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IMPROVING INDOOR AIR QUALITY WITHIN MUNCIPAL SOLID WASTE MANAGEMENT FACILITIES: A CASE STUDY APPROACH

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Abstract

The emission of pollutants during the process of municipal solid waste management (MSWM) is of great concern due to its hazardous effect on the quality of life of both workers in the facility and immediate surroundings. Therefore, the aim of this study is to address indoor air quality and odor control as crucial elements for the design of a sustainable solid waste management facility. Case study have been adopted as study of research methodology for the solid waste management facility. A modern segregated waste treatment plant, adjured to be compliant with regulations requirements regarding indoor air quality was taken as a case study. Indoor pollutants concentration was analyzed from their emission sources, and analyzed for odour and also their health effects. The influence of ventilation system in air quality is also addressed. As a result identifying pollutant of concern, controlling it at its source, and influence of building materials are ways to improve indoor air management.

Key-Words: - Indoor Air Quality, Source control, Waste management facility, Ventilation

1. INTRODUCTION

A proper integrated management of municipal solid waste facility engages in collecting, transferring, treating, recycling, recovering resources, and disposing of solid waste (OEHHA 2023). In certain cases of discomfort and symptoms, the waste management facility may be the very definition of an illness. The main culprit is various kinds of contamination within the building, and this contamination is usually referred to as poor quality of indoor air. According to Gobo (2002), a significant portion of people who live close to disposal sites and people who work with trash are typically infected with gastrointestinal parasites, worms, and other related organisms. The adverse effects due to poor air quality in closed spaces. Poorly ventilated spaces negatively impact the health of building occupants, resulting in a rise in recorded sick days, as well as the potential transmission of viruses (Dijken & Boerstra, 2021). These problems have increased with the construction of buildings that are designed to be more airtight and that recycle air with a smaller proportion of new air from the outside in order to be more energy efficient (Xavier et al, 2011). The fact that buildings that do not offer natural ventilation present risks of exposure to contaminants is now generally accepted. In this perspective, the design of the management facility and associated functions should be taken into consideration not only for their service function but to improve indoor air quality.

According to Cédric et al, (2020), indoor air pollution is a major public health challenge because we spend over 80% of our time in enclosed spaces. Research also indicates that pollutant levels can be higher indoors than outdoors (Ponessa, 2021). Therefore it is a measure of how clean the air is inside the buildings in which we work, live, or play. Cédric et al (2020) stated, the application of indoor air quality (IAQ) in industrial buildings depends on so many factors: the materials used in the building's structure as well as its equipment, the ventilation system and how occupants behave. Air pollution are caused by contaminants emitted from Industrial processes which is strongly harmful to indoor operators. The indoor air we breathe can put us at risk for health-related problems, since most of our time is spent indoors (USEPA, 2008). Indoor air quality is a key public health issue that has many dimensions and is addressed by government and the public on many different levels. (Environmental Law Institute, 1997).

1.1 Indoor air quality in solid waste management facilities

The study aims at reducing indoor air pollution because of the potential negative impact it has in solid waste management facilities. The operations of these facilities needs to meet specific EPA requirements. According to CMM Group the two most common ways factories can reduce their air pollution emissions are:

i. Optimizing the factory's operations

Here more energy-efficient operations tend to reduce the amount of pollution a factory generates. Companies can optimize different parts of their operation to save energy, thus reducing the facility's overall emissions.

ii. Destroying pollutants before they enter the atmosphere

Factory operators can also employ abatement mechanisms that help destroy VOCs, HAPs, and other pollutants before they enter the environment. Some techniques to reduce pollutants include: (a) Regenerative Thermal Oxidizer, (b) Recuperative Thermal Oxidizer, (b) Catalytic Oxidizer and (d) Oxidizers with Rotary Concentrators.

2. LITERATURE REVIEW

According to the USEPA (2008) Indoor Air Quality (IAQ) is the term used to describe the air quality inside and around buildings and other structures, particularly as it relates to the health and comfort of occupants. Indoor air quality pollutants in solid waste management facilities originates from numerous sources, including waste materials, industrial-strength cleaning products and production process emissions. Either the production equipment emissions are not controlled at all (i.e., no exhaust system), or the existing exhaust system does not adequately capture the process fumes (APC Technologies, 2018). To reduce the chance of developing indoor health issues, it is important to understand and manage prevalent indoor contaminants. Above all the quality of indoor air is extremely dependent on the quality of outdoor air (Cédric et al, 2020). It can be proposed here that better air quality can only be delivered through ambitious measures to reduce outdoor pollution. (Cédric et al, 2020) outlined two basic consideration for improving indoor air quality.

