoor semi volatile organic compounds based on neuronal death, Toxicol. Lett. 279 (2017) 33–42.
[106] R.L. Corsi, Connect or stagnate: the future of indoor air sciences, Indoor Air 25 (3) (2015) 231–234.
[107] A. Curto, D. Donaire-Gonzalez, J. Barrera-Gómez, J.D. Marshall, M.J. Nieuwenhuijsen, G.A. Wellenius, C. Tonne, Performance of low-cost monitors to assess household air pollution, Environ. Res. 163 (2018) 53–63.
[108] Y.L. Chen, J. Wen, Sensor system design for building indoor air protection, Build. Environ. 43 (7) (2008) 1278–1285.
[109] A.S. Ali, Z. Zanzinger, D. Debose, B. Stephens, Open Source Building Science Sensors (OSBSS): a low-cost Arduino-based platform for long-term indoor environmental data collection, Build. Environ. 100 (2016) 114–126.
[110] J. Li, H. Li, Y. Ma, Y. Wang, A.A. Abokifa, C. Lu, P. Biswas, Spatiotemporal distribution of indoor particulate matter concentration with a low-cost sensor network, Build. Environ. 127 (2018) 138–147.
[111] J.A. Foster, K.-A. McVey Neufeld, Gut–brain axis: how the microbiome influences anxiety and depression, Trends Neurosci. 36 (5) (2013) 305–312.
[112] S. Malan-Muller, M. Valles-Colomer, J. Raes, C.A. Lowry, S. Seedat, S.M.J. Hemmings, The gut microbiome and mental health: implications for anxiety- and trauma-related disorders, OMICS A J. Integr. Biol. 22 (2) (2017) 90–107.
[113] A. Sarkar, S. Harty, S.M. Lehto, A.H. Moeller, T.G. Dinan, R.I.M. Dunbar, J.F. Cryan, P.W.J. Burnet, The microbiome in psychology and cognitive neuroscience, Trends Cognit. Sci. 22 (7) (2018) 611–636.
[114] M.G. Gareau, Microbiota-gut-brain Axis and cognitive function, in: M. Lyte, J.F. Cryan (Eds.), Microbial Endocrinology: the Microbiota-Gut-Brain Axis in Health and Disease, Springer New York, New York, NY, 2014, pp. 357–371.
[115] J.F. Cryan, S.M. O'Mahony, The microbiome-gut-brain axis: from bowel to behavior, Neuro Gastroenterol. Motil. 23 (3) (2011) 187–192.
[116] R.D. Heijtz, S. Wang, F. Anuar, Y. Qian, B. Björkholm, A. Samuelsson, M.L. Hibberd, H. Forssberg, S. Pettersson, Normal gut microbiota modulates brain development and behavior, Proc. Natl. Acad. Sci. Unit. States Am. 108 (7) (2011) 3047–3052.
[117] E.A. Mayer, K. Tillisch, A. Gupta, Gut/brain axis and the microbiota, J. Clin. Investig. 125 (3) (2015) 926–938.
[118] M.W. Hale, G.A. Rook, C.A. Lowry, Pathways underlying afferent signaling of bronchopulmonary immune activation to the central nervous system, Chem. Immunol. Allergy 98 (2012) 118–141.
[119] K.F. Budden, S.L. Gellatly, D.L.A. Wood, M.A. Cooper, M. Morrison, P. Hugenholtz, P.M. Hansbro, Emerging pathogenic links between microbiota and the gut–lung axis, Nat. Rev. Microbiol. 15 (2016) 55.
[120] N.A.o, Engineering, E. National Academies of Sciences, Medicine, Microbiomes of the Built Environment: A Research Agenda for Indoor Microbiology, Human Health, and Buildings, The National Academies Press, Washington, DC, 2017.
[121] R.I. Adams, S. Bhangar, K.C. Dannemiller, J.A. Eisen, N. Fierer, J.A. Gilbert, J.L. Green, L.C. Marr, S.L. Miller, J.A. Siegel, B. Stephens, M.S. Waring, K. Bibby, Ten questions concerning the microbiomes of buildings, Build. Environ. 109 (2016) 224–234.
[122] J. Chase, J. Fouquier, M. Zare, D.L. Sonderegger, R. Knight, S.T. Kelley, J. Siegel, J.G. Caporaso, Geography and location are the primary drivers of office microbiome composition, mSystems 1 (2) (2016).
[123] A. Barberan, J. Ladau, J.W. Leff, K.S. Pollard, H.L. Menninger, R.R. Dunn, N. Fierer, Continental-scale distributions of dust-associated bacteria and fungi, Proc. Natl. Acad. Sci. U.S.A. 112 (18) (2015) 5756–5761.
