# Anticipation, Recognition, Evaluation, and Control of Indoor Environmental Hazards Impacting Syrian Refugees in Lebanon

A thesis submitted for the degree of Doctor of Philosophy
by

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# Dedication

To every human forced out of their country, community, or home,

to every child deprived of their childhood,

against the limited access to adequate healthcare,

against the restricted right to a healthy environment,

against the undermined right to breathe clean air.

Syrian Refugee Children at the Bar Elias Informal Tented Settlement Camp in Bekaa, Lebanon.

(Consent for publication and reuse of image obtained through Save the Children Lebanon)

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Attestation:

Except where otherwise specified, I attest that all field sampling, data collection, figures, and photographs were performed and collected by me.

I attest that this thesis originates from my own work and research.

# Abstract

A pilot study of indoor air quality in Syrian refugee settlements in Lebanon found indoor mould growth significantly linked with moisture and ventilation levels. A follow-up cross-sectional study was subsequently performed in 4 provinces of Lebanon. It was revealed that although non-residential shelters had the highest mean total indoor count (TIC), 3 mould genera were strongly associated with non-permanent shelters ($p<.001$) and occupancy was found strongly associated with some of the genera. Regarding shelter conditions, highest TIC was observed in unfinished structures. These findings suggest shelter category, condition and occupancy significantly influence indoor mould concentrations and may lead to increased respiratory health risks for Syrian refugees in Lebanon. Biomonitoring using the fractional exhaled breath nitric oxide ($F_ENO$) biomarker and clinical interpretation of results suggested potential persistent exposure to allergens**.** Two mitigation technologies were developed for deployment in non-permanent shelters: Solar-powered Window Air Cleaning (SWAC) and Solar-powered Wall Air Vent (SWAV). Operating at 100% outdoor air intake, the SWAC unit exceeded the ASHRAE standard 62.2 minimum requirement for an average refugee household occupancy ($n=6$) and total floor area (56 $m^2$) and met equivalent outdoor air requirements for the most stringent ASHRAE standard 52.2 particle range (0.3 – 1.0 µm) operating at 50% outdoor air. The SWAV unit exceeded ASHRAE ventilation requirements for individual refugee rooms (15 $m^2$) at average occupancy. In conclusion, this project provides a rare insight into the poor indoor air quality of refugee shelters in Lebanon. Exposures to indoor mould can increase susceptibility to respiratory health risks in this vulnerable population, already impacted by multiple factors, from poor hygiene to displacement trauma and poverty. However, the low-cost renewable mitigation technologies developed here, offer a sustainable solution to remediate poor indoor air quality in refugee shelters accommodating displaced populations not only in Lebanon, but in refugee settings globally.

# Table of Contents

# Appendix

# List of Tables

# List of Figures

# Glossary

| Acronym | Definition |
|---|---|
| AC | Alternating Current |
| ACH | Air Changes per Hour |
| AHAM | Association of Home Appliance Manufacturers |
| ANOVA | Analysis of Variance |
| ARDS | Acute Respiratory Distress Syndrome |
| ASHRAE | The American Society of Heating, Refrigeration, and Air-conditioning Engineers |
| ATS | American Thoracic Society |
| $^0C$ | Degrees Celsius |
| CADR | Clean Air Delivery Rate |
| cc | Cubic centimeters |
| CDC | Centers for Disease Control and Prevention |
| CFD | Computational Fluid Dynamics |
| CFM | Cubic Feet Per Minute |
| CFU/m$^3$ | Colony Forming Units Per Cubic Meters |
| $C_6H_6$ | Benzene |
| cm | Centimeter |
| CO | Carbon Monoxide |
| CO2 | Carbon Dioxide |
| COHb | Carboxyhaemoglobin |
| COPD | Chronic Obstructive Pulmonary Disease |
| COVID-19 | Coronavirus Disease 2019 |
| dB | Decibels |
| DC | Direct Current |
| DIY | Do-It-Yourself |
| DNL | The Design for Nanomanufacturing Laboratory |
| DPNA | Development for People and Nature Association |
| EBC | Exhaled Breath Condensate |
| ELISA | Enzyme-linked Immunosorbent Assay |
| EPA | Environmental Protection Agency |
| ETS | Environmental Tobacco Smoke |
| ft | Feet |
| ft$^2$ | Square feet |
| FeNO | Fractional Exhaled Nitric Oxide |
| GBD | Global Burden of Disease |
| HAP | Household Air Pollution |

| Acronym | Definition |
|---|---|
| HEPA | High Efficiency Particulate Air |
| $H_2S$ | Hydrogen Sulphide |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IAQ | Indoor Air Quality |
| IARC | International Agency for Research on Cancer |
| IEQ | Indoor Environmental Quality |
| IL-2 | Interleukin 2 |
| iNOS | Inducible Nitric Oxide Synthetase |
| I/O | Indoor/Outdoor Ratio |
| IOM | Institute of Medicine |
| IgE | Immunoglobulin E |
| ISAAC | International Study for Asthma and Allergies in Childhood |
| ISO | International Standards Organization |
| ITS | Informal Tented Settlements |
| L/min | Liters per minute |
| µmol/L | Micro mol Per Liter |
| m | Meter |
| $m^2$ | Square Meters |
| mg | Milligrams |
| $m^3$/hr | Cubic Meters per Hour |
| mg/$m^3$ | Milligrams per cubic meter |
| mm | Millimeter |
| MCP-1 | Monocyte Hemoattractant Protein-1 |
| MENA | Middle East and North African |
| MERV | Minimum Efficiency Reported Value |
| NaCl | Sodium Chloride |
| NGO | Non-governmental Organization |
| NICE | National Institute for Health and Care Excellence |
| NO2 | Nitrogen Dioxide |
| NO | Nitric Oxide |
| NPC | Non-permanent Children |
| NPA | Non-permanent Adults |
| NRA | Non-residential Adults |
| NRC | Non-residential Children |
| $O_3$ | Ozone |
| OUC | Ouzai University Complex |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PCBs | Polychlorinated biphenyls |

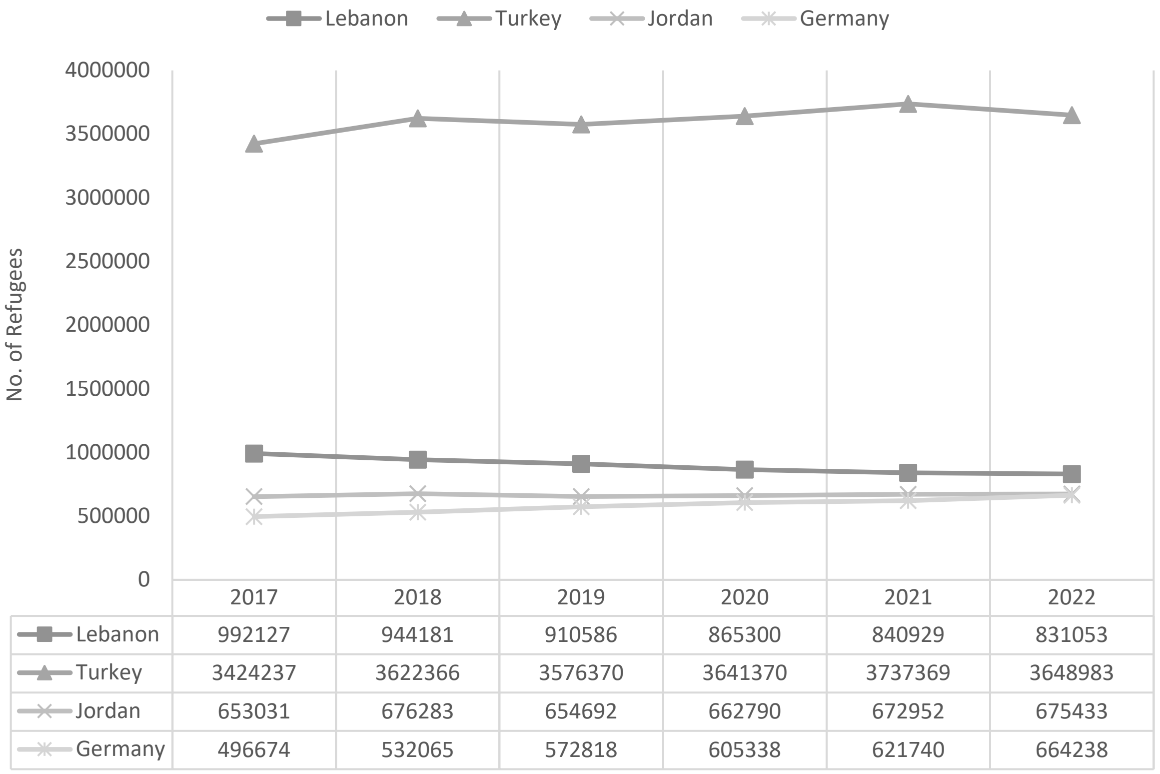
| Acronym | Definition |
|---|---|
| PCS | Pepsi Collective Shelter |
| PDGFBB | Platelet-derived Growth Factor BB |
| PM | Particulate Matter |
| PM2.5 | Dust particles with a diameter of less than or equal to 2.5 microns. |
| PM10 | Dust particles with a diameter of less than or equal to 10 microns. |
| PPB | Parts per Billion |
| PPM | Parts per Million |
| PSI | Product Sustainability Index |
| PV | Photovoltaic |
| PVC | Polyvinyl Chloride |
| RH% | Percentage Relative Humidity |
| SMPS | Scanning Mobility Particle Sizer |
| $SO_2$ | Sulphur Dioxide |
| SVOCs | Semi-Volatile Organic Compounds |
| SWAC | Solar-powered Window Air Cleaner |
| SWAV | Solar-powered Wall Air Vent |
| T2 | Type 2 Inflammation |
| TIC | Total Indoor Count |
| TIMP2 | Tissue Inhibitory of Metalloproteinase 2 |
| TVOCs | Total Volatile Organic Compounds |
| UNHCR | United Nations High Commissioner for Refugees |
| UNRWA | United Nations Relief and Works Agency for Palestine Refugees in the Near East |
| UNICEF | United Nations International Children's Emergency Fund |
| USEPA | United States Environmental Protection Agency |
| UV | Ultraviolet |
| V | Volts |
| VOCs | Volatile Organic Compounds |
| VVOC | Very Volatile Organic Compounds |
| W | Watts |
| $W/m^2$ | Watts per Square Meter |
| WASH | Water, Sanitation, and Hygiene |
| WHO | World Health Organization |

# Introduction

## 1. Background

### 1.1. The Refugee Population and Hosting Country

The Syrian war displaced over 10 million Syrians of which 7.5 million were displaced internally. By 2016, the number of Syrian refugees registered with the United Nations High Commissioner for Refugees (UNHCR) in Lebanon, exceeded 1 million (equivalent to 25% of the local population), making it the third largest refugee populations globally. Nevertheless, in 2017, Lebanon became the second largest Syrian refugee hosting country after Turkey and maintained this position through 2022 (Figure 1-1) [1-3].



| | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|
| Lebanon | 992127 | 944181 | 910586 | 865300 | 840929 | 831053 |
| Turkey | 3424237 | 3622366 | 3576370 | 3641370 | 3737369 | 3648983 |
| Jordan | 653031 | 676283 | 654692 | 662790 | 672952 | 675433 |
| Germany | 496674 | 532065 | 572818 | 605338 | 621740 | 664238 |

Figure 1-1. Syrian Refugees Population by Host Country. Lebanon maintained its position through 2022 as second largest Syrian refugee-hosting country after Turkey, followed by Jordan and Germany.

As of January 2022, there were an estimated 1.5 million Syrian refugees in Lebanon of which about 840,000 were registered with UNHCR, forming over 230,000 households

[4]. Lebanon, a relatively small Mediterranean country compared to its neighbours, with a population of around 4.5 million, has been the centre of regional turmoil which has tested the national health system resilience several times throughout the past three decades [5]. Lebanon has around 450,000 Palestinian refugees registered with the United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA), residing in 12 major camps and around 70,000 more Palestinians have fled the war in Syria seeking asylum in the country [6,7]. The flux of refugees created a public health challenge to the hosting country from an epidemiological and health coverage perspective. The ageing population of refugees, lifestyles, and poor hygiene have caused a high burden of non-communicable diseases combined with a burden of common diseases. These refugees arrived to Lebanon with pre-existing chronic conditions and injuries suffered during the conflict [7,8].

Several surveys on Syrian refugee housing and living conditions were conducted between 2013 and 2021, categorizing shelters into residential, non-residential, and non-permanent. Compared to the Lebanese host population, Syrian refugees required more medical care, whereby around 60% for medical care needs of children were attributed to respiratory problems and the majority of medical care needs of adults were reported as infections and communicable diseases [9]. Access to healthcare and secondary care has been challenging to Syrian refugees mainly due to socio-economic factors and a competing host community of which 50% are uninsured and sponsored by the ministry of public health [7-10].

### 1.1.1. Refugees Distribution and Settlements

In mid-June 2018, the distribution of Syrian refugees across the 4 major provinces in Lebanon, was 36% in Bekaa, 26.2% in Beirut, 25.8% in Northern Lebanon, and 12.1% in Southern Lebanon. About 47.5% of refugees were males and 52.5% were females with children under the age of 17 accounting for 55.5% of the population. Refugee households resided in urban, suburban and rural areas [3,11,12]. While 70% of refugees lived in apartments and rented rooms, 16% of households lived in temporary structures known as informal tented settlements (ITS), 5% resided in unfinished buildings and 9% as annexed structures to existing houses. Moreover, 44% of refugee households had 5 or more people sharing one bedroom [9]. A similar crowding occurred in neighbouring countries accommodating Syrian refugees. Within Za’atari camp in Jordan, for example, the needs of refugees had already surpassed the camp’s capacity, leading to sanitation problems and limited access to medical care [10]. Syrian refugees in Lebanon have been lacking essential services relating to access to drinking water and sanitation, due partially to budget constraints of non-governmental humanitarian organizations and restrictions on the establishment of larger refugee camps imposed by the Lebanese government [8,13].

## 1.2. Environment and Health

Many efforts have been pulled to assess the global burden of disease (GBD), estimating portion of the burden attributable to specific risk factors [14,15]. According to a report published by the World Health Organization (WHO) in 2016 using comparative risk assessment and emphasizing fractions of population affected by household air pollution (HAP) and second-hand smoking, lung cancer accounted for 17%, chronic obstructive pulmonary disease (COPD) 24%, and lower respiratory infections 35%. Furthermore, the report suggested that 23% of global deaths are attributable to the environment and 26% of deaths can be prevented among children under the age of 5 if environmental risks were eliminated [16]. The method used for assessment which is comparative risk is important for environmental policy making and implies a systematic evaluation of the changes in population health resulting from a modification in distribution of exposure to risk factors [17].