I. First is eradication of the sources of polluting emissions via upstream emission reduction and the development of business activities for modeling and measuring air quality, to evaluate the effects.

II. The second concerns protection for people in enclosed spaces through the promotion of ventilation and filtration systems, indoor air pollution treatment and realignment of energy efficiency regulations with health standards.

The USEPA, (2008) explained the strategies for controlling indoor pollutant sources; For instance the ventilation techniques used so that fresh air can easily flow in and around the products, thereby quickly removing any pollutants emitted from the products. (Clausen et al, 2003) observed that ventilation is an important parameter for the indoor air quality in buildings. In general the more ventilation the lower the exposure to pollutants from inside. Simultaneously, indoor environmental quality can also obviously influence operating efficiency (Sundell 1996; Wargocki et al. 1999). Woods (1989) conducted a telephone survey, and the results showed that 20% of operators complained that low indoor air quality (IAQ) reduced their operating efficiency. The requirements for good indoor air quality and energy efficiency have often been considered to conflict with each other (Clausen et al, 2003). This is based on the assumption that good indoor air quality requires more and more energy through more ventilation. However, the results of the European Audit project showed that buildings with lower specific energy consumption also had a lower prevalence of sick building symptoms (Roulet et al., 1995). Good IAQ, as a relevant part of the indoor environment, shall not be obtained at the expenses of the outdoor environment, be it at the local/regional or at the global level. The major strategies for good IAQ identified by the (Clausen et al, 2003) are;

I. Source control of waste materials

Source control means the action or group of actions that lead to avoid the emissions at the place they would have been liberated or to confine the source of indoor air pollution before the emissions reach the whole space. Formaldehyde (HCHO) and other VOCs are significant indoor pollutants released from materials and products (Logue, 2012). IAQ is affected by the characteristics of various indoor pollutant sources along with the current status of outside air (Sun et al, 2019). Source control or eradication includes reduced use of certain consumer products; choice of low-emitting decorative products, furnishings, flooring, etc. to reduce the air pollution load in buildings. Source control is also a more cost-efficient approach to protecting indoor air quality than increasing ventilation because increasing ventilation can increase energy costs (USEPA, 2008).

II. Improved ventilation systems

Ventilation indoors relies on sufficient air exchange between the indoor and outdoor environments. In most instances the amount of ambient air brought indoors should be maximized to improve indoor air quality (Emma, 2021). Ventilation air can be supplied to rooms through mechanical ventilation systems or with the help of natural forces such as wind pressure and the buoyancy effects caused by air temperature differences between indoor and outdoor air (Awbi, 2003). Ventilation also helps remove or dilute indoor airborne pollutants coming from indoor sources reducing the level of contaminants and improves indoor air quality (USEPA, 2008). Ventilation occupies an important position in the building design process since building occupants expect good standards of indoor air quality and comfort (Awbi, 2003).

2.1 Ventilation systems and Air quality

There are three main ventilation methods: natural, mechanical and a combination of the two the hybrid ventilation

How architectural designs with Natural ventilation affect air quality: According to Awbi, (2003) natural ventilation is the term used to describe the air flow to or from a building through specific openings in the building envelope, such as openable windows. Clausen et al, (2003) explained Passive stack ventilation systems have intended exhaust openings in rooms, outdoor air enters the building through building envelope or intended openings for ventilation in building envelope. Therefore driving forces of ventilation are wind and thermal difference between indoor and outdoor air. Natural ventilation is generally either wind driven or buoyancy driven (Emma, 2021). Natural ventilation proved to have great potential, combining energy savings and occupants satisfaction (Harvey 2009). Studies reveal that with the right ventilation strategy, performance can increase by as much as 15% when building occupants work in an indoor environment with fresh air (Olesen, 2020).