[124] R.I. Adams, A.C. Bateman, H.M. Bik, J.F. Meadow, Microbiota of the indoor environment: a meta-analysis, Microbiome 3 (1) (2015) 49.

[125] A. Hoisington, J.P. Maestre, K.A. Kinney, J.A. Siegel, Characterizing the bacterial communities in retail stores in the United States, Indoor Air 26 (6) (2016) 857–868.
[126] J.F. Meadow, A.E. Altrichter, A.C. Bateman, J. Stenson, G.Z. Brown, J.L. Green, B.J.M. Bohannan, Humans differ in their personal microbial cloud, PeerJ 3 (2015) e1258.
[127] D. Hospodsky, J. Qian, W.W. Nazaroff, N. Yamamoto, K. Bibby, H. Rismani-Yazdi, J. Peccia, Human occupancy as a source of indoor airborne bacteria, PLoS One 7 (4) (2012) 1–10.
[128] C.E. Estrada-Perez, K.A. Kinney, J.P. Maestre, Y.A. Hassan, M.D. King, Droplet distribution and airborne bacteria in an experimental shower unit, Water Res. 130 (2018) 47–57.
[129] P. Ji, W.J. Rhoads, M.A. Edwards, A. Pruden, Impact of water heater temperature setting and water use frequency on the building plumbing microbiome, ISME J. 11 (2017) 1318.
[130] R.R. Dunn, N. Fierer, J.B. Henley, J.W. Leff, H.L. Menninger, Home life: factors structuring the bacterial diversity found within and between homes, PLoS One 8 (5) (2013) e64133.
[131] E.M. Kettleson, A. Adhikari, S. Vesper, K. Coombs, R. Indugula, T. Reponen, Key determinants of the fungal and bacterial microbiomes in homes, Environ. Res. 138 (2015) 130–135.
[132] A.J. Prussin, D.O. Schwake, L.C. Marr, Ten questions concerning the aerosolization and transmission of Legionella in the built environment, Build. Environ. 123 (2017) 684–695.
[133] B. Brooks, M.R. Olm, B.A. Firek, R. Baker, B.C. Thomas, M.J. Morowitz, J.F. Banfield, Strain-resolved analysis of hospital rooms and infants reveals overlap between the human and room microbiome, Nat. Commun. 8 (1) (2017) 1814.
[134] S.M. Gibbons, The built environment is a microbial wasteland, mSystems 1 (2) (2016).
[135] S.O. Reber, P.H. Siebler, N.C. Donner, J.T. Morton, D.G. Smith, J.M. Kopelman, K.R. Lowe, K.J. Wheeler, J.H. Fox, J.E. Hassell Jr., B.N. Greenwood, C. Jansch, A. Lechner, D. Schmidt, N. Uschold-Schmidt, A.M. Fuchsl, D. Langgartner, F.R. Walker, M.W. Hale, G. Lopez Perez, W. Van Treuren, A. Gonzalez, A.L. Halweg-Edwards, M. Fleshner, C.L. Raison, G.A. Rook, S.D. Peddada, R. Knight, C.A. Lowry, Immunization with a heat-killed preparation of the environmental bacterium Mycobacterium vaccae promotes stress resilience in mice, Proc. Natl. Acad. Sci. U.S.A. 113 (22) (2016) E3130–E3139.
[136] M.G. Frank, L.K. Fonken, S.D. Dolzani, J.L. Annis, P.H. Siebler, D. Schmidt, L.R. Watkins, S.F. Maier, C.A. Lowry, Immunization with Mycobacterium vaccae induces an anti-inflammatory milieu in the CNS: attenuation of stress-induced microglial priming, alarmins and anxiety-like behavior, Brain Behav. Immun. 73 (2018) 352–363.
[137] M.G. Frank, L.K. Fonken, L.R. Watkins, S.F. Maier, C.A. Lowry, Could probiotics Be used to mitigate neuroinflammation? ACS Chem. Neurosci. 10 (1) (2019) 13–15.
[138] J.H. Fox, J.E. Hassell Jr., P.H. Siebler, M.R. Arnold, A.K. Lamb, D.G. Smith, H.E.W. Day, T.M. Smith, E.M. Simmerman, A.A. Outzen, K.S. Holmes, C.J. Brazell, C.A. Lowry, Preimmunization with a heat-killed preparation of Mycobacterium vaccae enhances fear extinction in the fear-potentiated startle paradigm, Brain Behav. Immun. 66 (2017) 70–84.
[139] L.K. Fonken, M.G. Frank, H.M. D'Angelo, J.D. Heinze, L.R. Watkins, C.A. Lowry, S.F. Maier, Mycobacterium vaccae immunization protects aged rats from surgery-elicited neuroinflammation and cognitive dysfunction, Neurobiol. Aging 71 (2018) 105–114.