The GBD project performed in 2010 ranked risk factors by region, whereby tobacco smoke including second-hand smoking ranked 2nd and HAP from solid fuels ranked 4th globally. The same risk factors ranked 3rd and 13th respectively in the Middle East and North African (MENA) region [15]. The global rank of ambient air pollution was higher than that of MENA region mainly due to urbanization of the developed compared to the developing world. However, this is not the case when it comes to indoor air pollution which is a major public health concern for developing countries causing 2 million deaths annually [18,19].

HAP mainly affects women and children due to the nature of activities performed indoors such as cooking and other domestic practices, accounting for 60% of premature deaths. Additionally, HAP contributes to 50% of child pneumonia, the single biggest killer of children under 5 years of age worldwide [16,20]. Indoor air pollution in the developing world poses a greater threat than ambient air pollution among women and children since they spend up to 7 hours daily near pollution sources during cooking and heating [18]. Moreover, solid fuels use, in particular, has been strongly correlated with acute infections in children under the age of 4 and to lung cancer and chronic obstructive pulmonary disease in women aged 30 and above [21] .

Other studies performed in the Middle East have also linked gender-specific practices such as smoking and grilled/barbecued food to exposure to Polycyclic Aromatic Hydrocarbons (PAH), mainly pyrene, naphthalene, phenanthrene and fluorene. The results suggested that urinary-PAH is more detected in men than in women due to smoking habits [22].

### 1.2.1. Indoor Environmental Quality and Housing

Air quality as a risk factor varies in terms of health implications based on the medium characteristics, concentration of contaminants, and interaction with humans. Built environments such as buildings, apartments, and offices affect occupants' health in many ways depending on the adopted type of ventilation and air exchange between the indoor and outdoor environment [23-25]. The concentration of pollution in a breathing environment over a specified duration is referred to as exposure and the temporal factor is of great significance since people tend to spend more than 90% of their time indoors, according to the US Environmental Protection Agency (EPA), compared to 67% in France and 80% in North Korea [18,25-27]. Ventilation may occur naturally through infiltration or mechanically through HVAC systems. Natural ventilation, when adopted intentionally, uses pressure differences between the indoor and outdoor air to create air exchange without mechanical intervention, thus reducing energy cost. Mechanical ventilation on the other hand, requires electrical consumption to adjust temperature and control humidity [28,29]. Nevertheless, both methods have their drawbacks. Natural ventilation in urban settings, introduces harmful pollutants from the untreated outdoor air and does not contribute to dilution of indoor contaminants concentration which according to the US EPA may be 2 to 5 times and in some cases 100 times more concentrated than outdoor air [27,30,31]. As for mechanical ventilation, poorly maintained HVAC systems can be a potential source of pollutants contributing to microbial growth as a result of condensation from heat exchange [32].

While ventilation is a major factor influencing housing quality, other conditions within the built environment can impact occupants' health. Emissions from building material are a potential source of toxicity, and a medium for microbial growth [24,32-35]. Formaldehyde vapor, in addition to other volatile organic compounds, asbestos, and microbial growth are examples of indoor pollutants related to building material and household activities that will be discussed in more details in subsequent sections.

Studies related to housing and health in refugee camps in the Middle East have shown a strong association between poor housing quality and respiratory illnesses such as asthma prevalence in children and women's health worsening in general. Before the Syrian war, humanitarian research focused on internally displaced and asylum-seeking Palestinian refugees. El-Sharif et al. surveyed 12 schools in Palestine in 2000 using the International Study for Asthma and Allergies in Childhood (ISAAC) and concluded that children from refugee camps appear to be at higher risk of asthma than children from neighbouring villages and cities [36]. In 2001, 1625 households were surveyed in the Gaza strip and environmental health and hygiene was found to play a major role in the occurrence of parasites and diarrhoea with high prevalence among children between the age 1-4 [37]. Another study conducted also in a Palestinian refugee camp by Al-Khatib et al. in 2002, during which 150 women were interviewed, revealed a strong association between women's health and unhealthy housing conditions such as overcrowding, inadequate ventilation, and hygiene [38]. Research outside the Middle East in similar settings concluded that these risk factors can also lead to rodent infestations. A study in a Sierra Leone refugee camp about Lassa fever nosocomial outbreak demonstrated a strong correlation between external hygiene or housing conditions and the presence of vector rodents [39]. Additionally, poor sanitary infrastructure and overcrowding have led to Cholera outbreaks in refugee camps in Thailand, Ghana, Congo DR, and Pakistan between 2005-2006, among which fatalities have been recorded [40].

## 1.3. Aims and Objectives

The aim of this research was to contribute knowledge to understand the nature of risks within the context of indoor air quality (exposure and community health) of Syrian refugees in Lebanon by anticipating, recognizing, evaluating, and ultimately controlling hazards with the development of novel mitigation technologies [41].

The following objectives were executed to achieve this aim:

1. Survey to determine the nature of the community and their residential settings to generate the context for the study. This was executed by the collection and consolidation of demographic information (age, gender, location, number of occupants per household) in four governorates in Lebanon (Beirut, South, Bekaa, and North governorates) following ethical approvals and in collaboration with the relevant NGOs (Save the Children Organization).
2. Conducting an initial indoor environmental quality investigation in Syrian refugee settlements in Lebanon surveying two settlements in southern Lebanon in collaboration with the United Nations International Children's Emergency Fund (UNICEF).
3. Refining the study design following the initial investigation for target indoor environmental parameters and pollutants in refugee households by investigating the relationship between environmental pollutants (mould) and shelter types and conditions in the 4 identified governorates.
4. Use FeNO, a minimally invasive biomarker of pulmonary inflammation, as a biological response to mould exposure in two selected refugee shelters in the Bekaa and Southern governorates.
5. Design, fabrication and testing of novel low-cost sustainable mitigation technologies to remediate indoor air quality in refugee shelters.

## 2. Indoor Pollutants, Health Effects, and Guidelines

The research background emphasized conditions that render refugees potentially susceptible to adverse indoor environmental conditions. Figure 2-1 below summarizes the hazard anticipation based on the literature and vulnerability of the subject population.

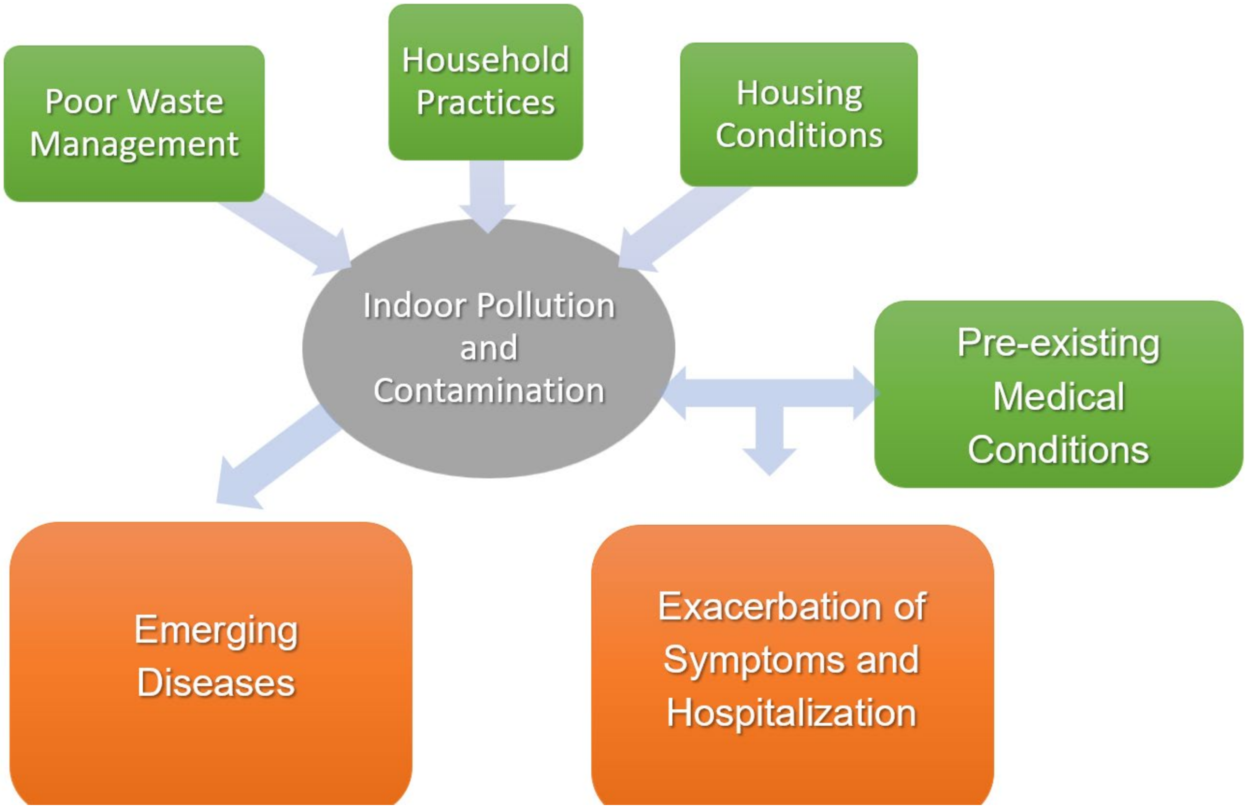


Figure 2-1. Hazard Anticipation and Potential Health Impact in Syrian Refugees in Lebanon.

To further understand how the indoor environment could affect refugees, this chapter will focus on select pollutants and anticipated health impact. Indoor pollutants can be classified into biological pollutants such as mould, bacteria, pollen and viruses, and non-biological or chemical pollutants such as volatile organic compounds and toxic gases. The main source of pollution occurring indoors is from human activity such as cleaning, heating, and cooking, and from building material and furniture [42-44]. Vulnerable individuals such as infants, the elderly, and patients with chronic diseases and allergies are more predisposed and likely to present with environmentally related symptoms. The common site of injury by airborne pollutants is the lungs, however, toxicological and host-related factors may result in non-respiratory acute effects [43-45].

Several organizations and government agencies have identified commonly encountered indoor pollutants with sources of emission and growth, and established guidelines for exposure limits and associated health effects. WHO published in 2009 a report on dampness and moulds and another report on selected indoor pollutants in 2010, with focus on benzene, carbon monoxide (CO), formaldehyde, naphthalene, nitrogen dioxide ($NO_2$), polycyclic aromatic hydrocarbons (PAH), radon, trichloroethylene, and tetrachloroethylene. Although exposure to combined indoor pollutants exists, there are no guidelines for co-exposure, instead, reducing particulate matter which has biological, chemical and physical properties, may be effective to reduce exposure effects to multiple pollutants [42,46]. There are many pollutants of interest, however, below is a summary of the most encountered and sampled for indoor biological and non-biological pollutants with sources, health effects, and exposure limits:

## 2.1. Particulate Matter (PM)

Particulate Matter (PM) is the mixture of solid particles and liquid droplets suspended in the air [47]. PM is characterized by size and aerodynamic diameter which determine its airborne transportation and inhalability [48]. Particles are further categorized into primary and secondary depending on emission sources. Primary particles result from combustion and are emitted directly from road transport, industrial processes, and domestic coal burning. Secondary particles, on the other hand, are products of atmospheric chemical reactions such as $SO_2$, $NO_2$, and VOCs oxidation [49]. Furthermore, PM is categorized into ultra-fine, fine, coarse, and thoracic particles. Ultra-fine particles consist of particles of diameter 0.1 μm or less which poses a greater health risk due to their ability to deeply penetrate lungs and cross the air-blood barrier. Fine particles, also referred to as respirable particles, can reach the alveolar gas exchange region. They are primarily released from combustion and include particles with diameter size between 0.1 and 2.5 μm to form PM2.5 together with ultra-fine particles. As for coarse particles, these consist of particles with diameters greater than 2.5 μm and include black smoke, dust, mechanically generated particles, secondary particles, salt, and soil. Additionally, coarse particles include biological aerosols such as fungal spores and pollen. Particles with a diameter of 10 µm or less are known as PM10 and termed as thoracic particles. This particle range can bypass the oronasal tract through the larynx eventually reaching the thorax [49-51]. HAP contributes to 12% of global ambient fine PM pollution [20]. ETS is another major source of PM pollution emitting concentrations up to 10-fold those emitted from diesel engines [52]. PM in ETS leads to immunological and lung function impairment, pulmonary diseases and aggravation of cardiovascular and respiratory conditions [45].

PM exposure has been associated with hospitalization, morbidity, and mortality cases such as aggravation of COPDs, chronic cardiovascular diseases, decreased lung function, low birth weight, infant and foetal deaths [53-55]. Epidemiological studies have observed lung function and development impairment in children exposed to PM [56]. For instance, high prenatal exposure of PM2.5 during midgestation has been linked to the development of asthma by the age of 6 in boys [57]. Moreover, PM2.5 in particular has been adopted as a robust indicator of adverse effects leading to mortality [54]. Studies have proven that this PM category reduces life expectancy and accounts for 3% of cardiopulmonary and lung cancer mortality [58,59]. Araujo reviewed epidemiological studies of atherosclerosis in 2011 and attributed its aetiology to the proinflammatory and prooxidative effects of PM exposure [60]. Subsequently, Cachon et al. (2013) exposed human lung epithelial cells in vitro to PM2.5 and found a strong correlation between PM exposure, gene expression, and secretion of inflammatory cytokines [61]. WHO has set 24-hours and annual standards for PM2.5 and PM10 exposure as per table 2-1 below:

**Table 2-1. PM2.5 and PM10 Exposure Limits.**

| **Category** | **24-hours** | **Annual** | **Reference** |
|---|---|---|---|
| PM2.5 (µg/$m^3$) | 15 | 5 | [62] |
| PM10 (µg/$m^3$) | 45 | 15 | |

## 2.2. Carbon Dioxide ($CO_2$)

Carbon Dioxide ($CO_2$) is a colourless gas which is naturally present in the atmosphere and constitutes 0.03 to 0.06% of ambient air, and 0.08 to 0.1% of indoor air [63]. It is a normal constituent of the body which arises from cellular respiration. It binds to haemoglobin chemically and is exchanged by diffusion through the alveolar membrane then released by convection from the lungs [64]. Carbon Dioxide is 1.5 times heavier than air which makes indoor environments vulnerable to its build-up by replacing oxygen [65]. High concentrations of $CO_2$ may increase intracellular acidity by lowering the pH concentration through an increase in hydrogen ions [66].