How architectural designs with Mechanical ventilation affect air quality: In mechanically ventilated buildings the ventilation air is conditioned before it is supplied to the rooms via the duct system (Clausen et al, 2003). It can be proposed here that buildings with mechanical ventilation have fan powered supply air to and exhaust air from the rooms. It is often used in situations where natural ventilation is not suitable, such as spaces that require conditioned or filtered air, or spaces with high air demand (Emma, 2021). Yoshino and Haghighat, (1992) cited that indoor pressure increases when the ventilation fan is operated to supply outdoor air. On the other hand, indoor pressure decreases when the ventilation fan is operated to exhaust indoor air.

How architectural designs with Hybrid ventilation affect air quality: Hybrid ventilation systems are in the framework of IEA 35 defined as (Heiselberg, 1998) Hybrid ventilation systems can be described as systems providing a comfortable internal environment using different features of both natural ventilation and mechanical systems at different times of the day or season of the year. It is a ventilation system where mechanical and natural forces are combined in a two-mode system. This ventilation type places concern on the combination of both natural and artificial ventilation systems (Ejigini, 2022). Therefore it intends to combine the features of natural and mechanical ventilation. (Ejigini, 2022) further explained the mechanical and natural components may be used at the same time, or at different times of day, or in different seasons of the year. Since natural ventilation flow depends on environmental conditions, it may not always provide an appropriate amount of ventilation. In this case, mechanical systems may be used to supplement or regulate the naturally driven flow. (De Gids and Jicha, 2010)

2.2 Building materials and indoor air quality

Building materials affects many other high performance goals in addition to indoor air quality. All materials contaminate, some a little and others much, and together they contribute to a deterioration in the quality of indoor air (Xavier et al, 2011). The use of building and construction materials as well as consumer products in the home is a significant source of volatile and semi-volatile organic compounds (VOCs) (e.g. Shrubsole et al., 2019) and also some inorganic emissions, such as hydrochloric acid (HCl) and ammonia (NH3) from cleaning products (Rösch et al. 2014; Ampollini et al., 2019). USEPA (2022) potentially stated important sources of IAQ contaminants are interior building materials, furniture, and equipment. In particular, in new building, the generation of hazardous chemicals from building materials is reported as a major factor in indoor air pollution (Leung, 2015). Hence, the emission of VOCs from the building materials is influenced by the type of material and internal characteristics such as the total amount of VOC contained in the material (elapsed years), as well as the environmental conditions exposed to the material (Zhang et al., 2018). In addition, it is reported that the effect on indoor temperature and humidity causes a large difference in the amount of generation (Zhou et al., 2017). However, this is mostly the result of experiments in which environmental conditions are strictly controllable, and there are actually more factors affecting the emission of chemical substances in the indoor living environment (Wang et al., 2020). The important factors of indoor air pollution are the indoor microclimatic factors related to temperature and humidity (Salthammer et al., 2018), the application of building materials made of chemical substances (Schito et al., 2016), lifestyle, and the influence of the external environment (Yu and Kim, 2011). Among them, research has been conducted to reveal the major causes and the degree of their impact on building materials and furniture, as well as harmful substances generated during the construction process (Harb et al., 2018). Also, it has been reported via many research that the emission pattern of hazardous substances from building materials tends to decrease with time (Kaunelienė et al., 2016). Hazardous substances in buildings are emitted from various building materials such as wood, plywood, and furniture (Lee, 2011; Böhm et al., 2012). VOCs are emitted from household appliances and textile products of various clothes (Bari et al., 2015; Lucattini et al., 2018). In particular, the main cause of the release of CH2O is the adhesive used to attach the building finish (Yu and Kim, 2012).

III. METHODOLOGY

The case study research methods used in this project are both qualitative and descriptive. Key raw data were obtained from existing research articles, online sites, etc. Case study has to do with studies done on the architecture and layout of common areas in solid waste management facilities. Tremendous implementations such as improving indoor air quality and efficient lighting were adopted. A survey of international literature on comparable situations revealed recycling facilities with sustainable qualities, which also serve as the basis for architectural design. This study tends to analyze two solid waste management facilities, Sunset park material recovery facility and Center for Recycling Materials Collection. Here, the building layout, design and its environment are examined and how these features has helped to improve indoor air quality.

