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Occupant health and safety risk and opportunity in the delivery of building energy retrofits

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Abstract

Purpose – The process of retrofitting presents occupational health and safety (OHS) challenges, including the possibility of indoor air quality (IAQ) issues, occupational diseases and injuries, exposure to toxic materials and unintentional falls. This has resulted in significant resentment against the retrofit trade. This study aims to clarify the health and safety concerns of occupants in existing South African buildings during the process of retrofitting for energy efficiency.

Design/methodology/approach – The study adopted a qualitative research approach to gather information on how service providers comprehend health and safety concerns during implementation of building energy retrofit projects in existing buildings in South Africa.

Findings – The findings from the study identified several OHS concerns associated with building energy retrofit projects. These include the presence and potential disturbance of asbestos-containing materials or polychlorinated biphenyls (PCBs) during lighting replacement, the trapping of moisture behind spray foam insulation, mould intrusion during system or component replacement, improperly vented combustion gases and occupant exposure to carbon dioxide (CO_2). Furthermore, the study clarified viable methods for mitigating these issues, which have significant implications for the effective implementation of building energy retrofit projects in existing buildings.

Originality/value – The analysis reveals that every operation involved in a building energy retrofit project entails potential OHS implications. Understanding these risks enables stakeholders to develop standardized and optimized approaches for implementing building energy retrofit projects without compromising occupant safety.

Keywords Building, CO_2 emission, Energy, Health and safety, Retrofit, Sustainability

Paper type Case report

1. Introduction

The design, construction, operation and maintenance of building energy retrofits can have an effect on the air quality, energy usage and occupant health (United States Environmental Protection Agency, 2022). Furthermore, the implementation of carbon dioxide (CO_2) emission reduction techniques has the potential to exacerbate pre-existing indoor environmental issues and compromise indoor air quality (IAQ) (UNEPA, 2024). Additionally, it can give rise to novel challenges when there are alterations in the frequency or intensity of unfavourable outdoor circumstances (UNEPA, 2024). In order to ensure the safety and well-being of individuals inside buildings and to create a healthy indoor environment, it is important to consider the health, well-being and safety of the inhabitants when considering building energy retrofits (United States Environmental Protection Agency, 2017).

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Deep building energy retrofits can be classified as an energy conservation measure in an existing building that significantly enhances the overall energy efficiency of the building. A deep energy retrofit, as defined by Less and Walker (2014), is a comprehensive assessment and enhancement procedure for a building that aims to reduce on-site energy consumption by 50% or more compared to the baseline energy usage (determined through utility bill analysis). This is achieved by utilizing existing technologies, materials and construction practices. Retrofit projects yield numerous benefits, both in terms of energy and non-energy, for the client (Less and Walker, 2014; Fawcett *et al.*, 2014). Deep energy retrofit projects are guided by distinct phases, including pre-planning, project planning, construction and test out (Fawcett, 2013; Less and Walker, 2014). Retrofitting existing structures is more complex than developing a new sustainable building from the beginning, as stated in the documentation by Miller and Buys (2011). The incorporation of multiple disciplines complicates the delivery process (Godwin, 2011). On a global scale, the largest portion of the constructed environment is made up of existing buildings. It is crucial to begin implementing energy retrofits in order to decrease energy consumption and the expenses associated with heating, cooling and lighting.

The Construction Industry Development Board (CIDB) in South Africa has emphasized the importance of retrofitting the existing buildings in the country, as mentioned in the study by Milford (2009) quoted in Okorafor *et al.* (2019). Nevertheless, upgrading existing structures serves a purpose beyond energy conservation; it can also be employed to establish a high-performance building (Paradis, 2012). Moreover, the practice of retrofitting is still in its early stages of development in South Africa (Okorafor *et al.*, 2019). There are five clear indicators that demonstrate this issue. Firstly, there is no existing delivery system for retrofitting. Secondly, the official schedule of rates for any government agency does not include energy retrofits. Thirdly, there is a scarcity of contractors and skilled artisans who are knowledgeable in this field. Fourthly, professionals have limited knowledge of retrofitting options. Lastly, the available information on retrofitting is not adequate. Consequently, the implementation of retrofitting as a strategy for controlling carbon emissions is hindered by several challenges, making it inaccessible to the average individual (Milford, 2009; Okorafor, 2019).

While global interest in energy-efficient retrofitting continues to rise, there remains a critical gap in understanding the occupational health and safety (OH&S) concerns specific to the South African context. This study seeks to fill that gap by examining how retrofitting activities interact with ageing infrastructure, weak regulatory enforcement and region-specific environmental conditions. Unlike countries with established retrofit standards, South Africa contends with persistent exposure to hazardous materials, such as asbestos, lead-based paint, mercury and mould, often embedded in outdated buildings (Milne *et al.*, 2013). These risks are further exacerbated by climatic factors such as high humidity and inadequate ventilation, which accelerate indoor moisture accumulation and increase associated health hazards. Consequently, this study seeks to elucidate the health and safety concerns of occupants in existing South African buildings during the energy retrofit process. By clarifying these interrelated risks, the study provides regionally grounded insights into the global discourse on retrofit safety and underscores the urgent need for policy reform and climate-adaptive retrofitting strategies within South African building practice.

2. Literature review

The process of retrofitting for sustainability is perceived as an expensive and disruptive undertaking (Oppong and Masahudu, 2014; Ernest *et al.*, 2016). Occupants of buildings display a strong dislike for both change and disruptive operations (Miller and Buys, 2011). Retrofit procedures commonly involve the addition of existing walls, opening walling components, removal and installation of heating, ventilating, and air-conditioning (HVAC) components, and strengthening of frames (Wilkinson, 2012). Consequently, there are costly ramifications such as major development, displacement of residents and demolition. Owners of buildings are sometimes prevented from improving their structures because of the disturbances that occur throughout these operations (Cheung *et al.*, 2000; Wilkinson, 2012), which inadvertently leads to a danger to OH&S. Building energy retrofit project designs should prioritize the mitigation or reduction of risks to workers and occupants, rather than relying on administrative processes, personal protective equipment (PPE), or other methods to prevent accidents.