[140] J.L. Green, Can bioinformed design promote healthy indoor ecosystems? Indoor Air 24 (2) (2014) 113–115.
[141] A.J. Hoisington, L.A. Brenner, K. Kinney, T. Postolache, C.A. Lowry, The microbiome of the built environment and mental health, Microbiome 3 (1) (2015) 60.
[142] A. Mahnert, C. Moissl-Eichinger, M. Zojer, D. Bogumil, I. Mizrahi, T. Rattei, J.L. Martinez, G. Berg, Man-made microbial resistances in built environments, Nat. Commun. 10 (1) (2019) 968.
[143] M.M. Stein, C.L. Hrusch, J. Gozdz, C. Igartua, V. Pivniouk, S.E. Murray, J.G. Ledford, M. Marques dos Santos, R.L. Anderson, N. Metwali, J.W. Neilson, R.M. Maier, J.A. Gilbert, M. Holbreich, P.S. Thorne, F.D. Martinez, E. von Mutius, D. Vercelli, C. Ober, A.I. Sperling, Innate immunity and asthma risk in amish and hutterite farm children, N. Engl. J. Med. 375 (5) (2016) 411–421.
[144] P.G. Holt, C.A. Jones, The development of the immune system during pregnancy and early life, Allergy 55 (8) (2000) 688–697.
[145] A.K. Simon, G.A. Hollander, A. McMichael, Evolution of the immune system in humans from infancy to old age, Proc. Biol. Sci. 282 (1821) (2015) 20143085.
[146] J. Stokholm, M.J. Blaser, J. Thorsen, M.A. Rasmussen, J. Waage, R.K. Vinding, A.-M.M. Schoos, A. Kunøe, N.R. Fink, B.L. Chawes, K. Bønnelykke, A.D. Brejnrod, M.S. Mortensen, W.A. Al-Soud, S.J. Sørensen, H. Bisgaard, Maturation of the gut microbiome and risk of asthma in childhood, Nat. Commun. 9 (1) (2018) 141.
[147] L.M. Christian, J.D. Galley, E.M. Hade, S. Schoppe-Sullivan, C. Kamp Dush, M.T. Bailey, Gut microbiome composition is associated with temperament during early childhood, Brain Behav. Immun. 45 (2015) 118–127.
[148] M.S. Cepeda, P. Stang, R. Makadia, Depression is associated with high levels of C-reactive protein and low levels of fractional exhaled nitric oxide: results from the 2007-2012 national health and nutrition examination surveys, J. Clin. Psychiatry 77 (12) (2016) 1666–1671.
[149] S.A. Eraly, C.M. Nievergelt, A.X. Maihofer, D.A. Barkauskas, N. Biswas, A. Agorastos, D.T. O'Connor, D.G. Baker, Assessment of plasma C-reactive protein as a biomarker of posttraumatic stress disorder risk, JAMA psychiatry 71 (4) (2014) 423–431.
[150] A.H. Miller, V. Maletic, C.L. Raison, Inflammation and its discontents: the role of cytokines in the pathophysiology of major depression, Biol. Psychiatry 65 (9) (2009) 732–741.
[151] A.H. Miller, C.L. Raison, The role of inflammation in depression: from evolutionary imperative to modern treatment target, Nat. Rev. Immunol. 16 (1) (2016) 22–34.
[152] C.L. Raison, C.A. Lowry, G.A. Rook, Inflammation, sanitation, and consternation: loss of contact with coevolved, tolerogenic microorganisms and the pathophysiology and treatment of major depression, Arch. Gen. Psychiatr. 67 (12) (2010) 1211–1224.
[153] A.H. Miller, C.L. Raison, Are anti-inflammatory therapies viable treatments for psychiatric disorders?: where the rubber meets the road, JAMA psychiatry 72 (6) (2015) 527–528.
[154] C.L. Raison, A.H. Miller, The evolutionary significance of depression in Pathogen Host Defense (PATHOS-D), Mol. Psychiatr. 18 (1) (2013) 15–37.
[155] C.L. Raison, L. Capuron, A.H. Miller, Cytokines sing the blues: inflammation and the pathogenesis of depression, Trends Immunol. 27 (1) (2006) 24–31.
[156] R. Raz, A.L. Roberts, K. Lyall, J.E. Hart, A.C. Just, F. Laden, M.G. Weisskopf, Autism spectrum disorder and particulate matter air pollution before, during, and after pregnancy: a nested case-control analysis within the Nurses' Health Study II Cohort, Environ. Health Perspect. 123 (3) (2015) 264–270.
[157] M.G. Weisskopf, M.A. Kioumourtzoglou, A.L. Roberts, Air pollution and autism spectrum disorders: causal or confounded? Current environmental health reports 2 (4) (2015) 430–439.