3.1 Sunset Park Material Recovery Facility

Sunset Park Material Recovery Facility is located at 2nd Avenue Brooklyn, New York in United States. It is a facility that processes New York City's curbside recyclables of metal, glass, plastic, asphalt, and rock. The building's architecture was motivated by its intended function as a recycling center, which encouraged reuse throughout including in the construction of buildings, plazas, and site fill. Other environmentally friendly pratices include bioswales for storm water management, the largest photovoltaics installation in New York City and a wind turbine that generates 15% of the building's energy (Arch Daily, 2014).

Fig 1: Site Plan (Arch Daily, 2014)

Fig 2: Tipping Building (Arch Daily, 2014)

In the zoning of this facility, the tipping building is placed away from others in other to mitigate odor from source. The plan is in an L form for direct flow of machine -from the point of collection to the point of distribution. The facility makes a significant environmental contribution with the use of natural ventilation which remove polluted indoor air and replace it with fresh, clean air from outside. Here the ventilation operates through openings which dimension, location and conditions of operation have to be better defined and controlled, and integrated in the whole building design. Therefore bringing in more outdoor air, natural ventilation has the potential to increase indoor concentrations of outdoor originating pollutants, while decreasing indoor emitted ones. Also the use of High-efficiency particulate air (HEPA) filters to collect and reduce indoor pollution, this filter is used in vacuums and air purifiers. High roof is used to provide max overhead space used for operating cranes, ventilation, illumination & installation of machines. Construction with IS steel girders, columns and trusses is used carrying the load.

3.2 Center for Recycling Materials Collection

The Facility is located at Schweinern in Austria. The community association for environmental protection of St. Pölten in Lower Austria created this center for recycling and waste management with the single goal of converting former garbage-disposal areas into a user-friendly infrastructure for the collection and separation of recyclable materials in the local community.

Fig 3: Slots for sorted waste
(Arch Daily, 2021)

Fig 4: Covered area for compost
(Arch Daily, 2021)

The emission from sources of pollution is reduced through proper air circulation, zoning classification and organization of buildings with efficient landscaping design in the facility. The building is supplemented with a covered loading space for green garbage and compost. Disposal of oil, batteries, electrical, and hazardous waste is planned in separate areas. For adequate air flow, shed roof with wide overhangs are used in the waste container slots which houses treated sorted wastes. Here natural ventilation utilizes weather factors such as wind pressure and thermal buoyancy to exchange air from outside to indoor spaces through openings. The choice of materials used are resource-saving, & of low impact that emit lower levels of volatile organic compounds (VOCs), harmful chemicals that can pollute indoor air e.g. laminated wood, latex paint, reinforced concrete & steel columns used for insulation.

IV. DISCUSSION

Seppänen (1998) summarized ventilation technologies and strategies sating that the strength of sources depend on the type of the building and activities in the building. Also the design and construction process should be developed so that the sources are known when the ventilation is designed, and ventilation rates selected. In practice but it is possible to set limits for emissions by classification of materials and other sources, and when the classified materials and sources are specified the ventilation rates can be selected to guarantee the selected indoor air quality level (Seppänen, 1998). Overall people in developed countries spend 80 to 90% of the time indoors (Kleipeis et al, 2001; Schweizer et al., 2007; Dimitroulopoulou et al., 2017), therefore much of their exposure to air pollution will occur indoors. Workers within factories and warehouses are exposed to substantial amounts of chemicals and pollutants such as carbon monoxide and other toxic gases from diesel forklifts driven inside. Etc.

The balance of the contribution of indoor versus outdoor sources to exposure will depend on the ventilation of the building, often represented by the air exchange rates. Therefore measures to improve IAQ include increasing the amount of fresh air supply to dilute the buildup of inside contaminants. It is important to follow ASHRAE 62.1-2007 recommendations regarding separating air intakes and exhausts. Also, verify the facility's pressure relative to outside because buildings under negative pressure could cause drains, stacks or exhaust vents to run backward (Chris, 2020).

The requirement for mechanical ventilation usually stems from other design considerations (for example heating, cooling and controlling humidity), but can be driven by air quality concerns. Standard assessment procedure (SAP), carried out under Part L of the Building Regulations (MHCLG, 2010) considers energy consumption, principally in relation to thermal comfort. There is a distinction between centralized and individual ventilation systems. Either system might include an element of both natural and mechanical ventilation. Overall building design, including location, layout and shape, also all have roles to play in controlling the effects of external pollutant emissions on indoor air.