Available research indicates that construction work is considered one of the most hazardous occupations globally, surpassing all other industries in terms of worker deaths (Department of Labour, 2022). As a result, the Department of Labour has categorized the construction industry as one of the most hazardous in the country. In order to mitigate the occurrence of accidents and diseases in the industry, representatives from the government, large corporations and organized labour have signed a Health and Safety (H&S) agreement, as reported by the Department of Labour in 2022. In addition, the South African government has made provision of an OH&S specifications document to assist in achieving compliance with the Occupational Health & Safety Act 85/1993 (OHS Act) and the now promulgated Construction Regulations (February 2014) to prevent or, as far as possible, reduce incidents and injuries (South African Reserve Bank, 2019). These specifications should serve as the foundation for developing the principal contractor's and other contractors' construction phase health and safety plans. Accurate data on occupational accidents and work-related diseases are essential for identifying root causes, recognizing new hazards and emerging risks, establishing priorities and ensuring effective preventive measures (ILO, 2023). Nonetheless, the collection of precise data continues to be a worldwide difficulty owing to the deficiencies in the recording and reporting systems present in several nations. To address this information gap, the International Labour Organization (ILO) has been producing estimates of fatal occupational injuries since 1998 and of work-related illnesses since 2001, using the most reliable data sources available (ILO, 2023). To substantiate this assertion, it should be noted that the construction sector has been classified as one of the most hazardous industries (Kamoli and Mahmud, 2022). Construction work has significant hazards and exhibits a substantial incidence of fatal accidents (Chan *et al.*, 2016; Nnaji and Awolusi, 2021). According to the ILO, in 2018, the industry exhibits a much higher incidence of accidents and fatalities in relation to its workforce. According to Umeokafor *et al.* (2022), it is one of the highest in comparison to other industries. Based on the 2019 report from the US Bureau of Labour Statistics, the construction sector accounted for 14% of workplace fatalities and 7% of non-fatal injuries in the United States in 2018. The construction sector holds great significance as a major and dynamic economic force globally, providing employment opportunities for millions of people (Rostami *et al.*, 2015). However, construction is a hazardous, labour-intensive, fragmented and constantly changing industry, despite its ability to provide income generation (Wang *et al.*, 2019a, b).

Its dynamism and fragmentation gave rise to the subject of discussion. Building energy retrofitting process (BERP) is relatively a new trade in the global south (Okorafor, 2019), and as such there are many issues surrounding the retrofit trade. For example, Rickaby *et al.* (2014) and Barrett-Duckett *et al.* (2014) posit that ill-considered retrofits without understanding of the risks, poor knowledge of building physics and poor attention to detail can result in interstitial condensation. These risks should not be underestimated nor overlooked. Various authors such as Barrett-Duckett *et al.* (2014) and Bonfield (2016) claimed that poor retrofit leads to poor internal air quality, surface condensation and mould growth. This leads to serious health risks that are susceptible to respiratory illnesses (Rickaby *et al.*, 2014; British Standards Institution, 2023). In the United Kingdom, the Code of Practice for managing energy retrofit in buildings (BSI, 2023) was extensively updated, and additional domestic retrofit guidance has been published by the Construction Products Association (Hansford, 2015; Rickaby *et al.*, 2014) and the Institute for Sustainability (Rickaby *et al.*, 2014; British Standards Institution, 2023), amongst others. In all this work, the importance of managing technical risks to buildings and serious health risks to occupants was emphasized. For example, in the United Kingdom, there were instances of retrofit failures following the launch of the Green Deal, a government initiative designed to increase the uptake of domestic retrofit by providing loans through commercial Green Deal Providers (Rickaby *et al.*, 2014).

The Green Deal ultimately failed due to the de-professionalization of the domestic retrofit industry, as professionals were deemed too expensive (Rickaby *et al.*, 2014; British Standards Institution, 2023). This argument was reinforced by Vince (2023), who asserted that professionals are better positioned to manage retrofit risks because they possess a deeper understanding of building physics and related factors. The authors further criticized the engagement of non-professionals who lacked formal training, had limited knowledge of building physics, and were poorly equipped to identify and manage retrofit risks (Vince, 2023; Hansford, 2015; Rickaby *et al.*, 2014). An important lesson learned from this project is that rectifying poor retrofit work is time-consuming and costs several times more than executing the original work correctly (Wang *et al.*, 2019a, b; Apps, 2022; Barrett-Duckett *et al.*, 2014; Bonfield, 2016). Moreover, damage to occupants' health resulting from inadequate retrofit practices is often difficult to remedy and, in some cases, fatal (Barrett-Duckett *et al.*, 2014; Bonfield, 2016). Following the Grenfell disaster, construction professionals have demonstrated increased awareness of retrofit-related issues; however, qualitative evidence suggests that specific technical knowledge remains insufficient (Mohamed *et al.*, 2019). To address this gap, changes in construction education and pedagogy, along with an expansion of facilities managers' roles, have been proposed (Mohamed *et al.*, 2019). It has also been argued that the poor professional culture within the retrofit industry significantly contributed to the negative outcomes associated with retrofit practices. These insights underscore the importance of the present study in the South African context.

3. Research method

This study employed a qualitative methodology, involving interviews with industry professionals. The interviews focused on the aspects of health, safety and occupant well-being in the implementation of building energy retrofit projects. The decision to use a qualitative technique was based on the fact that qualitative research methodologies enable thorough and extensive exploration and interrogation of interviewees' responses. Gray (2014) and Creswell (2013) have identified various forms of qualitative research methods, such as in-depth interviews, focus groups, ethnographic research, content analysis and case study research.

This study employed in-depth interviews and case studies. The case study component focused on existing buildings undergoing deep energy retrofit projects, with an average age of 29 years and an average of 14 floors. To achieve the study's objectives, research questions were developed based on a review of the literature, particularly Wang *et al.*'s (2019a, b) work on reducing energy consumption in buildings. A total of 12 case studies and eight interviews were selected based on the respondents' willingness to participate, the potential richness of the data expected from the case studies and the point of data saturation achieved. According to Baker and Edwards (2012), qualitative research experts argue that there is no definitive answer to the question of *how many* participants are required, as sample size depends on several epistemological, methodological and practical factors. Vasileiou *et al.* (2018) recommend that qualitative samples be large enough to generate a "new and richly textured understanding" of the phenomenon under study, yet small enough to permit the "deep, case-oriented analysis" characteristic of qualitative research. They further contend that the more useable data collected from each participant, the fewer participants are needed—an observation reflected in the current study. These scholarly assertions substantiate the methodological choice of 12 case studies and eight interview participants. Moreover, Ogden and Cornwell (2010) and Levitt *et al.* (2017) emphasize that the degree of question structure in qualitative interviews influences the richness of data generated; this consideration informed the design of interview questions (IQs) in the present study.

Information from the interviews was collected from project documents and by obtaining further details from the project participant. The data collection activity serves as a confirming link between the literature review and the data collection in the form of the in-depth interview. The interviewees were building energy retrofit experts who were selected based on their profession, their willingness to participate in the study, their experience and their interest in improving the field of research. All participants were provided with an information guide about the study that indicates that responses will remain strictly confidential, and data will be analysed and presented anonymously. The interviews were descriptively and thematically analysed. The textual data presented in this study follows emergent patterns from the set IQs. These include:

IQ1. Describe the activities that will lead to OHS concerns, along with the remedies in upgrading lighting fixtures to save energy.

IQ2. Describe the activities that will lead to OHS concerns, along with the remedies for upgrading roof and ceiling insulation.

IQ3. Describe the activities that will lead to OHS concerns, along with the remedies for upgrading wall insulation.

IQ4. Describe the activities that will lead to OHS concerns, along with the remedies in modifying or repairing existing moisture barriers.

IQ5. Describe the activities that will lead to OHS concerns, along with the remedies in altering or cleaning fan coils and unit ventilators.

IQ6. Describe the activities that will lead to OHS concerns, along with the remedies in pipe modifications.

IQ7. Describe the activities that will lead to OHS concerns, along with the remedies in HVAC controls to monitor/maintain IAQ (upgrades or modifications).