[158] G.B. Choi, Y.S. Yim, H. Wong, S. Kim, H. Kim, S.V. Kim, C.A. Hoeffer, D.R. Littman, J.R. Huh, The maternal interleukin-17a pathway in mice promotes autism-like phenotypes in offspring, Science 351 (6276) (2016) 933–939.
[159] R.R. Dietert, J.M. Dietert, Potential for early-life immune insult including developmental immunotoxicity in autism and autism spectrum disorders: focus on critical windows of immune vulnerability, J. Toxicol. Environ. Health B Crit. Rev. 11 (8) (2008) 660–680.
[160] C. Vert, G. Sanchez-Benavides, D. Martinez, X. Gotsens, N. Gramunt, M. Cirach, J.L. Molinuevo, J. Sunyer, M.J. Nieuwenhuijsen, M. Crous-Bou, M. Gascon, Effect of long-term exposure to air pollution on anxiety and depression in adults: a cross-sectional study, Int. J. Hyg Environ. Health 220 (6) (2017) 1074–1080.
[161] U. Łopuszańska, M. Makara-Studzińska, (2), The Correlations between Air Pollution and Depression vol. 18, (2017), p. 100.
[162] H.C. Ho, M.S. Wong, L. Yang, W. Shi, J. Yang, M. Bilal, T.C. Chan, Spatiotemporal influence of temperature, air quality, and urban environment on cause-specific mortality during hazy days, Environ. Int. 112 (2018) 10–22.
[163] L.K. Fonken, X. Xu, Z.M. Weil, G. Chen, Q. Sun, S. Rajagopalan, R.J. Nelson, Air pollution impairs cognition, provokes depressive-like behaviors and alters hippocampal cytokine expression and morphology, Mol. Psychiatr. 16 (10) (2011) 987–995 973.
[164] C.A. Lowry, D.G. Smith, P.H. Siebler, D. Schmidt, C.E. Stamper, J.E. Hassell Jr., P.S. Yamashita, J.H. Fox, S.O. Reber, L.A. Brenner, A.J. Hoisington, T.T. Postolache, K.A. Kinney, D. Marciani, M. Hernandez, S.M. Hemmings, S. Malan-Muller, K.P. Wright, R. Knight, C.L. Raison, G.A. Rook, The microbiota, immunoregulation, and mental health: implications for public health, Current environmental health reports 3 (3) (2016) 270–286.
[165] Y.-H. Lim, H. Kim, J.H. Kim, S. Bae, H.Y. Park, Y.-C. Hong, Air pollution and symptoms of depression in elderly adults, Environ. Health Perspect. 120 (7) (2012) 1023–1028.
[166] G.A. Rook, C.L. Raison, C.A. Lowry, Microbial 'old friends', immunoregulation and socioeconomic status, Clin. Exp. Immunol. 177 (1) (2014) 1–12.
[167] G.A. Rook, C.L. Raison, C.A. Lowry, Microbiota, immunoregulatory old friends and psychiatric disorders, Adv. Exp. Med. Biol. 817 (2014) 319–356.
[168] G.A.W. Rook, C.A. Lowry, The hygiene hypothesis and affective and anxiety disorders, in: G.A.W. Rook (Ed.), The Hygiene Hypothesis and Darwinian Medicine, Birkhäuser Basel, Basel, 2009, pp. 189–220.
[169] G.A. Rook, C.A. Lowry, The hygiene hypothesis and psychiatric disorders, Trends Immunol. 29 (4) (2008) 150–158.
[170] G.A. Rook, C.L. Raison, C.A. Lowry, Can we vaccinate against depression? Drug Discov. Today 17 (9–10) (2012) 451–458.
[171] G.A.W. Rook, C.A. Lowry, C.L. Raison, Microbial 'Old Friends', immunoregulation and stress resilience, Evolution, Medicine, and Public Health (1) (2013) 46–64 (2013).
[172] G.A. Rook, C.A. Lowry, C.L. Raison, Hygiene and other early childhood influences on the subsequent function of the immune system, Brain Res. 1617 (2015) 47–62.
[173] G.A.W. Rook, C.L. Raison, C.A. Lowry, Childhood microbial experience, immunoregulation, inflammation and adult susceptibility to psychosocial stressors and depression in rich and poor countries, Evolution, Medicine, and Public Health (1) (2013) 14–17 (2013).
[174] G.R.C. Rook, C.A. Lowry, Microbial "Old Friends", Immunoregulation and Psychiatric Disorders, Old Herborn University Press, 2013 Old Herborn University Monograph.
[175] A.E. Corcoran, M.R. Hodges, Y. Wu, W. Wang, C.J. Wylie, E.S. Deneris, G.B. Richerson, Medullary serotonin neurons and central CO2 chemoreception, Respir. Physiol. Neurobiol. 168 (1–2) (2009) 49–58.