Atmospheric $CO_2$ levels have also been demonstrated to increase allergenicity of fungal spores such as *aspergillus fumigatus*, a commonly found indoors fungal species [67]. In a report issued by WHO in 1990, an acceptable indoor $CO_2$ level limit was 1800 mg/$m^3$ and concern arises for levels exceeding 12000 mg/$m^3$ [68]. The American Society of Heat, Refrigeration, and Air-conditioning Engineers (ASHRAE) has also set guidelines for indoor concentrations of $CO_2$. Standard 62.1 “Ventilation for Acceptable Indoor Air Quality” indicates that indoor $CO_2$ levels should not exceed 1260 mg/$m^3$ (700 ppm) above outdoors levels which range between 540 to 900 mg/$m^3$ [69].

## 2.3. Carbon Monoxide (CO)

Carbon monoxide (CO) is a non-irritating, colourless and odourless gas occurring from incomplete combustion of carbon containing fossil-fuels [70,71]. Outdoor sources of carbon monoxide are mainly emissions from vehicles, other sources include emissions from aircrafts and industrial processes [72,73]. CO is emitted indoors from cooking and heating appliances that burn biomass fuels as well as from tobacco smoke. Incense burning can also be a source of CO emission indoors and could exceed US EPA’s guidelines. Outdoor infiltration from nearby exhausts and combustion sources also contributes to CO accumulation indoors [20,46,74].

Inhalation of CO is the route of exposure targeting organs such as the central nervous system, lungs, blood, and cardiovascular system. Symptoms related to CO exposure include tachypnoea, lassitude, angina, cyanosis, and syncope [70]. Non-specific signs and symptoms of CO poisoning such as headache, nausea and dizziness are often misdiagnosed and attributed to other diseases [75]. CO is an asphyxiant which has a high affinity for haemoglobin (245 times more than oxygen) forming carboxyhaemoglobin (COHb), thus hindering transport of oxygen to tissues, and resulting in hypoxia [45,46]. Symptoms arising from non-hypoxic effects are due to intracellular uptake of CO which releases Nitric Oxide (NO) leading to endothelial inflammation in the brain. Brain function has been demonstrated to be impaired at 2.5-10% COHb. Loss of consciousness occurs when the range bypasses 30% and eventually death at 60% and above. Furthermore, epidemiological studies have linked chronic exposure to CO to cardiovascular morbidity such as heart attacks, congestive heart failure, and ischemic heart failure. Additionally, such studies have suggested low birth weight, congenital defects, and infant mortality in relation to CO toxicological effects [46]. Cuinicia et al. have exposed pollen of 3 plant species to acceptable ambient levels of CO and $SO_2$. The pollutants increased the allergenicity of the pollen by altering its morphology which was evident in the higher IgE reactivity in sensitized patients [76].

Studies conducted in settings similar to refugees have demonstrated that the use of kerosene stoves in tents has led to high CO levels in blood whereby COHb reached 21.5% after 2 hours exposure [77]. Chimney and open biomass stoves have also been proven to produce high CO levels inside nomadic tents bypassing WHO guidelines [78]. Threshold limits established for carbon monoxide exposure are summarized in Table 2-2 below.

**Table 2-2. Carbon Monoxide Exposure Limits.**

| **Source** | **1 hour** | **8 hours** | **24 hours** | **Reference** |
|---|---|---|---|---|
| WHO ($mg/m^3$) | 30 | 10 | 4 | [62] |
| US EPA ($mg/m^3$) | 40 (35 ppm) | 10 (9 ppm) | | [79] |

## 2.4. Sulphur Dioxide ($SO_2$)

Sulphur Dioxide ($SO_2$) is an air pollutant arising from anthropogenic activities such as combustion of fossil fuels, industrial processes and vehicles exhausts [76,80,81]. Sulphurous acid is produced in the respiratory tract and eventually dissociates into bisulphite and sulphite which are absorbed by the blood and other body fluids [82]. In addition to morbidity, mortality and increase risk of cancer [83], epidemiological studies concluded that $SO_2$ was associated with high risk of current wheezing, severe asthma, nighttime cough, and eczema [84]. Since $SO_2$ is readily removed in the nasal passages, the oronasal route of inhalation provides greater transport into the tracheobronchial region. Accordingly, asthmatic children under 12 who tend to breathe through their mouth and asthmatic elderlies are at a greater risk than younger adults [85]. Furthermore, animal studies have demonstrated that $SO_2$ causes oxidative damage not only to the respiratory system but to the brain and liver as well [80]. Studies have also confirmed a correlation between $SO_2$ exposure in low and medium concentrations and allergic sensitization in addition to increasing allergenicity to pollen as previously mentioned [76,86]. Other studies have further established that inhalation of $SO_2$ in concentrations similar to traffic conditions and even in levels below accepted standards enhances the airway response of mild asthmatic patients to inhaled allergens and causes bronchoconstriction [87,88]. Guidelines related to $SO_2$ exposure limits are listed in the table 2-3 below:

**Table 2-3. Sulphur Dioxide Exposure Limits.**

| **Source** | **10 minutes** | **1 hour** | **24 hours** | **Reference** |
|---|---|---|---|---|
| WHO (μg/m$^3$) | 500 | | 40 | [62] |
| US EPA (μg/m$^3$) | | 197 (0.075 ppm) | | [89] |

## 2.5. Nitrogen Dioxide ($NO_2$)

The ambient air contains 7 oxides of nitrogen however nitric oxide (NO), and nitrogen dioxide ($NO_2$) are the 2 principal gases which originate from combustion of fossil fuels for heating, household appliances, power generation, and vehicles engines [90]. Although over 90% of nitrogen oxides are emitted as nitric oxide, the latter is rapidly oxidized in air to form nitrogen dioxide which is considered as the primary pollutant [19]. $NO_2$ acts mainly as an irritant affecting the mucosa of the eye and upper respiratory tract. High dose exposure to $NO_2$ may result in pulmonary oedema with signs of chest pain, cough, dyspnoea, and cyanosis, while continuous exposure could lead to chronic bronchitis [45,90]. Like other traffic related pollutants, $NO_2$ can infiltrate indoor environments and contribute to the build-up of total indoor $NO_2$ concentration. A study conducted in 2000 evaluated the effect of household proximity to traffic roads and asthma exacerbation. The results indicated that asthmatic children living near motorways suffered from wheezing with increased use of asthma medication [91]. A previous study in 1995 established a correlation between time-weighted exposure to outdoor $NO_2$ and wheezing bronchitis in children particularly girls who are also at higher risk than boys from indoor $NO_2$ sources such as gas stoves [92]. Furthermore, an Australian study involving 80 households with children between 7 and 14 years of age attempted to study the effect of $NO_2$ from gas stoves on respiratory health, whereby it was concluded that peak $NO_2$ exposure has adverse heath effect on children [93]. Belanger at al. performed environmental sampling for $NO_2$ in 728 homes and results revealed increased respiratory symptoms among asthmatic children in multi-family housing even at levels below WHO and EPA standards [94]. Exposure guidelines of $NO_2$ are summarized in table 2-4 below:

**Table 2-4. Nitrogen Dioxide Exposure Limits.**

| Source | 1 hour | 24 hours | Annual | Reference |
|---|---|---|---|---|
| WHO (µg/m$^3$) | 200 | 25 | 10 | [62] |
| US EPA (µg/m$^3$) | 188 (0.1 ppm) |  | 100 (0.053 ppm) | [95] |

## 2.6. Volatile Organic Compounds (VOCs)

Volatile organic compounds are carbon-based compounds characterized by high volatility (boiling point between 50 and 260 $^0$C) at ambient atmospheric pressure and categorized into very volatile (VVOC), volatile (VOC), and semi-volatile (SVOC) organic compounds according to WHO's 1989 classification of organic pollutants [96]. VOCs undergo photochemical reactions in the presence of sunlight with nitrogen oxides (NOx) and carbon monoxide (CO) to form ground level ozone ($O_3$) [97]. Studies using indoor/outdoor (I/O) concentration ratios have demonstrated that some VOCs such as chlorinated hydrocarbons, short chain (C5, C6) n-alkanes, and benzene are mainly from outdoor sources, whereas long chain (C10-C12) n-alkanes, terpenes, naphthalene, and styrene are from indoor sources, while other compounds have mixed indoor and outdoor sources [98]. Sampling performed in school settings revealed significant concentrations of formaldehyde, benzene, and naphthalene which are among WHO's 9 selected indoor pollutants due to their indoor abundance and carcinogenicity [46,99].

VOCs can be emitted from a variety of indoor sources such as building materials (e.g. ceiling tiles, paints, and floor coverings), consumer products (e.g. solvents, cleaning detergents, and personal care products), furniture (e.g. carpets and wood), and office equipment [100]. Vehicles exhausts and tobacco smoking are also combustion sources that contribute to indoor air accumulation of VOCs [98]. Brown et al. (1994) demonstrated that the average concentration of each VOC in established buildings is between 5 and 50 μg/m$^3$, however, emission rates vary depending on indoor sources. Furthermore, total volatile organic compounds (TVOC) concentration is higher than individual VOCs concentrations due to the large mixture of compounds available indoors [101].

VOCs have been closely related to sick building syndrome and their concentration depends on the activities taking place indoors [102]. Health effects and symptoms are usually reported at TVOC concentration of 25 mg/m$^3$ [103]. Of the major symptoms caused by VOCs inhalation are conjunctival irritation, nose and throat discomfort, headache, dyspnoea, nausea, emesis, decline in cholinesterase serum level, fatigue, and dizziness [45]. A study conducted by Molhave et al. (1985) exposed healthy subjects to a mixture of 22 non-carcinogenic VOCs at concentrations of 0, 5, and 25 mg/m$^3$ whereby irritation of the eyes, nose, and throat were significantly correlated with concentrations of 5 and 25 mg/m$^3$ [104]. Moreover, exposure to VOCs also results in asthma-like symptoms, affecting lung function and promoting bronchial hyperresponsiveness [105].

## 2.7. Benzene and ETS

Benzene ($C_6H_6$) is an aromatic compound with a six-member unsaturated carbon ring. It is a highly flammable and volatile liquid which evaporates rapidly at room temperature and can predominate in vapor form for up to two weeks [46]. Benzene is produced from emissions from vehicles exhausts, gasoline stations, and burning of coal and oil [106]. It is used in the production of various chemicals and the manufacturing of rubber, lubricants, detergents, dyes, pesticides, and even drugs [107]. Environmental Tobacco Smoke (ETS) is considered a major indoor source of benzene [46]. While 20% of benzene is from vehicle exhausts and industrial processes, half of benzene exposure in the United States is attributed to smoking and inhaling tobacco [107].

Chronic and acute non-cancerous effects of benzene also exist. Such effects are haematological, immunological, reproductive, neurological, endocrine, renal, and cardiovascular [46,107,108]. As for respiratory effects, acute exposure has been reported to be lethal, causing haemorrhage and lung oedema while there were no sufficient epidemiological studies to correlate respiratory diseases with chronic benzene exposure [108].

Both the IARC and US EPA have categorized benzene as a known human carcinogen (IARC: Group I, US EPA: Group A). Accordingly, WHO has not set any safe level of exposure to benzene and recommended keeping levels as low as possible [46].

## 2.8. Mould

Mould are eukaryotic microorganisms which grow filaments called hyphae [109]. They pertain to the kingdom Fungi and fall into 3 main common groups which are Zygomycetes, Basidiomycetes, and Ascomycetes, the group which contains the main fungi that colonize building materials [110]. Fungal mould growth is a major concern for architects and structural engineers, as fungus can cause a housing epidemic that leads to undesirable changes in the structural characteristics of buildings [111]. Fungi are ubiquitous in nature, they can be parasitic or symbiotic, however, most fungi are saprophytic, absorbing nutrients from decaying material. In indoor environments, materials such as wood, paper, paint, insulation, and dust are suitable for fungal growth [112]. These bio-receptive materials allow the growth of fungi such as *Alternaria*, *Stachybotrys*, *Cladosporium*, *Penicillium*, and *Aspergillus* spp. [113,114]. Mould growth also depends on certain environmental conditions such as temperature and relative humidity (RH%). Mould usually favours temperatures between 15 and $30^0$C, however, some species grow below or above this range [112]. As for relative humidity (RH%), a range between 30% and 50% should be maintained for a healthy indoor air (ASHRAE standard 62.1 recommends 30 and 65% RH) as fungal growth and dust mite infestations occur above 50% RH [69,115]. Although fungal spores can travel passively through environments, indoor fungal presence is mainly attributed to moisture, and growth can occur on material with water activity varying between < 0.8 and > 0.98 [116].

In 2004, the *Damp Indoor Spaces and Health Committee* of the *Institute of Medicine* (IOM) reviewed and summarized the scientific evidence for relationships between indoor air exposure and the development and exacerbations of asthma. It concluded among several studies sufficient evidence of an association between damp indoor exposure and certain respiratory health outcomes, but insufficient evidence of an association between the presence of mould and onset of asthma [117-119]. Conversely the *World Health Organization* (WHO) concluded the level of evidence was sufficient to suggest causality for asthma development and “almost” sufficient for the exacerbation of asthma irrespective of age group [42]. In refugee settings, such as Palestinian camps, studies which have examined dwellings, have observed dampness, leaks, and visible indoor mould growth in the majority of houses [36,37]. Generally speaking, there is a clinical association between microbiological exposure and allergies, asthma, respiratory symptoms, and immunological reactions. However, similar to chemical compounds exposure, individuals tend to inhale a mixture of these biological agents. Therefore, it is challenging to attribute health effects to individual species of microbes [42]. The below table summarizes major symptoms and diseases associated with mould exposure, adopted from Storey et al. (2004) *Guidance for Clinicians* [112]:

**Table 2-5. Clinical Outcomes of Mould Exposure.**

| **Health Effects** | **Illness/Symptoms** |
|---|---|
| Fungal Infections | Flu-like syndrome, interstitial or cavitary pneumonia, meningoencephalitis, tinea cruris, corporis, and pedis. |
| Allergic Rhinitis and Asthma | Upper airway: clear rhinorrhea, nasal congestion, sneezing, post-nasal drip with sore throat, coughing, and hoarseness.<br>Lower airway: bronchospasm, chest tightness, and shortness of breath. |
| Hypersensitivity Pneumonitis and Interstitial Lung Disease | Extrinsic allergic alveolitis, farmer's lung, Japanese summer-house, cryptogenic fibrosing alveolitis, idiopathic pulmonary fibrosis. |
| Bronchopulmonary Aspergillosis | Eosinophilic pneumonia, mucous plugs, or asthma exacerbations. |
| Allergic Fungal Sinusitis | Polyposis |
| Allergic Dermatitis | Dryness, pruritus, and skin rashes. |
| Irritation | Cough, skin irritation, and burning or itching of the eyes and nose. |
| Organic Dust Toxic Syndrome | Flu-like syndrome with prominent respiratory symptoms and fever. |

# 3. Pilot Study

## 3.1. Visual Inspection of Refugee Shelters

To get a better insight about indoor environmental conditions in refugee complexes, 2 settlements were identified in the southern Lebanese city of Sidon (Figure 3-1). The first settlement was facilitated by the United Nations International Children’s Fund (UNICEF) and Development for People and Nature Association (DPNA), a partnering local non-governmental organization (NGO), while access to the second settlement was in collaboration with the American University of Beirut Department of Civil Engineering.