Data collection continued until reaching saturation, which is the stage at which data starts to repeat and become redundant, and no longer provides any novel or additional insights (Ritchie *et al.*, 2014). According to Saunders *et al.* (2016), a sample size ranging from 4 to 12 participants is optimal for achieving data saturation in qualitative data gathering. The case studies are outlined in Table 1, while the interviewers' profiles are presented in Table 2. The

Table 1. Western Cape Hotel Facility 19 Description of the case study building

S/N	Location	Type of building	Age of the building (years)	Height in stories
1	Western Cape	Office complex	35	11
2	Western Cape	Government administrative building	27	7
3	Western Cape	Multi-purpose office complex	25	17
4	Western Cape	Hotel Facility	19	10
5	Free State	Government administrative building	27	12
6	Free State	Government administrative building	36	13
7	Gauteng	Government administrative building	30	27
8	Gauteng	Hotel Facility	41	12
9	Kwazulu-Natal	Government administrative building	22	18
10	Kwazulu-Natal	Hotel facility	20	14
11	Easter Cape	Government administrative building	38	9
12	Gauteng	Government administrative building	28	18

Source(s): Authors' own creation

Table 2. Interviewee's demographics

Interviewee	Position	Experience in years
1	Technical director	11
2	Site Manager	14
3	Managing director	12
4	Manager	7
5	Energy manager	15
6	HVAC Engineer	15
7	Electrician	12
8	Manager	12

Source(s): Authors' own creation

respondents are skilled individuals who are accountable for the process of upgrading the building in this specific case study. The researchers gather the participants' opinions of the consequences of BERP on health and safety, as well as their recommendations for resolving these consequences. The interviewees' information was collected using a digital recording device, which was explicitly shown to them before the interview began, to ensure their explicit agreement to being recorded. The recording equipment enabled the researcher to focus entirely on the responses while also making notes during and after the recording. These notes were considered during the process of analysing the data. Every interview was transcribed and then subjected to a thematic analysis that focused on identifying and examining key views, relationships and distinctions related to the subject matter. A comprehensive review of literature was conducted to ensure a thorough grasp of the research subject and to gather viewpoints from the participants. This involved re-examining and evaluating the interview transcripts to verify that the focus on the subject matter was precisely recorded.

The main goal of the case study (case interview sessions) was to collect information about the real-life experiences of relevant stakeholders who have been involved with the specific BERPs, while also evaluating the effectiveness of the operational aspects that contribute to OHS issues. The interviews took place in the headquarters of both organizations that had executed the case project. Each interview session had a duration of around 60 min on average. The sessions were tape-recorded with the interviewees' consent and transcribed word-for-word for analysis.

4. Research findings

Gathering information from a wide range of service providers is crucial for acquiring comprehensive knowledge on the subject of research. The interviews in the sample are drawn from a diverse range of organizations, backgrounds and levels of expertise. This ensured a wide range of perspectives on the topic issue. A purposive sample was utilized, consisting of 8 respondents who were interviewed. The participants possess an average of 12.3 years of experience in BERPs. The viewpoints were collected and consolidated for the purpose of facilitating presentation and analysis, as shown in Table 3. Figure 1 provides a summary of the OHS hazards and the associated control measures within the building system.

5. Discussions of findings

For ease of presentation, the discussion is done under each activity.

Table 3. Matrix of activities causing occupational health and safety concerns, and suggested remedies

Activities	Occupational health and safety issues	Solutions
Upgrading lighting fixtures to save energy	The study indicates that the presence of asbestos-containing material, lead paint, or PCBs could potentially be disrupted while replacing lighting fixtures. All interviewees lay claim to this issue. PCBs could potentially be found in older fluorescent lamp ballasts that lack proper labelling. Five interviewees supported this notion, while the remaining three were indifferent. Additionally, mercury vapour or mercury-laden powder may be present due to the breakage of fluorescent bulbs or the improper use of drum-top crushers. Two of the interviewees lay claim to redness/swelling of the eye in some instances and reduction in sense of smell. These activities can lead to a variety of consequences	The eight respondents in all the case study building recommended that the situation be addressed by removing and replacing old fixtures that contain hazardous compounds with ones that contain less dangerous components. Effectively disposing of lights containing mercury and fixtures containing PCBs will equally contribute to the solution
Upgrading roof and ceiling insulation	According to all the respondents, the process of updating roof and ceiling insulation has the potential to disrupt hazardous substances such as asbestos-containing material, lead paint, PCBs, or mould. The installation of spray-polyurethane foam can produce indoor pollutants. The eight respondents agree with the view. Installing spray foam insulation under a low-pitch wooden roof deck may cause moisture to accumulate, leading to concealed structural roof damage and mould growth. One respondent flagged the problem as one of the key issues that service providers often neglect, whereas all the respondents agreed that enhancing the building envelope can lead to higher concentrations of indoor pollutants such as radon, combustion by-products, moisture and mould, and VOCs. The majority of the participants alluded to falling from a height as another safety concern, especially if the roof trusses are relatively old	All the participants agreed that improving the situation was crucial. The participants recommended a thorough selection of moisture-resistant insulation, the correct installation of insulation materials, and the effective sealing of surfaces and assemblies susceptible to condensation. Additionally, the eight respondents proclaimed that sealing any undesired openings and leaks in the building structure would minimize infiltration and prevent conditions that attract pests. Furthermore, all the respondents concurred that, it is essential to have sufficient airflow to disperse and eliminate contaminants present indoors. The respondents concurred that adequate checks should be accorded to the roof upgrade to avoid falls from height, especially when the strength of the trusses is unknown
Upgrading wall insulation	All eight respondents claim that materials containing asbestos, lead paint, PCBs, or mould could potentially be disrupted during wall insulation upgrading. All six respondents are from the government office building. Six out of eight posited that the installation of spray-polyurethane foam can produce indoor pollutants, while two interviewees were indifferent on the issue. They all confirmed that enhancing the integrity of the building envelope can lead to higher concentrations of indoor pollutants, such as radon, combustion by-products, dampness and mould	To address the issue, all the participants proposed using measures to regulate moisture and condensation levels on surfaces, providing insulation that is resistant to moisture and guaranteeing effective management of exterior drainage and water. Furthermore, all the interviewees in all the case-study buildings unanimously concurred that it is important to seal any undesired openings and leaks in the building envelope to decrease penetration and create an environment that is less favourable for pests to enter. Proper ventilation is necessary to disperse and eliminate interior contaminants during the upgrade, as was alluded to
Modifying or repairing existing moisture barriers	All the participants in the case-study buildings acknowledge that there is a possibility of disturbing asbestos-containing material, lead paint, PCBs, or mould. Four out of eight participants believed that an exposed dirt floor might lead to an excessive influx of moisture into the building. All the respondents added that installing carpet or floor tile over a concrete floor with a chronic condensation or water pooling issue will probably result in the establishment of mould. Two interviewees assert that exposed dirt floors could potentially boost pest populations and foster the development of rodent habitats	Regarding the circumstance, all participants agreed unanimously that it is necessary to provide a sealed moisture barrier over dirt foundation flooring. Five out of eight participants explicitly stated that to effectively act as a moisture barrier underneath a concrete slab, it is important to choose sealants and adhesives with minimal or no VOC content or emissions, select transparent polymeric films that meet appropriate flame and smoke ratings, and implement additional radon mitigation measures as necessary