[176] P.L. Johnson, J.H. Hollis, R. Moratalla, S.L. Lightman, C.A. Lowry, Acute hypercarbic gas exposure reveals functionally distinct subpopulations of serotonergic neurons in rats, J. Psychopharmacol. 19 (4) (2005) 327–341.
[177] G.B. Richerson, Serotonergic neurons as carbon dioxide sensors that maintain pH homeostasis, Nat. Rev. Neurosci. 5 (6) (2004) 449–461.
[178] C.A. Severson, W. Wang, V.A. Pieribone, C.I. Dohle, G.B. Richerson, Midbrain serotonergic neurons are central pH chemoreceptors, Nat. Neurosci. 6 (11) (2003) 1139–1140.
[179] E. Cutz, A. Jackson, Neuroepithelial bodies as airway oxygen sensors, Respir.

Physiol. 115 (2) (1999) 201–214.
[180] B.M. Kious, D.G. Kondo, P.F. Renshaw, Living high and feeling low: altitude, suicide, and depression, Harv. Rev. Psychiatry 26 (2) (2018) 43–56.
[181] N. Bakunina, C.M. Pariante, P.A. Zunszain, Immune mechanisms linked to depression via oxidative stress and neuroprogression, Immunology 144 (3) (2015) 365–373.
[182] M.E. Sublette, T.T. Postolache, Neuroinflammation and depression: the role of indoleamine 2,3-dioxygenase (Ido) as a molecular pathway, Psychosom. Med. 74 (7) (2012) 668–672.
[183] S. Erhardt, C.K. Lim, K.R. Linderholm, S. Janelidze, D. Lindqvist, M. Samuelsson, K. Lundberg, T.T. Postolache, L. Traskman-Bendz, G.J. Guillemin, L. Brundin, Connecting inflammation with glutamate agonism in suicidality, Neuropsychopharmacology : official publication of the American College of Neuropsychopharmacology 38 (5) (2013) 743–752.
[184] A. Kewalramani, M.E. Bollinger, T.T. Postolache, Asthma and mood disorders, International journal of child health and human development : IJCHD 1 (2) (2008) 115–123.
[185] A.U. Amritwar, C.A. Lowry, L.A. Brenner, A.J. Hoisington, R. Hamilton, J.W. Stiller, T.T. Postolache, Mental health in allergic rhinitis: depression and suicidal behavior, Current treatment options in allergy 4 (1) (2017) 71–97.
[186] L.K. Fonken, M.G. Frank, A.D. Gaudet, S.F. Maier, Stress and aging act through common mechanisms to elicit neuroinflammatory priming, Brain Behav. Immun. 73 (2018) 133–148.
[187] C.L. Mumaw, S. Levesque, C. McGraw, S. Robertson, S. Lucas, J.E. Stafflinger, M.J. Campen, P. Hall, J.P. Norenberg, T. Anderson, A.K. Lund, J.D. McDonald, A.K. Ottens, M.L. Block, Microglial priming through the lung-brain axis: the role of air pollution-induced circulating factors, FASEB J. : official publication of the Federation of American Societies for Experimental Biology 30 (5) (2016) 1880–1891.
[188] J.L. Bolton, S.H. Smith, N.C. Huff, M.I. Gilmour, W.M. Foster, R.L. Auten, S.D. Bilbo, Prenatal air pollution exposure induces neuroinflammation and predisposes offspring to weight gain in adulthood in a sex-specific manner, FASEB J. : official publication of the Federation of American Societies for Experimental Biology 26 (11) (2012) 4743–4754.
[189] G.A. Rook, Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health, Proc. Natl. Acad. Sci. U.S.A. 110 (46) (2013) 18360–18367.
[190] J. Peen, R.A. Schoevers, A.T. Beekman, J. Dekker, The current status of urban-rural differences in psychiatric disorders, Acta Psychiatr. Scand. 121 (2) (2010) 84–93.
[191] E. Vassos, E. Agerbo, O. Mors, C.B. Pedersen, Urban-rural differences in incidence rates of psychiatric disorders in Denmark, Br. J. Psychiatry : J. Ment. Sci. 208 (5) (2016) 435–440.
[192] C.B. Pedersen, P.B. Mortensen, Evidence of a dose-response relationship between urbanicity during upbringing and schizophrenia risk, Arch. Gen. Psychiatr. 58 (11) (2001) 1039–1046.
[193] P.B. Mortensen, C.B. Pedersen, T. Westergaard, J. Wohlfahrt, H. Ewald, O. Mors, P.K. Andersen, M. Melbye, Effects of family history and place and season of birth on the risk of schizophrenia, N. Engl. J. Med. 340 (8) (1999) 603–608.