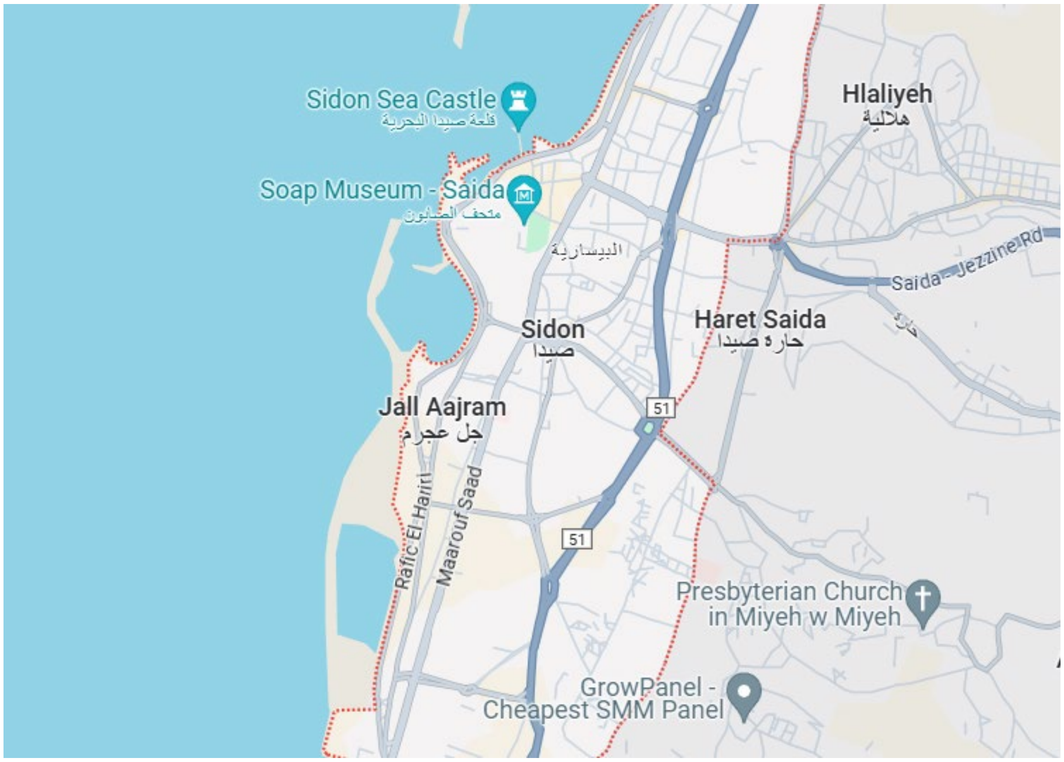


Figure 3-1. Map of City of Sidon in the Southern Lebanese Governorate. (Image source: Google Maps 2024)

### 3.1.1. The Pepsi Collective Shelter

The first settlement is known as the Pepsi Collective Shelter (PCS), due to its proximity to a Pepsi factory. The PCS is a three-story cement structure with residential apartments on the first through third floor housing 115 refugee households allocated to ground level repurposed units formerly used as mechanic garages and workshops (Figure 3-2). The majority of refugees were of Syrian nationality followed by Palestinians and other nationalities.

Figure 3-2. The Pepsi Collective Shelter. Pepsi Collective Shelter building overview (left). Refugee households in ground level repurposed workshops (right)

The walkthrough inspection identified several sub-optimal conditions for human occupancy evident in damage to the building's structure through cracks in walls and ceilings, exposing structural material such as steel and cinder blocks. Furthermore, improper wiring to supply additional appliances required by the refugee households revealed another hazard due to potential electrocution risk from suspended and frayed electrical wires (Figure 3-3).

Figure 3-3. PCS Safety Hazards. Electrocution hazard posed by suspended wired inside the Pepsi Collective Shelter.

In terms of hygiene-related observations, waste was poorly managed inside and outside the building, and children were observed playing around piles of waste in proximity to a visibly polluted Litany River (Figure 3-4).

Figure 3-4. PCS Hygiene Observations. Waste scattered inside the PCS building between household units (left). Contamination of the Litany River branch near the PCS (right).

### 3.1.2. The Ouzai University Complex

The Ouzai University Complex (OUC) in Saida is an incomplete concrete structure originally designed as a university building. The complex houses 240 refugee households inside classrooms spaces repurposed as multi-family units. Openings and cracks were covered with plywood and indoor finishes were absent (Figure 3-5).

Figure 3-5. The Ouzai University Complex housing Syrian refugees in Saida, Lebanon.

Similar to the PCS observations, the OUC had evident environmental health and safety risks to occupants, notably electrocution hazards, overall poor hygiene inside and outside the complex, with shared latrines between households, and sewers leaking in the complex's basement (Figure 3-6).

Figure 3-6. OUC Hygiene Observations. Sewers leaking in OUC basement (left). Unmanaged waste outside the OUC (right).

## 3.2. Indoor Environmental Quality (IEQ) Assessment

The IEQ scope included an initial limited indoor air quality assessment to test for parameters and potential pollutants following the walkthrough visual inspection. The following pollutant indicators and parameters were selected:

- Temperature
- RH% (Relative Humidity)
- $CO_2$ (Carbon Dioxide)
- CO (Carbon Monoxide)
- $H_2S$ (Hydrogen Sulphide)
- $SO_2$ (Sulphur Dioxide)
- $NO_2$ (Nitrogen Dioxide)
- TVOC (Total Volatile Organic Compounds)
- Mould

Hydrogen sulphide was selected to evaluate the impact of poor waste management inside and outside the shelters [120-122].

### 3.2.1. Methodology

A Graywolf Sensing TG-501 probe with electrochemical sensors for $SO_2$, $NO_2$ and $H_2S$, and an IQ-601 probe for temperature, %RH, CO, $CO_2$, and a photo ionization detector for TVOC, were used to conduct single 1-hour readings inside 5 households at each settlement for a total sample size of 10 households. The average floor area of sampled households was 65 $m^2$ with occupancy ranging between 4 and 11 refugees (Table 3-1). The probes were connected to a handheld Graywolf Direct Sense monitor to log sampled concentrations. Furthermore, an Anderson N6 single stage impactor was connected to a Zefon® pump adjusted at 28.3 L/min to sample for 5 minutes onto 9mm Sabouraud dextrose agar culture plates, acquired from bioMérieux, placed inside the impactor to collect samples. Sampling equipment were placed 1.5 meter above ground level throughout the sampling period [123-127]. The impactor was dismantled and disinfected with ethanol wipes between each sample collection. During the limited assessment, a single sample was collected from each household and an outdoor ambient air sample was also collected for comparison at each site for all parameters and pollutants Culture plates were stacked upside down to account for condensation and wrapped with parafilm inside a cooler bag then transported to the microbiology laboratory at the American University of Beirut Department of Agriculture and food Science for incubation and enumeration. The plates were incubated at $25^0$C and examined between 24 to 48 hours. Microscopic slides were inoculated with mould colonies from culture plates and stained with lactophenol blue. Identification of mould genera was performed under a light microscope.

**Table 3-1. Number of Occupants in Sampled Shelters.**

| Household | Settlement | No. Occupants |
|---|---|---|
| OUC1 | Ouzai University Complex | 4 |
| OUC2 | Ouzai University Complex | 11 |
| OUC3 | Ouzai University Complex | 6 |
| OUC4 | Ouzai University Complex | 6 |
| OUC5 | Ouzai University Complex | 6 |
| PCS1 | Pepsi Collective Shelter | 5 |
| PCS2 | Pepsi Collective Shelter | 6 |
| PCS3 | Pepsi Collective Shelter | 7 |
| PCS4 | Pepsi Collective Shelter | 5 |
| PCS5 | Pepsi Collective Shelter | 5 |

### 3.2.2. Results and Discussion

Results have shown that poor moisture control and overcrowding were two major factors of adverse conditions as evident in relative humidity and $CO_2$ levels exceeding ASHRAE guidelines. $CO_2$ levels were high in households with more than 5 occupants at the time of sampling (Figure 3-7 and 3-8).

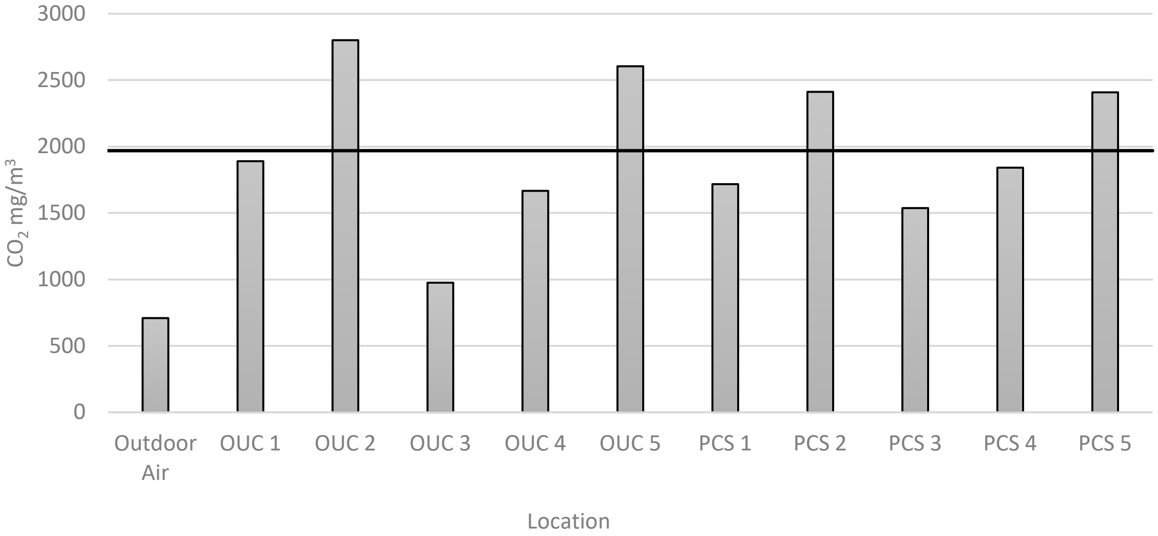


Figure 3-7. Carbon Dioxide. Levels were above ASHRAE standard 62.1 in 4 out of 10 households and 2 households had levels near the threshold limit. The black threshold line indicates 1260 mg/m$^3$ above outdoor air concentrations of $CO_2$ per ASHRAE standard 62.1.

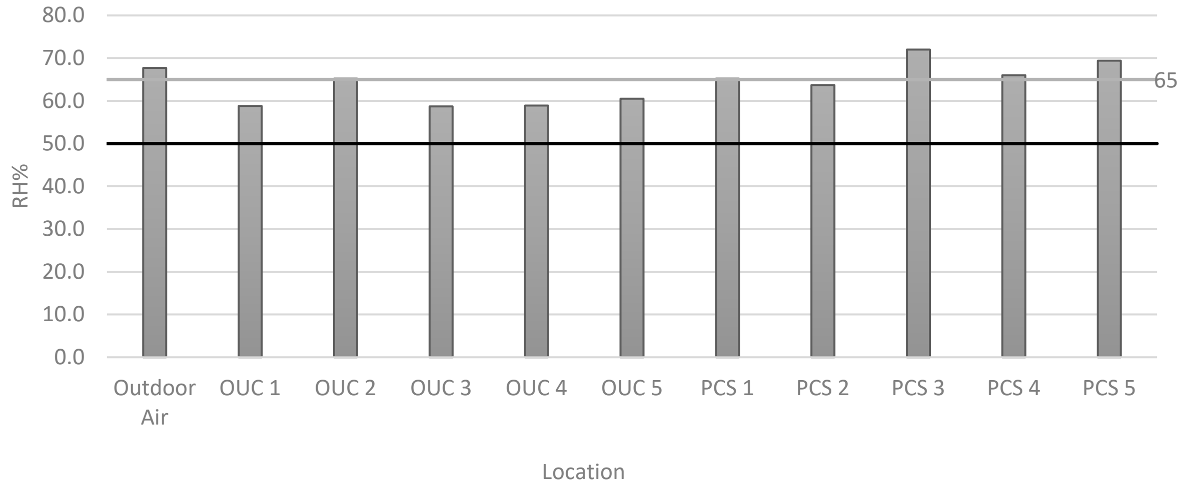


Figure 3-8. Relative Humidity. Levels bypassed ASHRAE standard 62.1 (grey threshold line) in 5 out of 10 selected Syrian refugee households and were above the recommended threshold for microbiological growth (black threshold line) in all sampled households.

Combustion gases levels were either not present or negligible since unlike refugees occupying informal tented settlements and other regions, refugees living on the coastal area of Lebanon have replaced most of the gas stoves with electrical ones and used electrical heaters instead of kerosene and wood stoves for heating to prevent fire incidents. Although poor waste management was evident in the presence of nearby accumulated dumpsters and leaking sewers, no traces of $H_2S$ were recorded indoors at the time of sampling. The non-detection of these indoor pollutants may have been attributed to the limited nature of this initial investigation and duration of sampling which is considered as a “snapshot” of existing environmental conditions inside refugee shelters. Furthermore, indoor pollutant levels are subject to temporal, seasonal, and spatial variations which influence results if those factors are not accounted for in study designs [128-130].