(*continued*)

Table 3. Continued

Activities	Occupational health and safety issues	Solutions
Altering or cleaning fan coil and unit ventilators	The responses from all the respondents verified that the process of duct installation, sealing, or replacement may result in the disturbance of asbestos-containing material, lead paint, mould, or other debris. Three out of eight assert that improper condensate drainage in units with cooling coils might create conditions that promote the growth of *Legionella* bacteria or mould. While all the respondents concurred that in humid climates, it may be necessary to use extra dehumidification methods when the amount of outdoor air being brought in is increased. Two of the respondents put it that improperly sealed and insulated ductwork can cause condensation issues when it goes through areas that are not temperature-controlled. Whereas the remaining six participants were quiet on the matter. All the participants agreed that inappropriate alterations to HVAC systems can lead to imbalanced flows and pressures, which may increase levels of dampness, radon and other contaminants from below ground	All the participants believed that it is important to minimize the infiltration of airborne pollutants into the building and to maintain appropriate levels of interior humidity. In addition, five out of eight have the notion that choosing goods that have low levels of VOCs does not include formaldehyde. Also, the five respondents affirm that offering ducts that are sealed and designed to be energy-efficient. Ensuring adequate ventilation and appropriately adjusting HVAC systems can help maintain positive indoor pressurization, which in turn reduces the entry of humid air into the building structure. The other three participants were silent on this matter
Pipe modifications: Converting from a one-pipe to a two-pipe steam system, OR converting from a two-pipe to a four-pipe heating and cooling system	According to all eight service providers, they accentuate that in replacing systems or components, there is a possibility of disturbing materials that contain asbestos, lead paint, or mould. Six out of eight respondents postulate that inadequate expelling of combustion gases and the possibility of occupants being exposed to CO_2 are possible hazards. The remaining two were silent on this. Three of the participants that are in charge of hotel building alluded that moisture or mould may accumulate when the HVAC system is inactive for prolonged periods. Whereas, all the service providers concurred that insufficient humidity control when the cooling system is running can lead to the formation of mould and create conditions that attract pests. Also, three out of the eight service providers that are handling government administrative buildings made it known that improper utilization of chilled water reset or airside economizers can result in cool and humid temperatures and the formation of condensation on cold surfaces. While five of the eight service providers confirmed that insufficient maintenance of the humidifier can result in microbial issues	All the interviewees believed that it is important to properly vent combustion gases and to ensure that mechanical rooms containing combustion equipment have adequate make-up air and ventilation. Also, five out of eight respondents agree that installing and maintaining CO_2 detection and warning equipment; ensuring that steam traps, combustion equipment and boilers are installed correctly; and ensuring that make-up air registers are not blocked are some of the remedies to the issue. Furthermore, all seven out of eight services confirmed that air conditioning systems should be properly sized and controlled to avoid humidity and moisture issues, especially under part-load conditions, and that they should be adequately sized for both cooling and dehumidification. The remaining respondents indicated that it is necessary to ensure well-maintained humidification equipment and controls are in place to promote occupant comfort and health during the heating season
HVAC controls to monitor/ maintain indoor air quality (IAQ) (upgrades or modifications). Building automation system that controls outdoor air and exhaust flow rates	Also, all the service providers reported that asbestos-containing material or lead paint may be disturbed during wall or ceiling penetrations. Six service providers that are handling hotel facilities, office complexes and government administrative buildings agreed that mercury from the removal of old mercury bulb thermostats may present a risk, whereas two were silent. In addition, two respondents that were handling multi-purpose office buildings and government administrative buildings affirmed that sensors that are not regularly calibrated may lead to IAQ problems. All the respondents believed that poor humidity control during cooling system operation can result in mould growth and present opportunities for pest infestations. Five respondents proposed that inappropriate use of chilled water resets or airside economizers can lead to cool and clammy conditions. Also, they all confirmed that indoor air can become too dry for occupant comfort and health during the heating season. All the respondents in the case study buildings affirmed that inadequate operation and maintenance of humidifier controls can lead to microbiological problems. Three respondents suggested that unbalanced flows and pressures from improper HVAC controls can result in heightened intrusion of moisture, radon and other subterranean contaminants. Six service providers confirmed that improperly vented combustion gases and occupant exposure to CO_2 are paramount	In resolving the situation. The eight interviewees expressed the belief that it is important to properly exhaust combustion gases and ensure that mechanical rooms containing combustion equipment have sufficient make-up air and ventilation. Also, three of the respondents agreed that installing and maintaining CO_2 detection and warning equipment to detect and alert to the presence of CO_2 gas is a welcome directive. The respondents believed that in ensuring the installation of steam traps, combustion equipment and boilers, checking that make-up air registers are not obstructed can also remediate the issue. Additionally, five out of eight respondents that are handling government administrative buildings assert that it is important to ensure that air conditioning systems are appropriately dimensioned and regulated to prevent problems related to humidity and moisture, especially while operating at less than full capacity