[194] C.B. Pedersen, P.B. Mortensen, Family history, place and season of birth as risk factors for schizophrenia in Denmark: a replication and reanalysis, Br. J. Psychiatry : J. Ment. Sci. 179 (2001) 46–52.
[195] G. Lewis, A. David, S. Andreasson, P. Allebeck, Schizophrenia and city life, Lancet 340 (8812) (1992) 137–140.
[196] L. von Hertzen, B. Beutler, J. Bienenstock, M. Blaser, P.D. Cani, J. Eriksson, M. Farkkila, T. Haahtela, I. Hanski, M.C. Jenmalm, J. Kere, M. Knip, K. Kontula, M. Koskenvuo, C. Ling, T. Mandrup-Poulsen, E. von Mutius, M.J. Makela, T. Paunio, G. Pershagen, H. Renz, G. Rook, M. Saarela, O. Vaarala, M. Veldhoen, W.M. de Vos, Helsinki alert of biodiversity and health, Ann. Med. 47 (3) (2015) 218–225.
[197] E.D. Sonnenburg, J.L. Sonnenburg, Starving our microbial self: the deleterious consequences of a diet deficient in microbiota-accessible carbohydrates, Cell Metabol. 20 (5) (2014) 779–786.
[198] J.C. Atherton, M.J. Blaser, Coadaptation of Helicobacter pylori and humans: ancient history, modern implications, J. Clin. Investig. 119 (9) (2009) 2475–2487.
[199] C. Ohnmacht, J.-H. Park, S. Cording, J.B. Wing, K. Atarashi, Y. Obata, V. Gaboriau-Routhiau, R. Marques, S. Dulauroy, M. Fedoseeva, M. Busslinger, N. Cerf-Bensussan, I.G. Boneca, D. Voehringer, K. Hase, K. Honda, S. Sakaguchi, G. Eberl, The microbiota regulates type 2 immunity through RORγt^{+} T cells, Science 349 (6251) (2015) 989.
[200] E. Sefik, N. Geva-Zatorsky, S. Oh, L. Konnikova, D. Zemmour, A.M. McGuire, D. Burzyn, A. Ortiz-Lopez, M. Lobera, J. Yang, S. Ghosh, A. Earl, S.B. Snapper, R. Jupp, D. Kasper, D. Mathis, C. Benoist, Individual intestinal symbionts induce a distinct population of RORγ^{+} regulatory T cells, Science 349 (6251) (2015) 993.
[201] T.S. Böbel, S.B. Hackl, D. Langgartner, M.N. Jarczok, N. Rohleder, G.A. Rook, C.A. Lowry, H. Gündel, C. Waller, S.O. Reber, Less immune activation following social stress in rural vs. urban participants raised with regular or no animal contact, respectively, PNAS 115 (20) (May 15, 2018) 5259–5264.
[202] N. Rohleder, Stimulation of systemic low-grade inflammation by psychosocial stress, Psychosom. Med. 76 (3) (2014) 181–189.
[203] K. Engemann, C.B. Pedersen, L. Arge, C. Tsirogiannis, P.B. Mortensen, J.-C. Svenning, Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood, PNAS 116 (11) (March 12, 2019) 5188–5193.
[204] R.H.B, R.F. Corwyn, Socioeconomic status and child development, Annu. Rev. Psychol. 53 (1) (2002) 371–399.
[205] B. Lalloué, J.-M. Monnez, C. Padilla, W. Kihal, N. Le Meur, D. Zmirou-Navier, S. Deguen, A statistical procedure to create a neighborhood socioeconomic index for health inequalities analysis, Int. J. Equity Health 12 (1) (2013) 21.
[206] D.R. Williams, M. Harris-Reid, Race and Mental Health: Emerging Patterns and Promising Approaches, A Handbook for the Study of Mental Health: Social Contexts, Theories, and Systems, Cambridge University Press, New York, NY, US, 1999, pp. 295–314.
[207] J.S. Feinstein, The relationship between socioeconomic status and health: a review of the literature, Milbank Q. 71 (2) (1993) 279–322.
[208] N.E. Adler, T. Boyce, M.A. Chesney, S. Cohen, S. Folkman, R.L. Kahn, S.L. Syme, Socioeconomic status and health. The challenge of the gradient, Am. Psychol. 49 (1) (1994) 15–24.
[209] K.A. Rollings, N.M. Wells, G.W. Evans, A. Bednarz, Y. Yang, Housing and neighborhood physical quality: children's mental health and motivation, J. Environ. Psychol. 50 (2017) 17–23.
[210] S.F. Suglia, C.S. Duarte, M.T. Sandel, Housing quality, housing instability, and maternal mental health, J. Urban Health 88 (6) (2011) 1105–1116.