Nevertheless, elevated mould concentrations were reported in all sampled locations and were significantly above outdoor counts which were used as a benchmark for maximum concentration (Figure 3-9). Sampling volume was not adjusted to account for overgrowth due to the fact that sampling from both settlement was completed over 2 consecutive days prior to enumeration of culture plates.

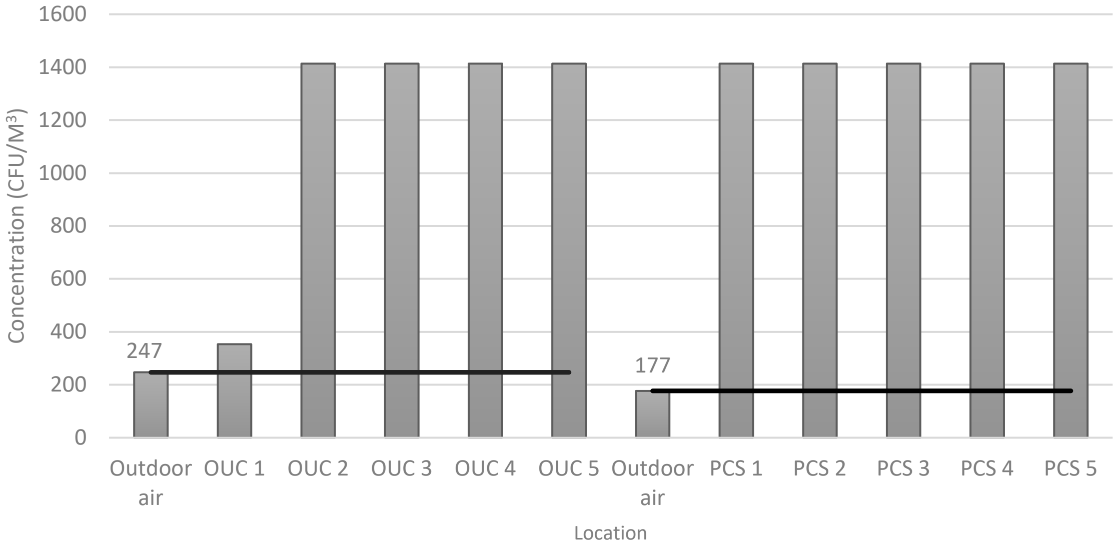


Figure 3-9. Mould Concentrations. Air samples revealed concentrations above outdoor samples in all sampled households.

As highlighted in the aims and objectives of this research, the purpose of the pilot study was to refine the research design and recognize target environmental pollutants impacting Syrian refugees. These findings were efficient to suggest a broader microbiological investigation into refugee shelters especially that although several studies have focused on refugee health in relation to the built environment [40,131-137], none have investigated the evidence for correlations between categories and conditions of settlements, and the type and prevalence of airborne mould knowing that vulnerable and immunosuppressed individuals (children, the elderly, HIV patients, pregnant women, and patients on immunosuppressive medication) account for more than 60% of the Syrian refugee population which put them “at risk” from health effects from exposure to elevated levels of pathogenic fungi [138-142]. Such information is vital to refugee management for planning locations and types of settlements according to season, resources, refugee demographics (composition and proportion of vulnerable groups) and refugee health status.

# Evaluation of Hazards

## 4. Fungal Exposure in Syrian Refugee Settlements

The previous chapter highlighting the pilot study conducted in the Lebanese city of Saida at 2 refugee shelters, revealed that the conditions surrounding the refugee population has potential adverse health effects due to the abundance of mould indoors. Accordingly, this research aimed to investigate correlations between mould concentrations and the residential, non-residential, and non-permanent categories of refugee shelters. Furthermore, shelter structural integrity was also assessed by measuring moisture content, for the purpose of establishing a potential association between shelter chronic dampness in building material and abundance of mould.

### 4.1. Materials and Methods

#### 4.1.1. Population Data

An original sample size representing the total number of registered refugee households by UNHCR was calculated to be 97 and rounded to 100 households with a 95% confidence interval and a 10% error margin. Access to refugee households was limited by geographical, logistical, and communication challenges. Consent for accessing the shelters was obtained on the same day of sampling by each head of household. The sample size was accordingly reduced to 80 refugee households due to these limitations. While random selection was the method of recruitment, only Syrian refugee households residing in the identified settlements were selected since other nationalities were also present, however, did not share the current humanitarian and socio-political profile of refugees governed by forced displacement and constricted temporary residency. Furthermore, an effort was made to obtain a close representation of shelter classifications under residential, non-residential, and non-permanent shelters (Table 4-1).

**Table 4-1. Distribution of Sampled Refugee Households (n=80).**

| **Governorate** | **Area** | **No. Households** | **Residential** | **Non-residential** | **Non-permanent** |
|---|---|---|---|---|---|
| Beirut | Bourj Hammoud | 20 | 20 | | |
| Bekaa | Bar Elias | 20 | 2 | | 18 |
| South | Abra | 20 | 7 | 13 | |
| North | Biret Akkar | 20 | | 20 | |

Settlements were selected from 4 Lebanese governorates using the beneficiaries' database of Save the Children in Lebanon (Figure 4-1). Households were anonymized and referenced as per Save the Children's internal Memoranda of Understanding established with the beneficiaries.

Figure 4-1. Syrian Refugee Settlements in Lebanon. The shaded orange areas represent refugees distribution in the 4 major governorates of Lebanon. (Image Source: Google Maps 2024)

The selected sample included non-residential (41.25%), non-permanent (22.5%), and residential (36.25%) households. Non-residential households included classrooms, garages, and storerooms; residential households included rented apartments and rooms in multi-family buildings, while non-permanent households were informal tented settlements, composed of detached structures made from timber, plywood ceilings and walls, draped with cloth and plastic sheets (Figure 4-2). The floor area of these structures was approximately 45 m$^2$ for single-family households and 100 m$^2$ for multi-family households. The average occupancy per household in all refugee shelters was 6 persons and children accounted for more than 50% of the selected population. As for the control group, 20 residential standard apartments were selected from the host population, representing indoor baseline conditions, whereby 10 apartments were located in Beirut and 10 in Mount Lebanon. Accordingly, the total sample size was 100 households with a 4:1 refugee to baseline control ratio. The cross-sectional study covering sampling and moisture assessment was performed in the spring season (May 2019).

Figure 4-2. Syrian Refugee Settlements Overview. Aerial views of the Bourj Hammoud neighbourhood in Beirut (left). Informal tented settlements in the Bekaa Bar Elias region (right).

The selected households were naturally ventilated through windows in residential and non-residential shelters, while non-permanent shelters (informal tented settlements) relied on natural air infiltration through structural gaps and guided exhaust from small wall-mounted fans. Shelters were further categorized based on structure such as concrete or wood, and on conditions such as “Standard”, “Damaged”, “Unfinished”, or

“Visible Mould” (Table 4-2). Standard shelters are mainly residential apartments with intact structural integrity. Damaged shelters, on the other hand, are any type of shelter which exhibited cracks in walls and/or ceiling, and/or a leaking roof. Unfinished shelters were rooms lacking insulation, floor tiles and/or paint primer. The presence of visible mould patches was considered evidence of fungal growth on building surfaces.

**Table 4-2. Shelter Condition.**

| Shelter Category | Standard | Damaged | Unfinished | Visible Mould |
|---|---|---|---|---|
| Residential<br>n=29 | 5 | 1 | 4 | 19 |
| Non-residential<br>n=33 |  | 13 | 20 |  |
| Non-permanent<br>n=18 |  |  |  | 18 |

### 4.1.2. Mould Air Sampling and Enumeration

A walkthrough inspection was performed in every household prior to sampling [143]. Photographs of building structural integrity and conditions were taken, including visible mould growth. Most shelters consisted of a single room and adjacent connected cooking area and shared toilet with low or absent interior walls. Images of visible mould growth typically seen on residential and informal settlement walls and ceilings are shown in Figures 4-3 and 4-4.

Figure 4-3. Mould in Residential Shelters. Examples of evident sporadic (left) and concentrated (right) mould growth on residential shelters ceilings.

Figure 4-4. Mould in Non-permanent Shelters. Example of mould growth on ceiling (left) and wall (right) wood panels inside informal settlements.

Similar to the methodology followed during the pilot study, an Andersen N6 single-stage impactor, consisting of 400 precision holes of 0.65µm cut-off diameter was placed on a tripod in the middle of the selected room at 1.5m above the ground [127]. The impactor was connected to a Zefon® pump adjusted to 28.3 L/min with 9mm Sabouraud dextrose agar media plates, acquired from bioMérieux, placed inside the impactor to collect samples. However, to obtain adequate statistical representation of indoor concentrations, a total of 2 samples were taken for 5 minutes and another 2 for 2.5 minutes according to ISO standard methods (ISO 16000-17) [144,145]. An ambient outdoor and a blank sample were collected to establish the ambient baseline concentrations for each monitoring exercise. Control (field blank) samples were processed alongside samples and treated in an identical manner for quality control [143]. An ethanol wipe was used to disinfect the sampler's components between each sampling event. Culture plates were stacked upside down to account for condensation and wrapped with a parafilm tape inside a cooling bag for transportation. Samples were incubated at $25^0$C on the day of collection at the microbiology laboratory at the American University of Beirut Department of Agriculture and Food Science, and observed for colony growth at 24, 48, 72 and 96 hrs. Enumeration was performed before overgrowth of colonies. Positive hole correction to calculate a probable count from the total raw count (assuming multiple particles can impact on the same hole) was applied to total counts before conversion to colony forming units per cubic meters (CFU/$m^3$) [144,145]. Positive hole correction, was calculated using the following equation:

Equation 4-1 $$Pr = N[1/N + 1/N-1 + 1/N-2 + \cdots 1/N-r+1]$$

Where;

$\mathrm{Pr}$ is the expected number of viable particles to produce 'r' positive holes.

$\mathrm{N}$ is the total number of holes which is 400 in the case of the Andersen N6 single-stage impactor.

Sampled volumes at 5 and 2.5 minutes were 141.5l and 70.75l, respectively. The concentration of colony forming units per cubic meters of air $C_I$ was calculated for each sample according to the following equation [145]:

Equation 4-2 $$C_I = \frac{n_{CFU}}{V_I}$$

Where;

$n_{CFU}$ is the total number of colony-forming units on the agar plates.

$V_I$ is the total sampling volume, in cubic metres.

To calculate the total concentration of moulds in each location, the 4 sampled volumes (2 x 141.5 l and 2 x 70.75 l) were added, as per the following equation:

Equation 4-3 $$C_I = \frac{n1_{CFU}+n2_{CFU}+n3_{CFU}+n4_{CFU}}{V_{I1}+V_{I2}+V_{I3}+V_{I4}}$$

The indoor/outdoor ratio (i/o) was calculated by dividing the total indoor count by the total outdoor count after positive hole correction adjustment.

### 4.1.3. Identification of Mould/Fungi

For the identification of indoor mould genera, a sample from distinctive colonies on the Sabouraud dextrose agar was taken by means of an inoculating loop and placed on alcohol covering the centre of the microscopic slide. A total of 3 drops of lactophenol cotton blue were used to stain the fungal culture and a cover slip was placed over the sample. Slides were gently heated before microscopic examination at 100, 40 and 20 x magnification to identify mould genera. Microscopic structures were identified using the Atlas of Clinically Important Fungi and the Pictorial Atlas of Soil and Seed Fungi [146-148]. Enumeration of specific mould type was estimated without the positive hole correction method reported as per cubic meters of air (CFU/m$^3$), for the purpose of establishing possible correlations between mould genera, and type and conditions of shelters.

STATA® V.17 software was used to run statistical analysis of results. Descriptive statistics were used to determine the percentages of each mould present within a household. Analysis of variance (ANOVA) was used to determine the statistical significance of any differences between mean mould concentration, indoor/outdoor (I/O) mould ratio and total indoor count (TIC), among different types of shelter. Barlett's test for sample variance was used to account for unequal sample sizes.

### 4.1.4. Moisture Content

Moisture content of shelter material was determined using a Tramex® non-destructive moisture meter using a scale of 5-30% moisture for wood structures and 0-100 scale for concrete structures. For concrete structures, an average of 3 reading was taken for study locations around windows, on shelter floors and walls adjacent to frequently damp environments (e.g., bathrooms & kitchens). For informal settlements, moisture was measured on wood structures (e.g., beams & ceiling panels). Readings were collected once the device was firmly placed against the structure and moved around until the highest reading was recorded [149].

Pearson correlation was used to determine associations between moisture content in concrete for residential and non-residential shelters, and wood for non-permanent shelters and the following parameters:

- Concentration of different mould types
- I/O ratio
- Total indoor count
- Occupancy

## 4.2. Results and Discussion

### 4.2.1. Mould Concentration

*Aspergillus*, *Cladosporium*, *Penicillium*, and *Rhizopus* spp. were the most prominent genera in the 3 shelter categories and baseline households (Figure 4-5). The results revealed that non-permanent shelters had the highest concentrations of *Stachybotrys* (8.6 CFU/m$^3$), *Aspergillus* (64 CFU/m$^3$), *Penicillium* (223.4 CFU/m$^3$), *Pithomyces* (7.5 CFU/m$^3$) and *Ulocladium* (3.9 CFU/m$^3$) spp., indicating that the shelter structure influenced the abundance of these genera. Furthermore, *Cladosporium* and *Alternaria* spp. ($P<.01$) were more abundant in non-residential compared to non-permanent and residential shelters, and significantly higher than baseline households. A final regression model ($R^2$=56.32%) established between types of shelter and the most abundant mould genera revealed significant association ($P<.001$) with *Aspergillus*, *Penicillium*, and *Stachybotrys* spp., which may be considered as predictors of informal architecture and design.