Source(s): Authors' own creation

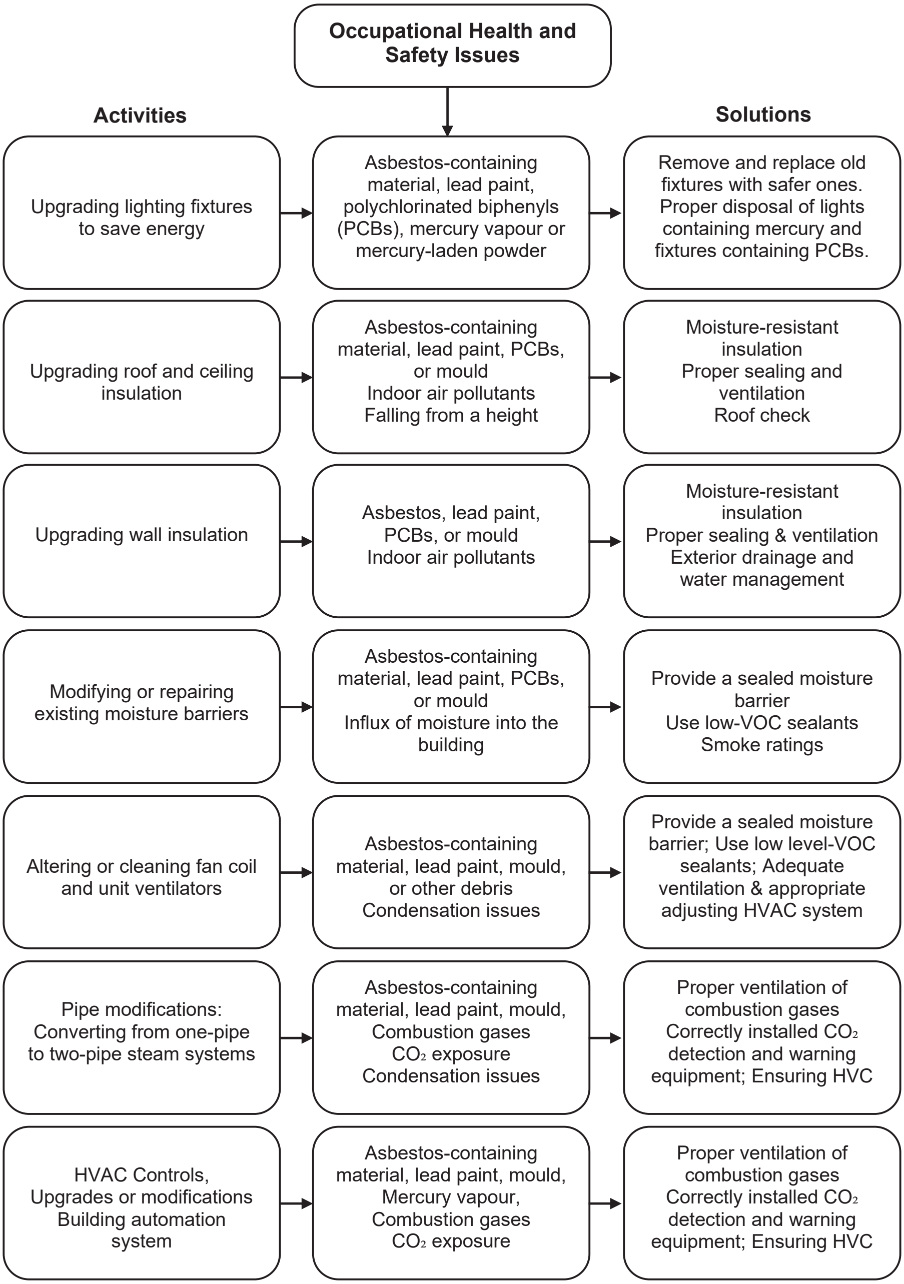

Figure 1. Synthesis of occupational health and safety hazards and corresponding control measures in building system upgrades. Source: Authors' own creation

5.1 Upgrading lighting fixtures to save energy

The respondents identified several OHS risks associated with lighting retrofits, including the presence of asbestos-containing materials, lead-based paints and polychlorinated biphenyls

(PCBs) in older electrical ballasts. These materials, if disturbed during retrofitting, can pose significant health threats, particularly where retrofitting is poorly planned, an issue also noted in studies from the UK and USA (Rickaby *et al.*, 2014; Barrett-Duckett *et al.*, 2014). However, unlike those contexts, the South African built environment includes a significant number of ageing buildings constructed before the enforcement of modern safety regulations, increasing the likelihood of hazardous materials being present during retrofits. Respondents further highlighted risks from mercury vapour or mercury-containing powder released by broken fluorescent bulbs, especially when drum-top crushers are improperly used, an issue compounded by limited training and regulation enforcement in parts of South Africa's construction sector (Bonfield, 2016).

These risks underscore the critical need for strict adherence to the Occupational Health and Safety Act 85 of 1993 and the Construction Regulations of 2014 (SARB, 2019). While international studies (e.g. Hodgson and Darton, 2000; National Cancer Institute, 2022; Tong and Gill, 2023) have established links between asbestos exposure and respiratory illnesses, including cancer, as well as mercury-related health issues, the South African situation presents unique challenges. These include inadequate record-keeping on hazardous materials in older buildings, gaps in contractor awareness and a lack of enforcement capacity, particularly in rural or informal sector projects. Respondents therefore emphasized the importance of carefully removing and replacing outdated fixtures with safer alternatives and ensuring proper disposal of mercury-containing lamps and PCB-laden components (Rickaby *et al.*, 2014; British Standards Institution, 2023). Although the use of asbestos is now highly regulated in countries like the USA (Skammeritz *et al.*, 2011), regulatory compliance and awareness remain inconsistent across many South African construction sites, which heightens the urgency for localized risk mitigation strategies.

5.2 Upgrading roof and ceiling insulation

In this particular activity, participants reported that ceiling retrofit activities often disturb hazardous substances such as asbestos-containing materials, lead-based paints, PCBs and mould, hazards also noted in international studies (Apps, 2022; Barrett-Duckett *et al.*, 2014; Bonfield, 2016). In addition, the use of spray polyurethane foam (SPF) insulation was flagged as a potential IAQ concern, particularly where moisture becomes trapped behind insulation installed under low-pitch wooden roof decks. This creates ideal conditions for hidden mould growth and long-term structural damage. While these risks are documented globally, in South Africa, their impact is compounded by the use of substandard materials, unregulated installation practices and inadequate training among insulation contractors, particularly in township and rural construction projects.

Moreover, respondents noted that ceiling insulation products used in South Africa frequently contain synthetic mineral fibres (SMFs) such as glass wool or rock wool, which are known to irritate the skin, eyes and respiratory system. The potential for exposure increases during retrofitting activities where PPE use is inconsistent and regulatory oversight is limited. These concerns align with findings from Worksafe Queensland (2012), which identified hazardous substances, including SMFs, asbestos, pesticides and residual chemicals, as frequently present during roof and ceiling upgrades.

To mitigate these risks, respondents emphasized the need to select moisture-resistant insulation materials and to ensure proper installation, especially in climate zones prone to high humidity or temperature extremes, as seen in parts of KwaZulu-Natal and Limpopo. Standard best practices recommended by respondents include sealing unintended openings in the building envelope to minimize moisture ingress and pest intrusion, measures that, although supported in international guidelines (BSI, 2023; Worksafe Queensland, 2012), are often inconsistently applied in South African projects due to skills shortages, limited funding and lack of client awareness.

5.3 Modifying or repairing existing moisture barriers

The study further indicates that during retrofitting activities, hazardous materials such as asbestos, lead-based paint, PCBs and mould may be disturbed. Additionally, respondents noted that uncovered or poorly sealed dirt floors, which are still present in some older or informal South African buildings, contribute significantly to moisture migration into interior spaces. Installing carpets or floor tiles over concrete slabs with persistent condensation or pooling water was also identified as a trigger for mould proliferation. These issues are especially problematic in regions with high humidity or seasonal rainfall and align with earlier findings by the United States Environmental Protection Agency (2013) and Barrett-Duckett *et al.* (2014), who traced similar moisture-related problems to design flaws, construction errors, or inadequate HVAC system maintenance.

In the South African context, HVAC systems are often under-maintained or absent altogether in low- and middle-income housing, where passive ventilation or hybrid systems are used instead. This increases the risk of condensation, thermal bridging and poor IAQ. The Chartered Institute of Building (CIOB, 2023) similarly notes that HVAC upgrades, if poorly implemented, may contribute to thermal bridging, internal leaks and rising damp. These factors create conducive conditions for mould growth, which, as reported by the Institute of Medicine (IOM) (IOM, 2004), has been epidemiologically linked to upper respiratory symptoms and other adverse health outcomes. While these associations are well documented internationally, the persistent use of low-cost construction materials and limited awareness of HVAC moisture dynamics among local contractors make these risks particularly acute in South African retrofit projects.