V. RECOMMENDATION AND CONCLUSION

Natural ventilation is one of the possible strategies for controlling the indoor air quality. The aim of natural ventilation devices is to guarantee that there is, within certain limits, the possibility for an acceptable indoor air quality. It is important to recognize that requirements concerning natural ventilation devices are not only determined by the expectations with respect to the indoor air quality. Hence, windows induces indoor ventilation due to wind forces. Clausen et al, (2003) highlighted assumptions concerning acceptable periods of rather poor indoor air quality, that it is impossible to guarantee with a natural ventilation system under all weather conditions excellent indoor climate conditions. One has therefore to define the maximum allowable deviations. Standards and regulations can be an important instrument for stimulating energy efficient ventilation systems. The performances of ventilation systems are not only determined by the design, but also by the performances of the components used in the installation, the quality of the installation and the operation and maintenance of the system.

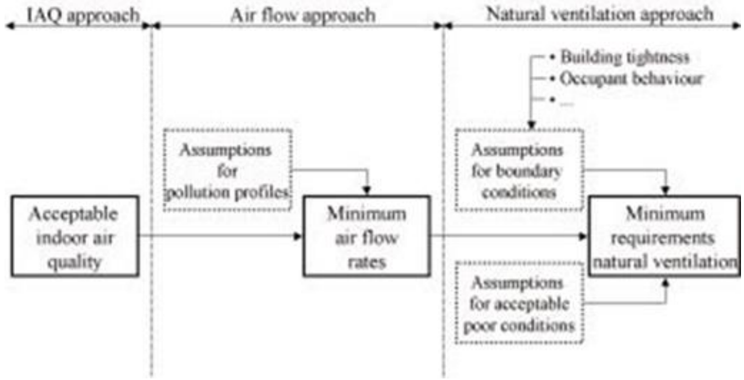

Fig 5: Requirements concerning natural ventilation

Source: Clausen et al (2003)

In summary, how, when and where air is drawn into and extracted from a building can greatly influence the indoor environment. Improving indoor air quality includes those associated with the building design and its in-built ventilation and/or fume extraction systems, those attributed to source control (external and internal sources, including those due to occupant activities and habits), occupant behaviors, and use of specialized equipment for filtration, purification and cleaning of indoor air. Schweiker et al. (2020) stated that occupants are more satisfied if they had perceived control over the indoor environment. the application of solutions for improvement of indoor air quality may as well arise from global or national policies, from local and community initiatives, or be implemented at organizational or single building level. By failing to convey interior air pollutants outside of the area and failing to bring in enough outside air to mitigate pollution from indoor sources, inadequate ventilation may increase the levels of indoor pollutants. Pollutant concentrations might be increased by hot and humid conditions. Hence, to achieve optimum interior air quality, natural ventilation as well as appropriate mechanical ventilation should be given and taken into account during design. In addition zoning & ventilation can reduce the overall impact of air pollution & infiltration of air. Better cleaning practices of equipment can improve employees' health, and improve the overall experience for visitors in the facility.

REFERENCE

1. Air Quality Expert Group. (2022). Indoor Air Quality.
2. Ampollini, L., Katz, E.F., Bourne, S., Tian, Y., Novoselac, A., Goldstein, A.H., Lucic, G., Waring, M.S., and DeCarlo, P.F. (2019) Observations and Contributions of Real-Time Indoor Ammonia Concentrations during HOMEChem.