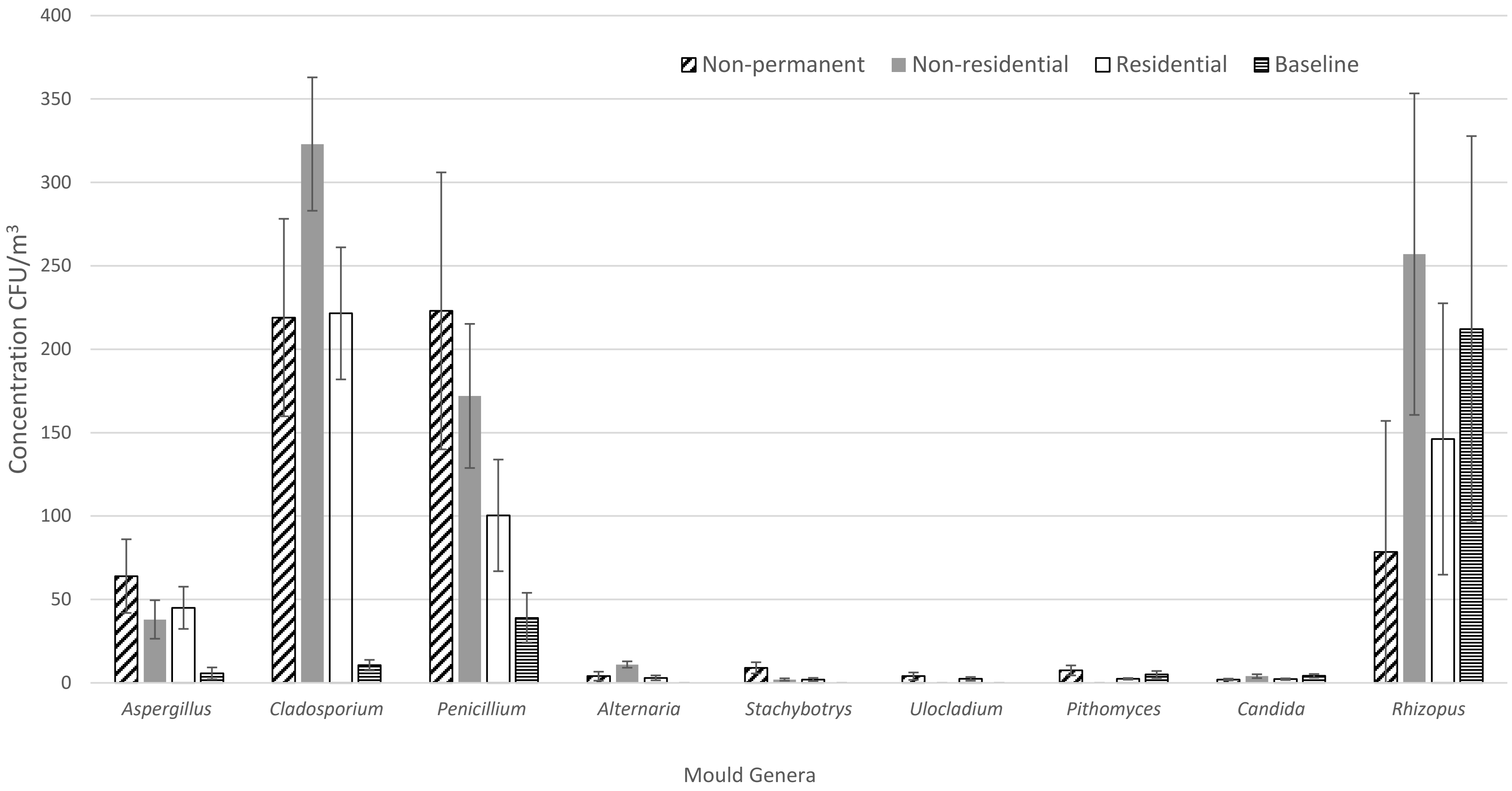


Figure 4-5. Indoor Mould by Type of Shelter, Mean Concentrations and Standard Error. Non-permanent (n=18); non-residential (n=33); residential (n=29); baseline households (n=20).

*Rhizopus* spp. was higher in non-residential shelters compared to other categories, followed by controls, however, no significant association was found. The presence of *Rhizopus* in control households may indicate that seasonal and psychometric factors, influence airborne concentrations, more than building material [150,151]. Additionally, despite the low concentrations of *Candida* spp. in all types of shelters, controls were found to have the highest counts and no significant association with refugee shelters. As seen with *Rhizopus* spp., *Candida* spp. abundance was attributed to factors unrelated to building structure, such as indoor emissions and/or human activity [146].

Health effects attributed to mould exposure include fungal infections, allergic rhinitis, asthma, hypersensitivity pneumonitis, interstitial lung disease, bronchopulmonary aspergillosis, allergic fungal sinusitis, and organic dust toxic syndrome. The illnesses and symptoms caused by such exposure range from flu-like syndromes and congestion to interstitial or cavitary pneumonia and fibrosis [112,152-154] . Furthermore, some of the identified genera, particularly *Aspergillus* and *Penicillium* spp., produce secondary mycotoxins such as aflatoxins and ochratoxins which can cause adverse health effects in exposed humans [155-157]. Simoni et al. (2005) reported a strong correlation between early childhood mould exposure and the onset of respiratory disorders and asthma, more evident in children than adolescents [158]. Furthermore, the Leipzig Allergy Risk Children Study (LARS) suggested a significant association between respiratory tract infection and exposure to *Penicillium* spores >100 CFU/m$^3$, and between allergic rhinitis and exposure to *Aspergillus* > 100 CFU/m$^3$ in 200 children aged 36 months [159].

The majority (67%) of identified mould genera are commonly found in air samples of moisture-damaged dwellings and in bulk samples of water-damaged building material [160,161]. Damaged structures had the highest concentrations of Aspergillus and Alternaria spp. ($P<.05$) compared to standard, unfinished and visibly mould-infested shelters. Cladosporium spp. was highest and equally abundant in damaged and unfinished shelters and lowest in standard shelters ($P<.001$). Compared to standard, damaged and visible mould-infested shelters, unfinished shelters had the highest concentrations of Penicillium and Rhizopus spp., however, this was not statistically significant (Figure 4-6).

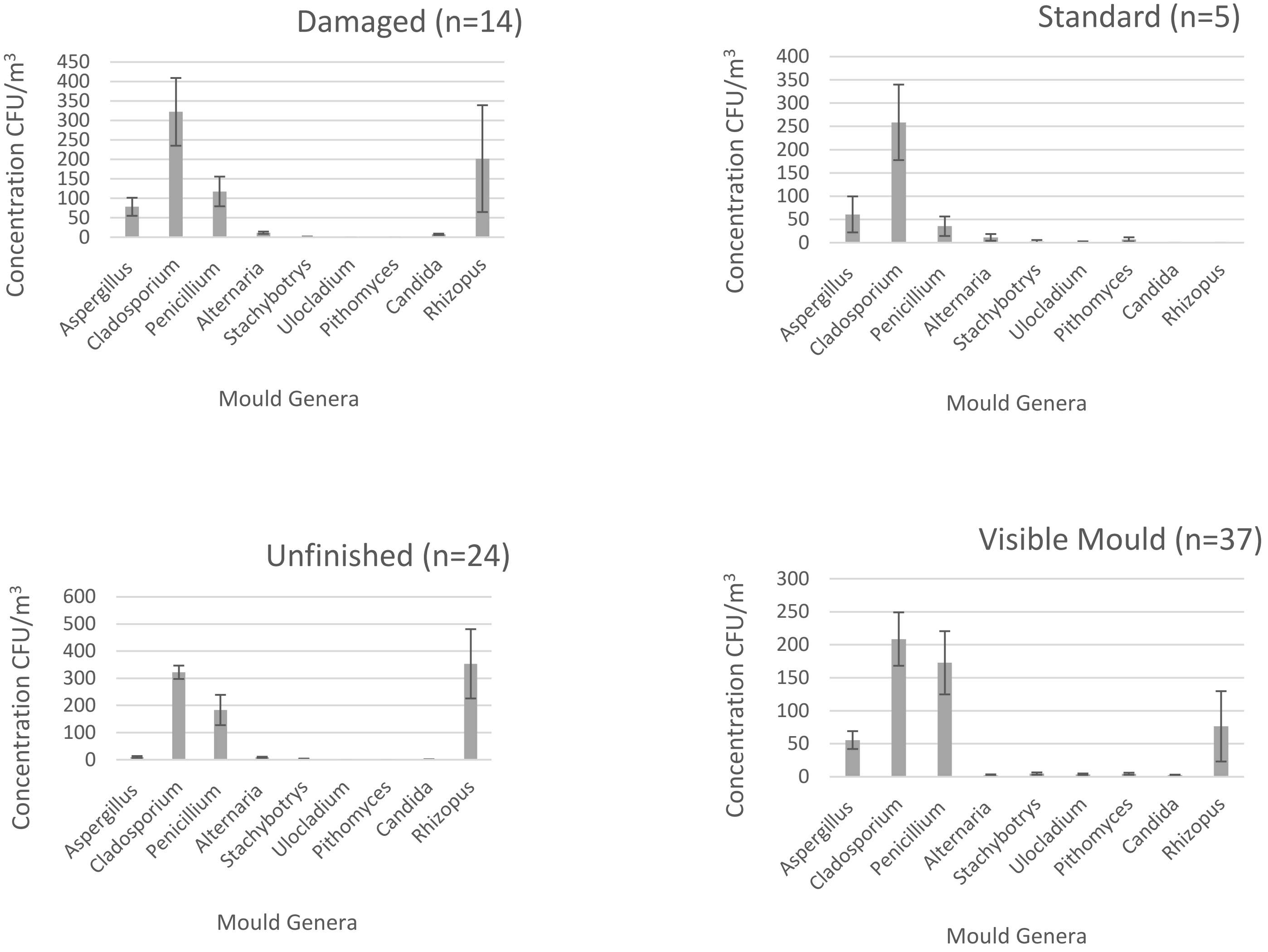


Figure 4-6. Indoor Mould Abundance by Shelter Condition (mean concentrations and standard error).

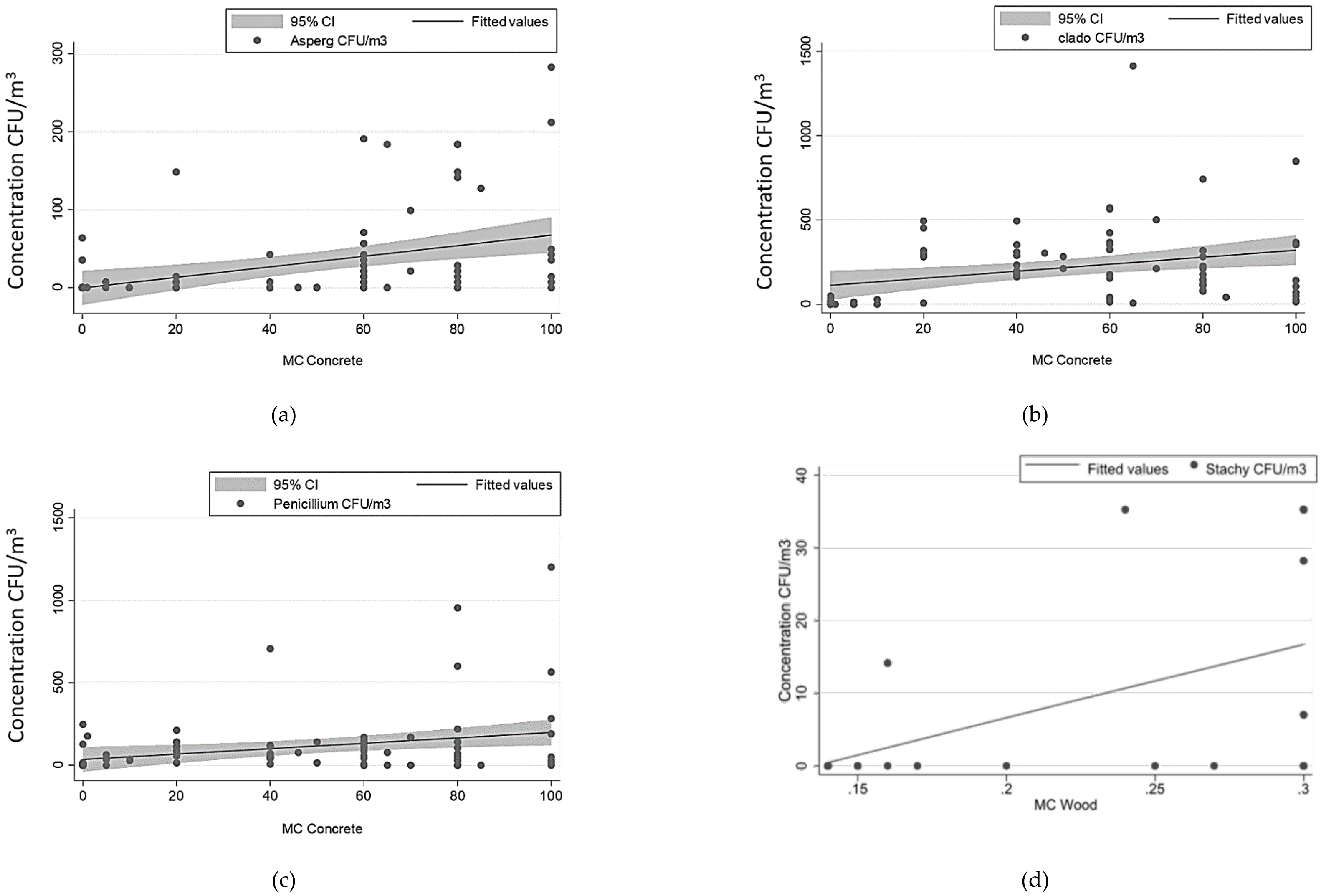
Among the 9 identified fungal genera, only *Cladosporium* ($P<.05$), *Stachybotrys* ($P<.001$), and *Ulocladium* ($P<.05$) spp. were significantly associated with occupancy (Table 4-3).

**Table 4-3. Correlation Between Mould Concentrations and Occupancy.**

| Genus | Occupancy | P-value | $R^2$ |
|---|---|---|---|
| *Aspergillus* | 0.075 | 0.461 | 0.6% |
| *Cladosporium* | 0.215 | 0.032* | 4.6% |
| *Penicillium* | -0.015 | 0.879 | 0.02% |
| *Alternaria* | 0.077 | 0.448 | 0.6% |
| *Stachybotrys* | 0.337 | <0.001* | 11.3% |
| *Ulocladium* | 0.216 | 0.031* | 4.7% |
| *Pithomyces* | -0.033 | 0.745 | 0.1% |
| *Candida* | -0.033 | 0.743 | 0.1% |
| *Rhizopus* | 0.014 | 0.893 | 0.02% |

*P-value less than 0.05 is considered to be significant.