[211] S.N. Shah, A. Fossa, A.S. Steiner, J. Kane, J.I. Levy, G. Adamkiewicz, W.M. Bennett-Fripp, M. Reid, Housing quality and mental health: the association between pest infestation and depressive symptoms among public housing residents, J. Urban Health : Bull. N. Y. Acad. Med. 95 (5) (2018) 691–702.
[212] G.E. Zahner, S.V. Kasl, M. White, J.C. Will, Psychological consequences of infestation of the dwelling unit, Am. J. Public Health 75 (11) (1985) 1303–1307.
[213] K. Byers, C. Himsworth, R. Lam, Beyond Zoonosis: the Mental Health Impacts of Rat Exposure on Impoverished Urban Neighborhoods, (2018).
[214] A. Bocquier, S. Cortaredona, C. Boutin, A. David, A. Bigot, B. Chaix, J. Gaudart, P. Verger, Small-area analysis of social inequalities in residential exposure to road traffic noise in Marseilles, France, Eur. J. Public Health 23 (4) (2013) 540–546.
[215] S.A. Stansfeld, M.M. Haines, M. Burr, B. Berry, P. Lercher, A review of environmental noise and mental health, Noise Health 2 (8) (2000) 1–8.
[216] A. Tarnopolsky, S.M. Barker, R.D. Wiggins, E.K. McLean, The effect of aircraft noise on the mental health of a community sample: a pilot study, Psychol. Med. 8 (2) (1978) 219–233.
[217] F. Hammersen, H. Niemann, J. Hoebel, Environmental noise annoyance and mental health in adults: findings from the cross-sectional German health update (GEDA) study 2012, Int. J. Environ. Res. Public Health 13 (10) (2016) 954.
[218] M.E. Beutel, C. Jünger, E.M. Klein, P. Wild, K. Lackner, M. Blettner, H. Binder, M. Michal, J. Wiltink, E. Brähler, T. Münzel, Noise annoyance is associated with depression and anxiety in the general population- the contribution of aircraft noise, PLoS One 11 (5) (2016) e0155357.
[219] H.A.R. Jensen, B. Rasmussen, O. Ekholm, Neighbour and traffic noise annoyance: a nationwide study of associated mental health and perceived stress, Eur. J. Public Health 28 (6) (December 2018) 1050–1055 cky091-cky091.
[220] A. Recio, C. Linares, J.R. Banegas, J. Díaz, Road traffic noise effects on cardiovascular, respiratory, and metabolic health: an integrative model of biological mechanisms, Environ. Res. 146 (2016) 359–370.
[221] R. Bentley, E. Baker, K. Mason, S.V. Subramanian, A.M. Kavanagh, Association between housing affordability and mental health: a longitudinal analysis of a nationally representative household survey in Australia, Am. J. Epidemiol. 174 (7) (2011) 753–760.
[222] R. Bentley, E. Baker, A. LaMontagne, T. King, K. Mason, A. Kavanagh, Does employment security modify the effect of housing affordability on mental health? SSM - population health 2 (2016) 778–783.
[223] J.A. Siegel, Primary and secondary consequences of indoor air cleaners, Indoor Air 26 (1) (2015) 88–96.
[224] W.J. Fisk, Health benefits of particle filtration, Indoor Air 23 (5) (2013) 357–368.
[225] R.D. Peng, A.M. Butz, A.J. Hackstadt, D.A.L. Williams, G.B. Diette, P.N. Breysse, E.C. Matsui, Estimating the health benefit of reducing indoor air pollution in a randomized environmental intervention, J. R. Stat. Soc. Ser. A 178 (2) (2015) 425–443.
[226] K.C. Dannemiller, J.F. Gent, B.P. Leaderer, J. Peccia, Influence of housing characteristics on bacterial and fungal communities in homes of asthmatic children, Indoor Air 26 (2) (2016) 179–192.
[227] B. Andersen, J.C. Frisvad, I. Søndergaard, I.S. Rasmussen, L.S. Larsen, Associations between Fungal Species and Water Damaged Building Materials, Applied and Environmental Microbiology, 2011.
[228] K. Mustonen, A.M. Karvonen, P. Kirjavainen, M. Roponen, B. Schaub, A. Hyvärinen, U. Frey, H. Renz, P.I. Pfefferle, J. Genuneit, O. Vaarala, J. Pekkanen, Moisture damage in home associates with systemic inflammation in children, Indoor Air 26 (3) (2016) 439–447.
[229] A.M. Karvonen, C. Tischer, P.V. Kirjavainen, M. Roponen, A. Hyvärinen, S. Illi, K. Mustonen, P.I. Pfefferle, H. Renz, S. Remes, B. Schaub, E. von Mutius, J. Pekkanen, Early age exposure to moisture damage and systemic inflammation at the age of 6 years, Indoor Air 28 (3) (2018) 450–458.