3. APC Technologies, Inc. (2018). Improving Indoor Air Quality at Manufacturing Plants
4. Awbi, H, B. (2003).Ventilation of Buildings.
5. Bari, M. A., Kindzierski, W. B., Wheeler, A. J., Héroux, M.-È., and Wallace, L. A. (2015). Source Apportionment of Indoor and Outdoor Volatile Organic Compounds at Homes in Edmonton, Canada. Building Environ. 90, 114–124. doi:10.1016/j.buildenv.2015.03.023
6. Charles, M., and Yingchun, J. (2021). Evaluating the perception of thermal environment in naturally ventilated schools in a warm and humid climate in Nigeria.
7. Chris, F. (2020). How to identify and correct IAQ issues at manufacturing facilities.
8. Cédric, B., Fanny, S., Leah, B., and Octave, M. (2020). Indoor air quality: tackling the challenges of the invisible.
9. De Gids, W, F., and Jicha, M. (2010). "Ventilation Information Paper 32: Hybrid Ventilation Archived 2015-11-17 at the Wayback Machine", Air Infiltration and Ventilation Centre.
10. Dimitroulopoulou, C., Ashmore, M, R., Terry, A., and Hill, M.T.R. (2017). Use of Population Exposure Frequency Distributions to simulate effects on policy interventions on NO2 exposure. Atmospheric Environment.
11. Dijken, F, V., and Boerstra, A. (2021). Implications of COVID-19 pandemic for application of natural ventilation, Brussels: REHVA Journal.
12. EFSA. (2018). Building Bulletin 101 Guidelines on ventilation, thermal comfort, and indoor air quality in schools V1.
13. Ejigini, T. (2022). Ventilation in Classrooms in Rivers State.
14. Emma, G. (2021). Ventilation.
15. Environmental Law Institute. (1997). State and Local Indoor Air Quality Programs: Five Case Studies.
16. EPA402-08/008. (2008) .Care for Your Air: A Guide to Indoor Air Quality. United Stated Environmental Protection Agency [USEPA].
17. United States Environmental Protection Agency, (2022). Controlling Pollutants and Sources: Indoor Air Quality Design Tools for Schools.
18. Geo, C., Eduardo D, O, F., Willem, D, G., and Tno, B. (2003). Urban Air, Indoor Environment and Human Exposure: Ventilation, Good Indoor Air Quality and Rational Use of Energy.
19. Gobo, A, E. (2002), "Solid waste management options for the Niger delta", Proceedings of the 3rd National Workshop on Waste Management and Pollution in the 21st Century, Rivers State Ministry of Environment and Natural Resources, Port Harcourt.
20. Harb, P., Locoge, N., and Thevenet, F. (2018). Emissions and Treatment of VOCs Emitted from wood-based Construction Materials: Impact on Indoor Air Quality. Chem. Eng. J. 354, 641–652. doi:10.1016/j.cej.2018.08.085

21. Harvey, L, D, D. (2009). Reducing energy use in the buildings sector: measures, costs, and examples. Energy Efficiency, 2(2), 139–163.
22. Heiselberg P., and Hybvent website, http://hybvent.civil.auc.dk/
23. Kaunelienė, V., Prasauskas, T., Krugly, E., Stasiulaitienė, I., Čiužas, D., and Šeduikytė, L., (2016). Indoor Air Quality in Low Energy Residential Buildings in Lithuania. Building Environ. 108, 63–72. doi:10.1016/j.buildenv.2016.08.018
24. Kleipeis, N, E., Nelson, W, C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., Behar, J.V., Hern, S.C. and Engelmann, W, H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants,. J. Expo. Anal. Environ. Epidemiol.
25. Lee, Y, S. (2011). Comparisons of Indoor Air Quality and thermal comfort Quality between Certification Levels of LEED-Certified Buildings in USA. Indoor Built Environ. 20 (5), 564–576. doi:10.1177/1420326x11409453
26. Logue, M, P, N., Price, M, H., and Sherman, B, C., Singer. (2012). A Method to Estimate the Chronic Health Impact of Air Pollutants in U.S. Residences, Environ. Health Perspect.
27. Lucattini, L., Poma, G., Covaci, A., de Boer, J., Lamoree, M. H., and Leonards, P. E. G. (2018). A Review of Semi-volatile Organic Compounds (SVOCs) in the Indoor Environment: Occurrence in Consumer Products, Indoor Air and Dust. Chemosphere 201, 466–482. doi:10.1016/j.chemosphere.2018.02.161
28. Leung, D, Y, C. (2015). Outdoor-indoor Air Pollution in Urban Environment: Challenges and Opportunity. Front. Environ. Sci. 2, 69. doi:10.3389/fenvs.2014.00069
29. MHCLG. (2010). Building Regulations 2010 and Associated Approved Documents https://www.gov.uk/government/collections/approved-documents
30. Olesen, B. (2020). Productivity and Indoor Air Quality, Copenhagen: Technical University of Denmark.
31. Ponessa, J. (2021). Indoor air quality. In: Carswell AT, editor. The Encyclopedia of Housing. Thousand Oaks, CA: SAGE Publications, Inc. pp. 392-396. DOI:10.4135/9781452218380.n137
32. Rösch, C., Kohajda, T., Röder, S., Bergen, M., and Schlink, U. (2014). Relationship between sources and patterns of VOCs in indoor air, Atmospheric Pollution Research, 5, 129-137.
33. Salthammer, T., Schieweck, A., Gu, J., Ameri, S., and Uhde, E. (2018). Future Trends in Ambient Air Pollution and Climate in Germany - Implications for the Indoor Environment. Building Environ. 143, 661–670. doi:10.1016/j.buildenv.2018.07.050