There were no significant correlations between concrete moisture content and mould concentrations, except for *Aspergillus* spp. ($R^2$=14.2%, $P<.001$), *Penicillium* spp. ($R^2$=7.6%, $P<.05$), and *Cladosporium* spp. ($R^2$=9.3%, $P<.05$). However, a significant correlation was observed between moisture content in wood and *Stachybotrys* spp. ($R^2$=24.3%, $P<.05$) only (Figure 4-7). Although, wood is used alongside concrete and other building material in residential and non-residential structures, it is the predominant material in non-permanent shelters and unlike other shelter categories, it is exposed to moisture and environmental conditions. The abundance of Stachybotrys spp. in non-permanent shelters could hence be attributed to the bioreactivity of exposed wood and timber and would lead to material biodeterioration as well as health implications [116,162,163].



(a)

(b)

(c)

(d)

Figure 4-7. Mould and Moisture Content. Confidence interval (95%) for relationship model between moisture content in shelters and concentration of *Aspergillus* spp. (a), *Cladosporium* spp. (b), and *Penicillium* spp. (c). Graph (d) represents confidence interval (95%) for regression model between moisture content in wood and concentration of *Stachybotrys* spp.

### 4.2.2. Total Mould Indoor Count

Mean TIC was highest in non-residential (1112 CFU/m$^3$), followed by non-permanent (780 CFU/m$^3$) and residential (732 CFU/m$^3$) shelters (Figure 4-7). To account for outliers in the selected sample, a Kruskal-Wallis test was conducted to determine the correlation between TIC and type of shelter and revealed a significant association (P<.05).

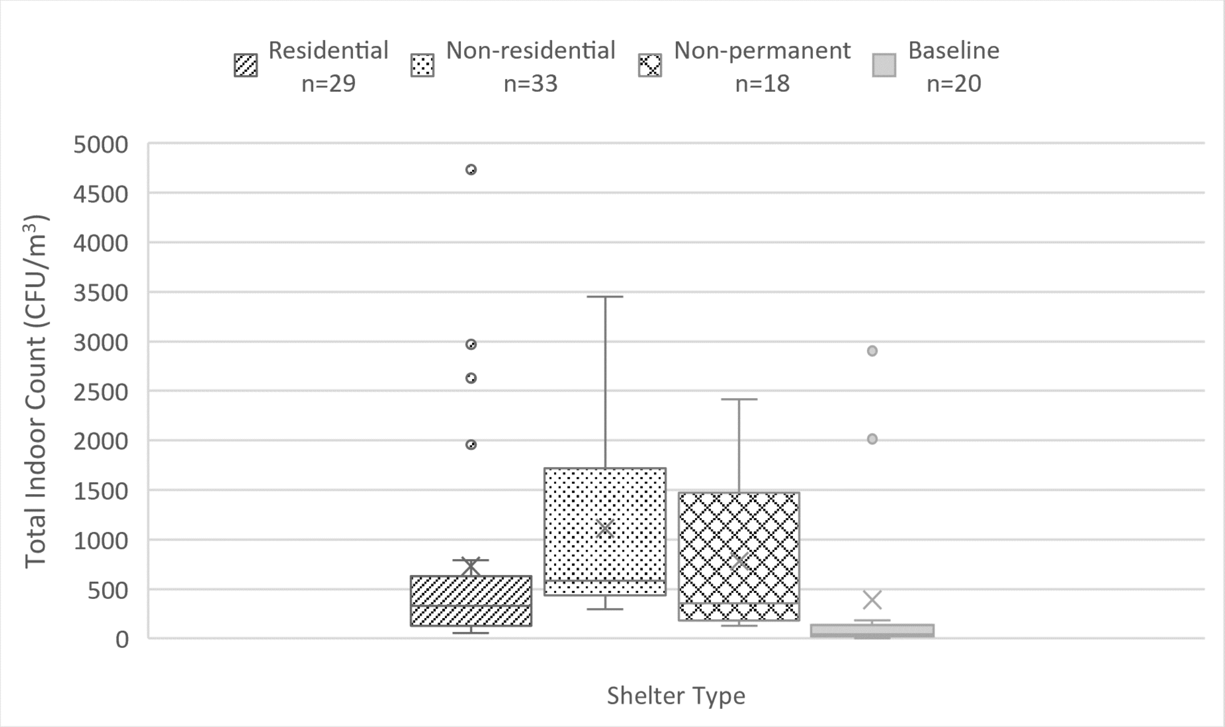


Figure 4-8. Mean total mould indoor count for each shelter type (Mean, depicted by the "×" mark; [range] CFU/m3). Residential (733; [57 – 792]). Non-residential (1112; [297 – 3449]). Non-permanent (782; [127 – 2417]). Baseline households (389; [0 – 184]).

Mean TIC (Figure 4-8) was significantly highest (1242.9 CFU/m$^3$) in unfinished shelters and lowest (393.5 CFU/m$^3$) in standard shelters (P<.05). Furthermore, robust regression performed to account for outliers in the sample also revealed significant association between TIC and occupancy (P<.05).

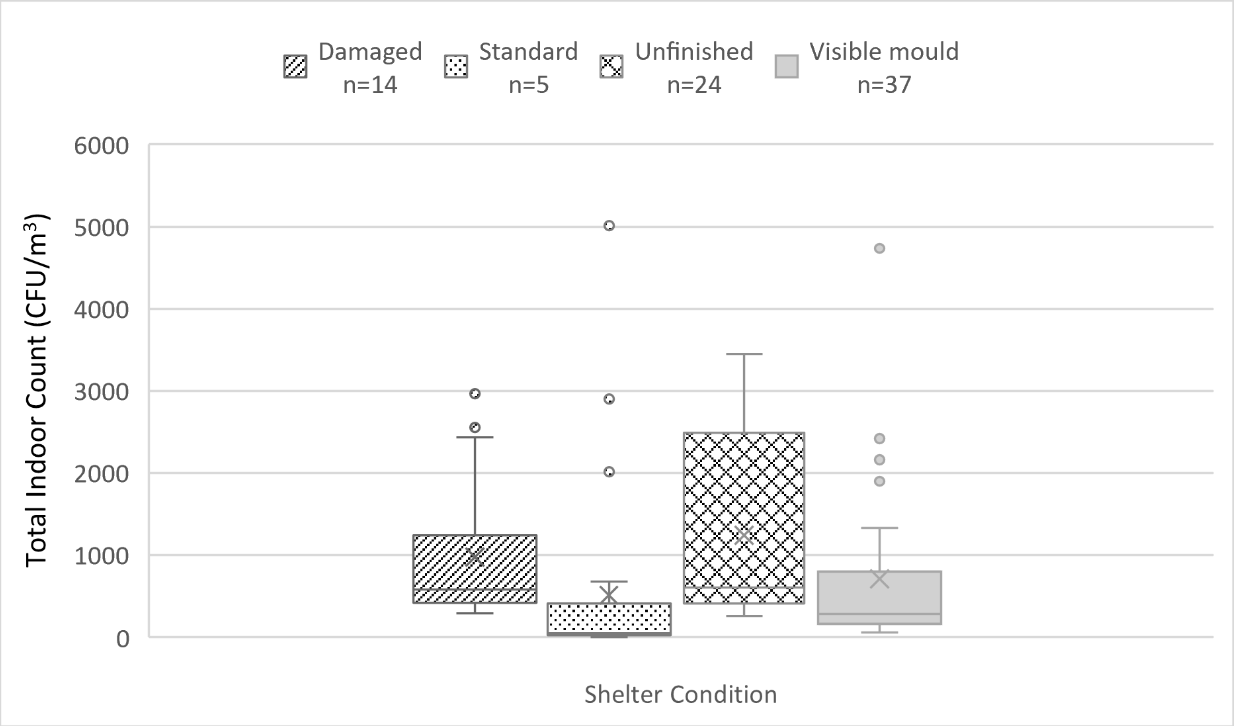


Figure 4-9. Mean Total Mould Indoor Count by Condition of Shelter With Lowest and Highest Concentrations (Mean, depicted by the “×” mark; [range] CFU/$m^3$). Damaged (977; [297 – 2438]). Standard (513; [0 – 678]). Unfinished (1243; [261 – 3449]). Visible mould (723; [57 – 1329]).

The outdoor air of the Bekaa region, where non-permanent settlements are established, had the second highest mould count compared to other regions which could be caused by outdoor concentrations of mould spores, reflecting higher infiltration and slow crossflow ventilation guided by exhaust fans inside the tents. The winter storms of (2018-2019) caused flooding of shelters in most regions of Lebanon which damaged construction material of especially non-permanent shelters. Poor building design of some residential and non-residential shelters resulted in plumbing leaks and permeability of surfaces to moisture, further exacerbating absorbance and retention in shelters. Nevertheless, one of the sources of indoor mould growth, as determined from walkthrough observations of the settlements, could be attributed to excessive moisture and dampness from human activity. This was mainly observed as indoor line drying of laundry and wet floors from cleaning, dripping laundry, bathing, and accidental spillage, all of which contribute to ambient humidity following evaporation (Figure 4-9).

(a) (b)

(c)

Figure 4-10. Line Drying of Laundry. Residential (c) and non-residential (a and b) shelters.

This was also evident as reflected by the significant association ($R^2$= 23.63%, P<.001) between moisture content in concrete material and occupancy (Figure 4-11) suggesting that human activity and indoor practices could influence moisture content in residential, non-residential, and standard shelters where concrete is the predominant building material. Nevertheless, the low R2 value indicates that occupancy reflected by human activity is just one of the factors affecting moisture content in structural material. The sampled shelters are architecturally different from each other and their susceptibility to moisture or water intrusion is determined by their design, age, and exposure to environmental factors [164,165].

The concern for inadequate ventilation and human activity in self-built shelters, was also reported in a study conducted in 6 countries including Turkey and Jordan which host Syrian refugees. Results revealed high concentrations of total volatile organic compounds

(TVOC= 102400 μg/m$^3$) and particulate matter (PM= 3000 μg/m$^3$) mainly attributed to cooking, smoking and poor aeration of the indoor environment [166].

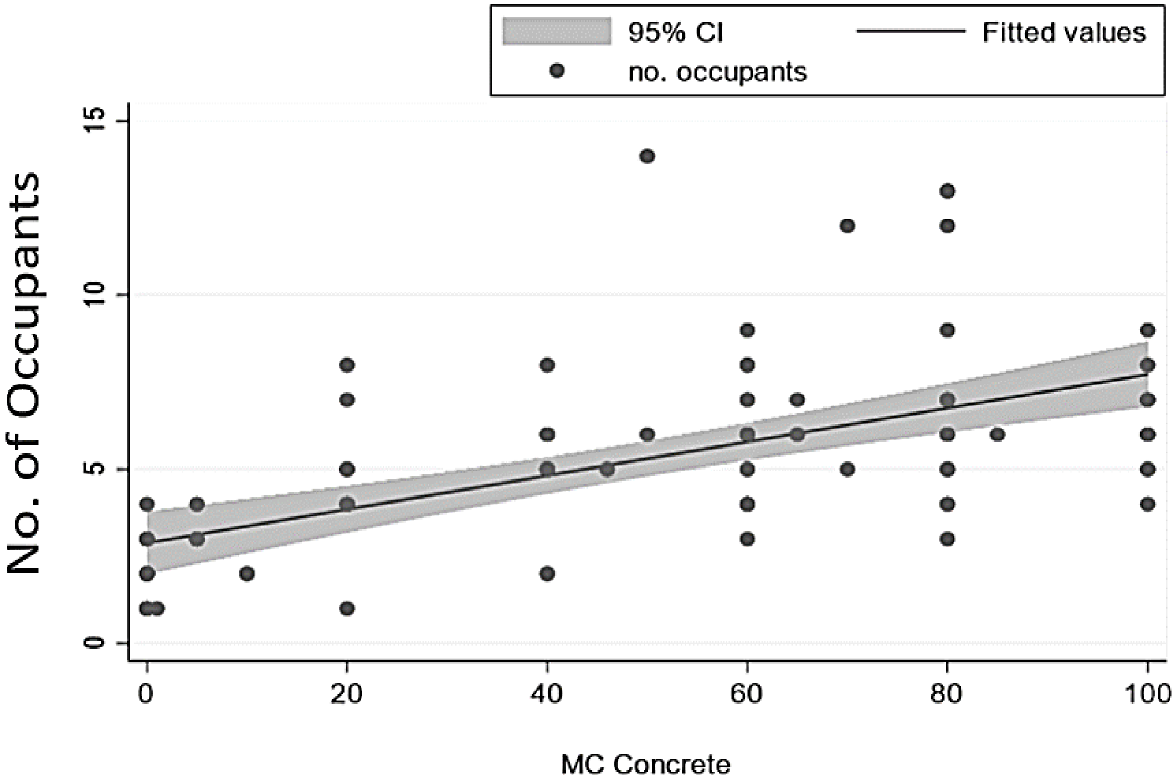


Figure 4-11. Moisture Content and Occupancy. Confidence interval (95%) for regression model between moisture content in concrete and occupancy ($R^2$= 23.63%).

### 4.2.3. I/O Ratio

The mean I/O ratio was higher than 1 in all sampled environments including controls. The ratio was highest in residential shelters (10.11) followed by baseline households (10.9) and non-residential shelters (3.6), and lowest in non-permanent shelters (1.8), with no significant association with types of shelters. In relation to shelter condition, the I/O ratio was highest in structurally damaged shelters (13.8) followed by standard (9.6), visible mould (6.8), and unfinished shelters (4.4), with no significant associations, however. No association between moisture content and I/O ratio was concluded. As for occupancy, there was a slightly negative correlation with the I/O ratio.

The outcomes can be attributed to the fact that outdoor concentrations vary depending on several factors and vastly influence the I/O ratio. Outdoor conditions due to weather or activity may supress the release of spores from outdoor sources leading to higher indoor concentrations albeit indoor sources of potential fungal growth may be absent [167]. Additionally, the exceedances in I/O ratios could be due to single-sided ventilation prevalent in residential shelters compared to other categories [42].

## 4.3. Conclusion, Limitations and Future Research

This study demonstrated significant correlations between refugee shelter types and conditions, household occupancy, and indoor mould abundance. Although mould is present in non-refugee households, sources of moisture are often remediated in residences with better socioeconomic status. Refugees, on the other hand, lack the privilege of improving living conditions, mainly due to prioritization of expenditure. Since remediation can be costly to refugee households and non-governmental agencies, household demographics and medical conditions should be taken into consideration during shelter assignment. Some remediation measures, however, are less costly than others such as in the case of non-permanent shelters where replacing water-damaged porous material such as wood could potentially reduce mould in indoor air. Finally, considering the large refugee population size vis-a-vis the availability of standard shelters, NGOs should focus on securing budgets to standardize living conditions of refugee households and prioritize those with immunocompromised members. Accordingly, efforts must be made to develop a universal design for temporary shelters, accounting for ventilation and psychrometric requirements for human occupancy.