5.4 Altering or cleaning fan coil and unit ventilators

The study reveals that incorrect condensate drainage in HVAC units with cooling coils can create environments conducive to the growth of mould, *Legionella* and other harmful bacteria. Additionally, poorly sealed or uninsulated ductwork, especially when routed through unconditioned spaces, was identified as a significant source of indoor condensation. These conditions increase the risk of respiratory illnesses, consistent with findings by IOM (2004) and Fisk *et al.* (2007), which linked such issues to upper respiratory tract symptoms among building occupants.

In the South African context, many buildings, particularly older commercial and public sector facilities, have ageing or poorly maintained HVAC systems. Respondents noted that improper installations and a lack of periodic inspection exacerbate health and energy efficiency risks. To address these challenges, participants emphasized the need to reduce airborne contaminants through better filtration and ventilation practices, maintain appropriate indoor humidity levels and use low VOC and formaldehyde-free materials. Furthermore, the installation of sealed, energy-efficient duct systems and properly balanced HVAC configurations was recommended to sustain indoor positive pressurization and minimize moisture ingress.

Supporting these views, Fisk *et al.* (2007) emphasized that failure to maintain fan coil units properly can lead to diminished energy performance, poor thermal efficiency and increased maintenance costs. Accumulation of dust, debris and microbial contaminants within units and ductwork, if left unaddressed, poses both functional and health risks. In South Africa, where building services maintenance is often reactive rather than preventive, these issues are particularly pressing, pointing to the need for targeted HVAC training and stricter facility management protocols.

5.5 Pipe modifications

According to the interviewees, pipe modification activities during retrofitting can result in improper venting of combustion gases, posing a significant risk of CO_2 exposure to building occupants. This concern aligns with United States Environmental Protection Agency

(USEPA) (2022), which emphasized that CO_2 systems must be designed with safeguards to prevent accidental discharge, particularly in energy efficiency upgrades. USEPA's study revealed that such exposures often stem from the absence of adequate safety procedures and fail-safe mechanisms during mechanical interventions (USEPA, 2022).

Respondents in this study also noted that moisture intrusion and the presence of undetected mould during pipe alterations could lead to microbiological contamination, consistent with findings by Fisk *et al.* (2007). These risks are especially pronounced in buildings with ageing plumbing infrastructure, inadequate ventilation, or poor-quality retrofitting work, factors commonly observed in South Africa's public and low-cost housing sectors.

To mitigate these risks, participants recommended the installation and regular maintenance of CO_2 detection systems. Additionally, they emphasized the importance of ensuring proper installation of steam traps, combustion equipment and boilers to minimize the chance of gas leakage or incomplete combustion. These measures, while standard in more regulated environments, are often inconsistently implemented in South Africa due to limited technical oversight and resource constraints, underscoring the need for stronger compliance monitoring and skills development in mechanical system retrofits.

5.6 HVAC upgrades

Participants reported that the removal of old mercury-containing thermostats during retrofitting poses a significant health risk. Mercury exposure, as confirmed by Morawska *et al.* (2013), has been shown to adversely affect the nervous and immune systems, while Tucaliuc and Cretescu (2014) also link it to damage of the respiratory system, kidneys, skin and eyes. These risks are heightened in South Africa, where legacy equipment is still commonly found in older residential and institutional buildings, and where mercury disposal protocols are inconsistently followed.

Additionally, respondents noted that building sensors, such as those used to monitor IAQ, temperature and humidity, often suffer from poor calibration and maintenance. This, they argued, can lead to undetected air quality problems, particularly in retrofitted environments where HVAC systems are upgraded without holistic system integration. Schweizer *et al.* (2007) and Semple *et al.* (2012) similarly observed that HVAC upgrades, if not properly managed, may become sources of indoor air pollutants.

Furthermore, poor humidity control during cooling operations was cited as a cause of mould growth and pest infestation, findings that align with the study by IOM (2004). Interviewees also emphasized that improper HVAC controls can result in unbalanced airflows and pressures, increasing the risk of intrusion by belowground contaminants such as radon, moisture, and other volatile substances. This is especially relevant in parts of South Africa where radon-prone soils intersect with under-ventilated or poorly sealed buildings. Yet, monitoring and mitigation strategies for such risks remain limited due to a lack of awareness and policy enforcement.

6. Study contributions

While many of the occupational health and environmental risks identified, such as asbestos, lead paint, PCBs, mercury exposure, mould growth and poor HVAC performance, are well documented in international literature, this study provides important contextual insights specific to South Africa's built environment. The findings reveal that these hazards are exacerbated locally by outdated infrastructure, limited regulatory enforcement, low technical capacity and a significant prevalence of informal and under-maintained building systems. Furthermore, the study draws attention to underreported issues such as sensor miscalibration, poor condensate management and substandard ventilation practices, which, in combination with regional climatic conditions and material usage patterns, present heightened risks to occupant health and building performance. These insights highlight the urgent need for context-specific retrofit guidelines, improved awareness among practitioners and stricter implementation of health and safety regulations to ensure sustainable and safe building upgrades in South Africa.

7. Conclusion and recommendations

This study set out to clarify the OH&S concerns associated with retrofitting existing buildings for energy efficiency in the South African context. The findings reveal that nearly every retrofit operation, whether upgrading lighting, insulation, HVAC systems or plumbing, carries potential OH&S risks. The main among these are exposure to hazardous legacy materials such as asbestos, lead-based paint, PCBs and mercury, as well as biological risks like moulds proliferation and chemical risks from volatile organic compounds (VOCs). These risks are further compounded by poor HVAC performance, sensor miscalibration and substandard ventilation practices, particularly in ageing buildings with limited regulatory oversight and under-maintained systems.

Crucially, the study identifies several top-priority risks that require immediate attention: (1) the disturbance of asbestos-containing materials during demolition or insulation work, (2) exposure to lead and PCBs in outdated fixtures, and (3) respiratory risks from mould and poor air quality due to malfunctioning or improperly balanced HVAC systems. These issues are intensified by South Africa's context of limited technical capacity and informal construction practices.

In response, the study recommends a proactive, risk-based approach to retrofitting. Key mitigation measures include the safe removal and disposal of hazardous materials, improved condensate management, sealed and well-balanced HVAC systems, and the specification of low-VOC, formaldehyde-free products. Stakeholders should incorporate OH&S risk checklists into procurement contracts and ensure compliance through rigorous supervision and technical training.

Ultimately, integrating these recommendations into the retrofit process will not only safeguard occupant health but also reduce liability, prevent costly remediation and enhance the long-term cost-benefit outcomes of energy efficiency initiatives. By addressing OH&S risks upfront, retrofitting projects in South Africa can be both energy-efficient and health-conscious, aligning safety, performance and sustainability goals.

References

Apps, P. (2022), *Show Me the Bodies: How We Let Grenfell Happen*, One world, London.

Baker, S.E. and Edwards, R. (2012), "How many qualitative interviews is enough? Expert voices and early career reflections on sampling and cases in qualitative research, National Centre for Research Methods Review Paper", available at: http://eprints.ncrm.ac.uk/2273/4/how_many_interviews.pdf (accessed 24 June 2025).