34. Schito, E., Testi, D., and Grassi, W. (2016). A Proposal for New Microclimate Indexes for the Evaluation of Indoor Air Quality in Museums. Buildings 6 (4), 41. doi:10.3390/buildings6040041
35. Schweiker, M., Ampatzi, E., Andargie, M. S., Andersen, R. K., Azar, E., Barthelmes, V. M., Berger, C., Bourikas, L., Carlucci, S., Chinazzo, G., Edappilly, L. P., Favero, M., Gauthier, S., Jamrozik, A., Kane, M., Mahdavi, A., Piselli, C., Pisello, A. L., Roetzel, A., Rysanek, A., Sharma, K. and Zhang, S. (2020) Review of multi-domain approaches to indoor environmental perception and behaviour. Building and Environment, 176 106804).
36. Schweizer, C., Edwards, R.D., Bayer-Oglesby, L., Gauderman, W.J., Ilacqua, V., Jantunen, M, J., Lai, H.K., Nieuwenhuijsen, M. and Kunzli, N.: Indoor time-microenvironment-activity patterns in seven regions of Europe, J. Expo. Sci. Environ. Epidemiol., 17, 170–181, 2007.
37. Shrubsole, C., Dimitroulopoulou, S., Foxall, A.K., Gadeberg, B. and Doutsi, A. (2019). IAQ guidelines for selected volatile organic compounds (VOCs) in the UK. Building and Environment, 165.
38. Sun, Y., Hou, J., Cheng, R.., Sheng, Y., Zhang, X., and Sundell, J. (2019). Indoor Air Quality, Ventilation and Their Associations with Sick Building Syndrome in Chinese Homes. Energy and Buildings 197, 112–119. doi:10.1016/j.enbuild.2019.05.046
39. Sundell, J. (1996). What we know, and don't know about sick building syndrome. ASHRAE Journal, 38(6): 51–57.
40. Wang, H., Zheng, J., Yang, T., He, Z., Zhang, P., and Liu, X. (2020). Predicting the Emission Characteristics of VOCs in a Simulated Vehicle Cabin Environment Based on Small-Scale Chamber Tests: Parameter Determination and Validation. Environ. Int. 142, 105817. doi:10.1016/j.envint.2020.105817
41. Wargocki, P., Wyon, D,P., and Baik Y, K. (1999). Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads. Indoor Air, 9: 165–179.
42. Woods. J, E. (1989). Cost avoidance and productivity in owning and operating buildings. State of the Art Reviews in Occupational Medicine, 4: 753–770.
43. Yu, W, F., and Kim, J, T. (2012). Long-term Impact of Formaldehyde and VOC Emissions from wood-based Products on Indoor Environments; and Issues with Recycled Products. Indoor Built Environ. 21 (1), 137–149. doi:10.1177/1420326x11424330
44. Xavier, G, S., Derrick, C., Dietrich, H, M., Gracia, R, F., Brian, F., María, J, B. (2011). General hazards; Indoor Air Quality

45. Zhang, X., Cao, J., Wei, J., and Zhang, Y. (2018). Improved C-History Method for rapidly and accurately measuring the characteristic parameters of formaldehyde/VOCs Emitted from Building Materials. Building Environ.
46. Zhou, C., Zhan, Y., Chen, S., Xia, M., Ronda, C., Sun, M., et al. (2017). Combined Effects of Temperature and Humidity on Indoor VOCs Pollution: Intercity Comparison. Building Environ. 121, 26–34. doi:10.1016/j.buildenv.2017.04.013