[230] M. Korkalainen, M. Täubel, J. Naarala, P. Kirjavainen, A. Koistinen, A. Hyvärinen, H. Komulainen, M. Viluksela, Synergistic proinflammatory interactions of microbial toxins and structural components characteristic to moisture-damaged buildings, Indoor Air 27 (1) (2017) 13–23.
[231] U. Haverinen-Shaughnessy, A. Hyvärinen, T. Putus, A. Nevalainen, Monitoring success of remediation: seven case studies of moisture and mold damaged buildings, Sci. Total Environ. 399 (1) (2008) 19–27.
[232] U. Lignell, T. Meklin, T. Putus, H. Rintala, A. Vepsäläinen, P. Kalliokoski, A. Nevalainen, Effects of moisture damage and renovation on microbial conditions and pupils' health in two schools—a longitudinal analysis of five years, J. Environ. Monit. 9 (3) (2007) 225–233.
[233] M.J. Mendell, J.M. Macher, K. Kumagai, Measured moisture in buildings and

adverse health effects: a review, Indoor Air 28 (4) (2018) 488–499.
[234] E.D. Shenassa, C. Daskalakis, A. Liebhaber, M. Braubach, M. Brown, Dampness and mold in the home and depression: an examination of mold-related illness and perceived control of one's home as possible depression pathways, Am. J. Public Health 97 (10) (2007) 1893–1899.
[235] R.I. Adams, W. Chen, K. Kumagai, J.M. Macher, M.J. Mendell, Relating measured moisture of gypsum board to estimated water activity using moisture meters, Build. Environ. 147 (2019) 284–298.
[236] C. Jiang, X. Wang, X. Li, J. Inlora, T. Wang, Q. Liu, M. Snyder, Dynamic human environmental exposome revealed by longitudinal personal monitoring, Cell 175 (1) (2018) 277–291 e31.
[237] M. Marmot, Social determinants of health inequalities, Lancet 365 (9464) (2005) 1099–1104.
[238] C.G. Hudson, Socioeconomic status and mental illness: tests of the social causation and selection hypotheses, Am. J. Orthopsychiatry 75 (1) (2005) 3–18.
[239] S. Sen, Socioeconomic status and mental health: what is the causal relationship? Acta Psychiatr. Scand. 125 (3) (2012) 187–188.
[240] S. Kvrgic, S. Harhaji, V. Mijatovic Jovanovic, E. Ac Nikolic, I. Radic, S. Cankovic, D. Cankovic, Gender differences in mental health among adult population in vojvodina, Serbia, Iran. J. Public Health 42 (8) (2013) 833–841.
[241] A. Boyd, S. Van de Velde, G. Vilagut, R. de Graaf, S. O'Neill, S. Florescu, J. Alonso, V. Kovess-Masfety, Gender differences in mental disorders and suicidality in Europe: results from a large cross-sectional population-based study, J. Affect. Disord. 173 (2015) 245–254.
[242] T.S. Hottes, L. Bogaert, A.E. Rhodes, D.J. Brennan, D. Gesink, Lifetime prevalence of suicide attempts among sexual minority adults by study sampling strategies: a systematic review and meta-analysis, Am. J. Public Health 106 (5) (2016) e1–e12.
[243] H.M. Skeels, Adult status of children with contrasting early life experiences: a follow-up study, Monogr. Soc. Res. Child Dev. 31 (3) (1966) 1–65.
[244] F. Cirulli, N. Francia, A. Berry, L. Aloe, E. Alleva, S.J. Suomi, Early life stress as a risk factor for mental health: role of neurotrophins from rodents to non-human primates, Neurosci. Biobehav. Rev. 33 (4) (2009) 573–585.
[245] B.S. McEwen, Early life influences on life-long patterns of behavior and health, Ment. Retard. Dev. Disabil. Res. Rev. 9 (3) (2003) 149–154.
[246] A.E. Barrett, R.J. Turner, Family structure and mental health: the mediating effects of socioeconomic status, family process, and social stress, J. Health Soc. Behav. 46 (2) (2005) 156–169.
[247] C.E. Adair, B. Kopp, J. Lavoie, J. Distasio, S.W. Hwang, A. Watson, S. Veldhuizen, K. Chislett, J. Voronka, M. Ahmad, N. Ahmed, P. Goering, Development and initial validation of the Observer-Rated Housing Quality Scale (OHQS) in a multisite trial of housing first, J. Urban Health : Bull. N. Y. Acad. Med. 91 (2) (2014) 242–255.
[248] T.H.M. Moore, J.M. Kesten, J.A. López-López, S. Ijaz, A. McAleenan, A. Richards, S. Gray, J. Savović, S. Audrey, The effects of changes to the built environment on the mental health and well-being of adults: systematic review, Health Place 53 (2018) 237–257.