Barrett-Duckett, H., Warren, E. and McLaren Webb, C. (2014), "Retrofit for the Future: reducing energy use in existing homes – a guide to making retrofit work", *Technology Strategy Board*, available at: https://assets.publishing.service.gov.uk/media/5a82135fe5274a2e87dc1041/Retrofit_for_the_future_-_A_guide_to_making_retrofit_work_-_2014.pdf (accessed 24 June 2025).

Bonfield, P. (2016), "Each home counts: an independent review of consumer advice, protection, standards and enforcement for energy efficiency and renewable energy", available at: https://assets.publishing.service.gov.uk/media/5a7f1384e5274a2e8ab49f6b/Each_Home_Counts__December_2016_.pdf (accessed 24 June 2025).

British Standards Institution (2023), *Retrofitting Dwellings for Improved Energy Efficiency – Specification and Guidance*, British Standards, London.

Chan, A., Javed, A.A., Lyu, S., Hon, C. and Wong, F. (2016), "Strategies for improving safety and health of ethnic minority construction workers", *Journal of Construction Engineering and Management*, Vol. 142 No. 9, pp. 1-10, doi: 10.1061/(ASCE)CO.1943-7862.0001148.

Chartered Institute of Building (CIOB) (2023), "Mould growth in buildings", available at: https://www.designingbuildings.co.uk/wiki/Mould_growth_in_buildings (accessed 26 September 2023).

Cheung, M., Foo, S. and Granadino, J. (2000), *Seismic Retrofit of Existing Buildings: Innovative Alternatives*, Public works and government services, Canada, pp. 1-10.

Creswell, J.W. (2013), *Research Design: Qualitative, Quantitative, and Mixed Methods Approach*, 4th ed., SAGE, Los Angeles.

Department of Labour (2022), “Occupational hygiene in construction work”, available at: https://www.labour.gov.za/DocumentCenter/Publications/Occupational%20Health%20and%20Safety/Occupational%20hygiene%20in%20construction%20work.pdf (accessed 24 September 2023).

Ernest, K., Ankomah, E.N., Tengan, C. and Asamoah, R.O. (2016), “Challenges to retrofitting and adaptation of existing building within the major central business district in Ghana”, *Journal of Construction Project Management and Innovation*, Vol. 6 No. 2, pp. 1460-1476.

Fawcett, T. (2013), “Exploring the time dimension of low carbon retrofit: owner-occupied housing”, *Building Research and Information*, Vol. 42 No. 4, pp. 477-488, doi: 10.1080/09613218.2013.804769.

Fawcett, T., Killip, G. and Janda, K.B. (2014), “Innovative practices in low carbon retrofit: time, scale and business models”, *In Paradigm Shift: From Energy Efficiency to Energy Reduction through Social Change*, Oxford, England, available at: http://behaveconference.com/wpcontent/uploads/2014/08/F_Tina_Fawcett_University_of_Oxford.pdf (accessed 23 January 2023).

Fisk, W.J., Lei-Gomez, Q. and Mendell, M.J. (2007), “Meta-analyses of the associations of respiratory health effects with dampness and mould in homes”, *Indoor Air*, Vol. 17 No. 4, pp. 284-295, doi: 10.1111/j.1600-0668.2007.00475.x.

Godwin, P.J. (2011), “Building conservation and sustainability in the United Kingdom”, *Procedia Engineering*, Vol. 20, pp. 12-21, doi: 10.1016/j.proeng.2011.11.135.

Gray, D.E. (2014), *Doing Research in the Real World*, 3rd ed., SAGE publishing, London, 1 Oliver’s Yard, 55 City Road.

Hansford, P. (2015), “Solid Wall Insulation: unlocking demand and driving up standards”, in *A Report to the Green Construction Board and Government by the Chief Construction Adviser*, Department for Business Innovation and Skills, London, available at: https://assets.publishing.service.gov.uk/media/5a74ebf540f0b65f61323554/BIS-15-562-solid-wall-insulation-report.pdf (accessed 23 January 2023).

Hodgson, J.T. and Darton, A. (2000), “The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure”, Stanley Precinct, L20 3QZ, in *Epidemiology and Medical Statistics Unit, Health and Safety Executive*, Magdalen House, Bootle, UK, 2000.

Institute of Medicine (2004), “Damp indoor spaces and health”, available at: http://www.iom.edu/Reports/2004/Damp-Indoor-Spaces-and-Health.aspx (accessed 26 September 2023).

International Labour Organisation (2023), “Realizing the fundamental right to a safe and healthy working environment worldwide”, *ILO Introductory Report: 27-30 November 2023 Sydney, Australia*.

Kamoli, A., Mahmud, S.H.B. and Syamsul Hendra Bin Mahmud,(2022), “Roles of construction organizations in revitalizing occupational health and safety of the Nigerian construction industry”, *Journal of Advanced Research in Applied Sciences and Engineering Technology*, Vol. 26 No. 1, pp. 97-104, doi: 10.37934/araset.26.1.97104.

Less, B. and Walker, I. (2014), *A Meta-Analysis of Single-Family Deep Energy Retrofit Performance in the U.S. (No. LBNL-6601E)*, Lawrence Berkeley National Laboratory, Berkeley, CA, available at: http://eetd.lbl.gov/sites/all/files/a_meta-analysis_0.pdf (accessed 9 February 2023).

Levitt, H.M., Motulsky, S.L., Wertz, F.J., Morrow, S.L. and Ponterotto, J.G. (2017), “Recommendations for designing and reviewing qualitative research in psychology: promoting methodological integrity”, *Qualitative Psychology*, Vol. 4 No. 1, pp. 2-22, doi: 10.1037/qup0000082.

Milford, R. (2009), *Greenhouse Gas Emission Baselines and Reduction Potentials from Buildings in South Africa*, United Nations Environment Programme, Paris, available at: https://www.cidb.org.za/wp-content/uploads/2021/04/Greenhouse-Gas-Emission-Baselines-and-Reduction-Potentials-from-Buildings-in-South-Africa.pdf (accessed 9 February 2023).

Miller, E. and Buys, L. (2011), "Retrofitting commercial office buildings for sustainability: tenants expectations and experiences", in Wamelink, J.W.F., Volker, L. and Geraedts, R.P. (Eds), *MISBE 2011 – Proceedings of the International Conference on Management and Innovation for a Sustainable Built Environment*, Delft University of Technology, pp. 1-10, available at: http://misbe2011.fyper.com/proceedings.htm.

Milne, S.J., Garton, E., Nelson, G., Murray, J., Davies, J.C.A. and Phillips, J.I. (2013), "A South African database of samples analysed for the presence of asbestos", *Occupational Health Southern Africa*, Vol. 19 No. 6, pp. 14-21.

Mohamed, F., David, D.J., Mateo-Garcia, G., Costin, G. and Thwala, W.D. (2019), "An investigation into the construction industry's view on fire prevention in high-rise buildings post Grenfell", *International Journal of Building Pathology and Adaptation*. doi: 10.1108/IJBPA-05-2019-0048.

Morawska, L., Afshari, A., Bae, G.N., Buonanno, G., Chao, C.Y.H., Hänninen, O., Wierzbicka, A., Isaxon, C., Jayaratne, E.R., Pasanen, P., Salthammer, T. and Waring, M. (2013), "Indoor aerosols: from personal exposure to risk assessment", *Indoor Air*, Vol. 23 No. 6, pp. 462-487, doi: 10.1111/ina.12044.

Nnaji, C. and Awolusi, I. (2021), "Critical success factors influencing wearable sensing device implementation in AEC industry", *Technology in Society*, Vol. 66, pp. 1-14, doi: 10.1016/j.techsoc.2021.101636.

Ogden, J. and Cornwell, D. (2010), "The role of topic, interviewee, and question in predicting rich interview data in the field of health research", *Sociology of Health and Illness*, Vol. 32 No. 7, pp. 1059-1071, doi: 10.1111/j.1467-9566.2010.01272.x.

Okorafor, C. (2019), "Retrofitting to reduce carbon emissions from existing buildings in Bloemfontein, South Africa", a thesis submitted in partial fulfilment of the requirements for the degree Doctor of engineering in Civil Engineering at the Central University of Technology, Free State, South Africa.

Okorafor, C., Emuze, F.A. and Das, D.K. (2019), "A South African experience of building energy retrofit project challenges and solutions", *Proceedings of the International Conference of the Sustainable Ecological Engineering Design for Society (SEEDS)*, Leeds, United Kingdom.

Oppong, R.A. and Masahudu, M. (2014), "Exploration of building adaptation and retrofitting challenges in Ghana: the case study of selected rural bank projects", *Structural Survey*, Vol. 32 No. 5, pp. 349-364, doi: 10.1108/SS-12-2013-0041.

Rickaby, P.A., Willoughby, J., Warren, E. and McLaren, W., C. (2014), *An Introduction to Low Carbon Domestic Refurbishment*, 2nd ed., Construction Products Association and RIBA Publishing, London.

Ritchie, J., Lewis, J., McNaughton, N.C. and Ormston, R. (2014), *Qualitative Research Practice: A Guide for Social Science Students and Researchers*, 2nd ed., SAGE, Los Angeles, CA.

Rostami, A., Sommerville, J., Wong, I.L. and Lee, C. (2015), "Risk management implementation in small and medium enterprises in the UK construction industry", *Journal of Engineering, Construction and Architectural Management*, Vol. 22 No. 1, pp. 91-107, doi: 10.1108/ecam-04-2014-0057.

Saunders, M., Lewi, P. and Thornhill, A. (2016), *Research Methods for Business Students*, 9th ed., Pearson Education, Harlow, 978-1-292-40272-7.

Schweizer, C., Edwards, R.D., Bayer-Ogllesby, L., Gauderman, W.J., Ilacqua, V., Lai, H.K., Nieuwenhuijsen, M. and Kunzli, N. (2007), "Indoor time-microenvironment-activity patterns in seven regions of Europe", *Journal of Exposure Science and Environmental Epidemiology*, Vol. 17 No. 2, pp. 170-181, doi: 10.1038/sj.jes.7500490.

Semple, S., Garden, C., Coggins, M., Galea, K.S., Whelan, P., Cowie, H., Sanchez-Jimenez, A., Thorne, P.S., Hurley, J.H. and Ayres, J.G. (2012), "Contribution of solid fuel, gas combustion, or tobacco smoke to indoor air pollutant deposition in Irish and Scottish homes", *Indoor Air*, Vol. 22 No. 3, pp. 212-223, doi: 10.1111/j.1600-0668.2011.00755.x.

Skammeritz, E., Omland, L.H., Johansen, J.P. and Omland, Ø. (2011), "Asbestos exposure and survival in malignant mesothelioma: a description of 122 consecutive cases at an occupational clinic", *The International Journal of Occupational and Environmental Medicine*, Vol. 2 No. 4, pp. 224-236.

South African Reserve Bank (2019), "Occupational health and safety specification guidelines-file", available at: https://www.resbank.co.za/content/dam/sarb/contact-us/procurement/j1/Annexure%20K2%20of%202%20Rev%204_2019%20ARB%20Occupational%20Health%20and%20Safety%20Specifications.pdf (accessed 24 June 2025).

Tong, T.Q., Gill, T.E., Sprigg, W.A., Van Pelt, R.S., Baklanov, A.A., Barker, B.M., Bell, J.E., Castillo, J., Gassó, S., Gaston, C.J., Griffin, D.W., Huneeus, N., Kahn, R.A., Kuciauskas, A.P., Ladino, L.A., Li, J., Mayol-Bracero, O.L., McCotter, O.Z., Méndez-Lázaro, P.A., Mudu, P., Nickovic, S., Oyarzun, D., Prospero, J., Raga, G.B., Raysoni, A.U., Ren, L., Sarafoglou, N., Sealy, A., Sun, Z. and Vimic, A.V. (2023), "Health and safety effects of airborne soil dust in the Americas and beyond", *Reviews of Geophysics*, Vol. 61 No. 2, e2021RG000763, doi: 10.1029/2021rg000763.

Umeokafor, N., Evangelinos, K. and Windapo, A. (2022), "Strategies for improving complex construction health and safety regulatory environments", *International Journal of Construction Management*, Vol. 22 No. 7, pp. 1333-1344, doi: 10.1080/15623599.2019.1707853.

United States Environmental Protection Agency (2017), "Health, energy efficiency and climate change", available at: https://www.epa.gov/indoor-air-quality-iaq/health-energy-efficiency-and-climate-change (accessed 9 September 2023).

United States Environmental Protection Agency (2022), "Carbon dioxide as a fire suppressant: examining the risks", available at: https://www.epa.gov/snap/carbon-dioxide-fire-suppressant-examining-risks (accessed 28 September 2023).

Vasileiou, K., Barnett, J., Thorpe, S. and Young, T. (2018), "Characterising and justifying sample size sufficiency in interview-based studies: systematic analysis of qualitative health research over a 15-year period", *BMC Medical Research Methodology*, Vol. 18 No. 1, p. 148, doi: 10.1186/s12874-018-0594-7.

Vince, G. (2023), *Nomad Century: How to Survive the Climate Upheaval*, Allen Lane, London, available at: https://cdn.penguin.co.uk/dam-assets/books/9780141997681/9780141997681-sample.pdf (accessed 9 September 2023).

Wang, R., Lu, S. and Li, Q. (2019a), "Multi-criteria comprehensive study on predictive algorithm of hourly heating energy consumption for residential buildings", *Sustainable Cities and Society*, Vol. 49, 101623, doi: 10.1016/j.scs.2019.101623.

Wang, Z., Hong, T. and Piette, M.A. (2019b), "Predicting plug loads with occupant count data through a deep learning approach", *Energy*, Vol. 181, pp. 29-42, doi: 10.1016/j.energy.2019.05.138.

Wilkinson, S. (2012), "Analysing sustainable retrofit potential in premium office buildings", *Structural Survey*, Vol. 30 No. 5, pp. 398-410, doi: 10.1108/02630801211288189.

Worksafe Queensland (2012), "Insulation – installing ceiling insulation and your health and safety", available at: https://www.worksafe.qld.gov.au/news-and-events/alerts/workplace-health-and-safety-alerts/2009/safety-alert-insulation-installing-ceiling-insulation-and-your-health-and-safety (accessed 26 September 2023).

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