The Fungal investigation study did have its limitations, more specifically it did not address seasonal variation in mould concentrations as it was being performed only in the Spring season. Additionally, moisture content and dampness should ideally have been assessed more frequently to better reflect extreme weather events such as flooding over the winter period preceding sampling, as this increases background moisture levels. The I/O ratio should also be established for identified mould genera as the study only reported total outdoor counts without details on outdoor populations. Nevertheless, indoor microorganisms and dampness will persist in Syrian Refugee shelters in Lebanon and will worsen without proper intervention including improved ventilation and dilution. This investigation shows the vulnerability of shelters to climatic and environmental factors which worsens living conditions and indoor air quality.

# 5. Human Biomonitoring and Biomarkers

According to the CDC, human biomonitoring can be defined as “the method for assessing human exposure to chemicals or their effect by measuring these chemicals, their metabolites or reaction products in human specimens” [168]. In epidemiological studies, biomonitoring is used in combination with health data to address the biological or toxic effects of pollutants also known as the body burden. This tool can be an indicator of temporal exposure trends in relation to geographic characteristics and identifying vulnerable subpopulations [169]. Although biomonitoring cannot indicate the source of exposure, it can document routes of exposure such as inhalation, dermal absorption, and ingestion. Most importantly, biomonitoring helps in establishing or ruling out correlations between environmental exposure and associated health effects [170].

Biomonitoring includes sub-organismal measurements known as biomarkers which are defined as biochemical responses and chemically induced histopathological alterations [171]. There are three types of biomarkers: markers of exposure, markers of effect, and markers of susceptibility [172]. Biomarkers of exposure characterise tissue and body fluids chemical residues, in addition to metabolites of xenobiotic compounds, and exposure-related physiological changes. Biomarkers of effects are quantifiable biochemical and physiologic changes resulting from exposure ranging from biomolecular changes at the sub-cellular level to organ and tissue level changes. Biomarkers of susceptibility, such as polymorphisms of xenobiotic compounds, reflect fundamental characteristics of organisms which render them prone to adverse effects of exposure to specific substances [169,172].

Lam and Gray (2003) summarized the benefits of adopting biomarkers in environmental assessments. The authors argued that biomarkers are effective tools of early warning signals of adverse biological effects when they are optimally sensitive. Furthermore, the advantage of biomarkers over chemistry-based surveillance is in the ability of biomarkers to indicate biological effects. Biomarkers are also effective in reflecting the overall toxicities of complex mixtures. In this regard, specific biomarkers indicate that toxicity occurs when chemicals bind to specific receptors to trigger a toxic action. These responses are developed into bioassays such as enzyme-linked immunosorbent assay (ELISA) which are considered economical compared to chemical analysis of toxins [173]. The specificity and sensitivity of biomarkers are extremely important to justify their use and receive accurate exposure or effect information.

Moreover, blood, serum, and plasma are biological matrices generally used as they have well established standard operating procedures for sampling. Urine and other matrices are also used based on the type of toxin or pollutant. The choice of matrix also depends on whether it is invasive or non-invasive [169].

## 5.1. Exhaled Breath Biomarkers

Infection, trauma, or exposure to exogenous toxins and irritants stimulate reactions such as inflammation and oxidative stress. In order to detect and monitor cytokine-mediated inflammation and oxidant stress, exhaled gases provide an effective tool of measurement [174]. Human breath contains endogenous compounds such as inorganic gases (NO and CO), VOCs, and non-volatile substances such as isoprostanes, peroxynitrite and cytokines [45]. These endogenous compounds have been vastly investigated in the literature for their diagnostic potential [175,176].

### 5.1.1. Fractional Exhaled NO ($F_ENO$)

NO is produced by different types of pulmonary cells including inflammatory cells, endothelial, and airway epithelial cells, and has been implicated in the pathophysiology of lung disease, playing key roles in vasodilation and bronchodilation, and as an inflammatory mediator [174,177]. Measurement of exhaled NO has been suggested in non-invasive diagnosis and monitoring of diseases in which airway excretion of NO is altered [178]. Additionally, the fraction of NO in exhaled air, also known as $F_ENO$, is highly correlated with eosinophilic airway inflammation and its measurement has been adopted in the diagnosis of respiratory illnesses such as asthma, COPD, cystic fibrosis, and primary ciliary dyskinesia [178,179]. The presence of NO in the airways is due to the activation of the transcription factor NK-kB by cytokines in epithelial cells, which triggers the production of the enzyme, inducible nitric oxide synthetase (iNOS), responsible for the production of NO [180].

Tang et al. (2017) collected exhaled breath condensate (EBC) and serum from 102 acute respiratory distress syndrome (ARDS) patients in ICU, aged between 42 and 73, before treatment. EBC and serum NO from ARDS patients was significantly higher than controls (47.81 µmol/L in EBC and 48.45 µmol/L in serum compared to 15.65 µmol/L and 18.76 µmol/L respectively in controls). Although levels were significantly lower 5 days after treatment had been administered, EBC and serum NO were still higher than controls levels in treated ARDS patients. The findings suggest that quantifying EBC NO level can help in the evaluation of treatment efficacy and determining prognosis of ARDS [181].

A study conducted by Nguyen-Thi-Bich et al. in 2016 attempted to evaluate the correlations between $F_ENO$ and atopic status, blood eosinophil levels, FCER2 mutation, and asthma control in 42 Vietnamese children with uncontrolled asthma. $F_ENO$ was significantly higher in patients with a positive skin prick test for respiratory allergens ($P<.05$) and was significantly correlated with blood eosinophil levels ($r=0.5217$; $P=0.0004$), inferring that $F_ENO$ level is a feasible biomarker for the prediction of clinical and biological status of asthmatic children [182]. Another study in asthmatic children performed by Brzozowska et al. (2015) aimed at showing correlations between $F_ENO$ level and cytokine concentrations. The results revealed a significant positive correlation between the $F_ENO$ level and IL-2, monocyte hemoattractant protein-1 (MCP-1), platelet-derived growth factor BB (PDGFBB) and tissue inhibitory of metalloproteinase 2 (TIMP2) and suggested that EBC may be a useful non-invasive tool to phenotype asthma [183].

Further interpretation of $F_ENO$ results could also suggest the likelihood of type 2 (T2) inflammation, which is used in the aetiology and pathogenesis of asthma and is driven by the production of pro-inflammatory type 2 cytokines [184-187]. Intermediate levels suggest likelihood of T2 inflammation while high levels suggest significant T2 inflammation [188]. No body of evidence exists to conclude correlations between $F_ENO$ and severe asthma, nevertheless, results from clinical studies and research do correlate with the management of asthma and the maintenance of inhaled corticosteroids [188-191].

## 5.2. The Syrian Refugees Study

In 2015, the most prevalent reported chronic condition among refugees under 17 was chronic respiratory diseases including asthma, emphysema, chronic bronchitis, and chronic obstructive pulmonary disease, accounting for 12.9% of reasons for hospitalization. Asthma and pulmonary disease which were among the 5 most prevalent chronic conditions reported by surveyed Syrian refugees in 2015, grew to 19% in 2021, becoming the highest reported chronic conditions among the total refugee population [9,192]. The war impacted the Syrian population as a whole, causing depression and post-traumatic stress disorder among various age groups [193-195]. Surveys conducted in Syrian refugee settings revealed that consumption of tobacco products is well established among the youth and adult groups, and suggested smoking to be a potential leading cause of some prevalent types of cancer reported within Syrian refugees [194-197]. Counting for more than 50% of the Syrian refugee population in Lebanon, children with asthma and respiratory diseases are at an even higher risk in terms of susceptibility to indoor pollutants [198,199].

The reported medical conditions by Syrian refugees have not been correlated with housing, shelter type, nor environmental factors. Moreover, since access to medical information was challenging due to confidentiality and lack of formal diagnosis, this study was designed to obtain cross-sectional epidemiological data that is both minimally invasive and prompt, by collecting FENO samples from the same settlements which were selected for the fungal exposure study presented in the previous chapter. The aim of the study was an attempt to create a respiratory health and susceptibility profile for refugees based on shelter type, without attributing health conditions to housing or shelter type since many refugees arrived in Lebanon with pre-existing medical conditions. Thus, it is of utmost importance to investigate emerging health effects in refugee settlements in Lebanon, especially for younger age groups, due to the fact that newborn children and children up to the age of about 14 years of refugee families who fled the war in 2010 were born in refugee camps.

### 5.2.1. Methodology

A NIOX VERO® Airway Inflammation Monitor (Circassia AB, Sweden) was used to measure FENO from Syrian refugees following ethical approval obtained from Brunel Research ethics Committee. The device included a breathing handle connected to a display instrument which includes an NO sensor. Subjects were required to exhale forcefully and steadily into the breathing handle through a disposable patient filter and mouthpiece attached to the handle. The device displayed animation specially to guide children on how to maintain a steady flow. The device allowed measurement of exhaled breath via a 10 or 6 s option, depending on the age of the subject [200].

Similar to the sampling methodology adopted in the previous study (Chapter 4) [201], consent was obtained on the same day of sampling and memoranda of understanding were used to reference anonymized subjects. Other nationalities that did not share the same humanitarian and socio-political profile of Syrian refugees were excluded from this study. Additionally, individuals with recently diagnosed infections or exhibiting infectious symptoms were also excluded from this study. The study was limited to 2 days due to national security concerns following the aggravation of the civil uprising in Lebanon which began in October 2019 and hindered transportation to refugee settlements with restricted mobilization of NGOs. The study was then discontinued following the COVID-19 pandemic due to shelter-in-place orders and the nature of the study which was considered an aerosol-generating procedure (AGP) in a non-controlled environment.

Subjects were asked whether they were diagnosed with respiratory illnesses and whether they were smokers, then further labelled by age group (child “C”, adult “A”, or elderly “E”) and gender (male “M” or female “F”) (Table 5-1). The 57 selected subjects, of whom 60% were children, delivered a single exhaled breath measurement each. FENO measurements were taken between December 2019 and January 2020 in non-residential and non-permanent shelters only, in the South governorate and Bekaa regions of Lebanon, respectively, with the following demographic distribution.

**Table 5-1. FENO Population Data (n=57).**

| Type of Shelter | Gender | Children (<18) | Reported Conditions | Adults (18<, <60) | Reported Conditions | Elderly (60<) | Reported Conditions |
|---|---|---|---|---|---|---|---|
| Non-residential | F | 8 | Asthma (1) | 6 | Asthma (1) | 1 | Allergies (1) |
| | M | 6 | Smoker (1)<br>Asthma (1)<br>Allergy (1) | 3 | Smoker (2) | 2 | Asthma (2) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Non-permanent | F | 10 | Asthma (1) | 6 | Asthma (1)<br>Allergy (1) | 0 | None |
| | M | 10 | Asthma (2) | 4 | Smoker (1) | 1 | None |

### 5.2.2. Results and Discussion

FENO results were interpreted as low, intermediate, or high, based on the official clinical practice guideline of the American Thoracic Society (ATS) and the National Institute for Health and Care Excellence (NICE). The ATS cut off level for high levels of FENO is 50 parts per billion compared the 40 (ppb) set by the NICE guidelines which were adopted for this study's clinical interpretation. Accordingly, the NICE intermediate levels are 25-40 ppb and 20-35 ppb for adults and children, respectively [191,202].

#### 5.2.2.1. Non-residential Shelters

Of the 26 monitored refugees in non-residential shelters, 6 children (4 M and 2 F) reported high levels of FENO (>40 ppb), 2 of which reported asthma and 1 reported allergy. Only 1 adult (F) had high levels of FENO and 1 child (17 years, M), who is a smoker, had intermediate levels (Figure 5-1).

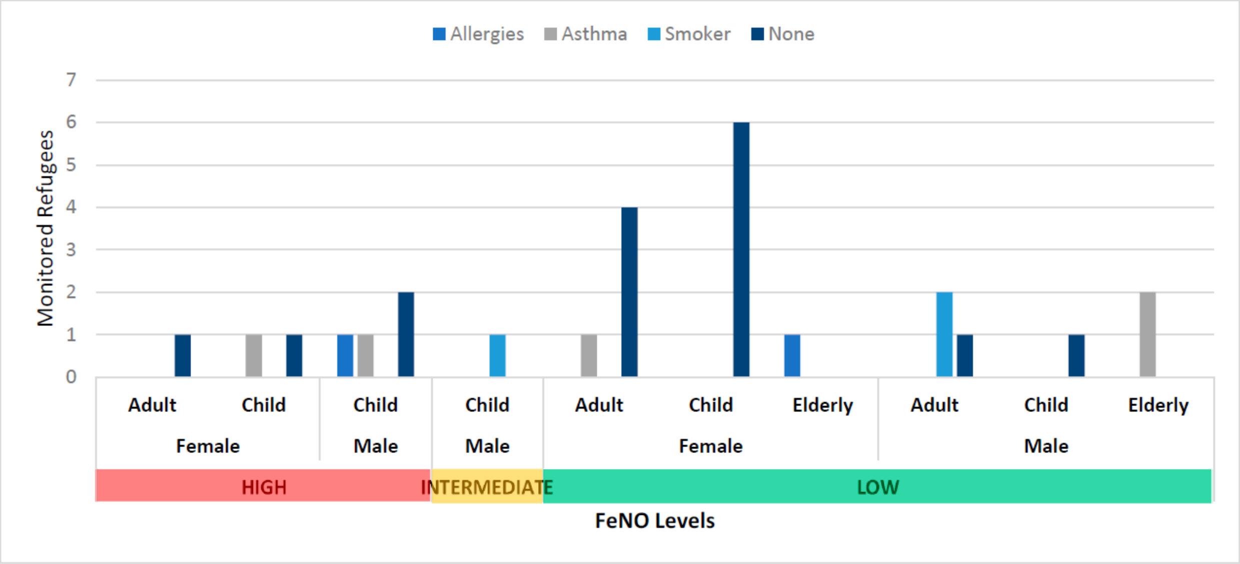


Figure 5-1. Non-residential FENO Results.

### 5.2.2.2. Non-permanent Shelters

Monitoring results in non-permanent shelters reported high $F_ENO$ levels in 4 children (2 M and 2 F), 2 of which had asthma. Furthermore, 3 adults (2 F and 1 M) reported high levels of $F_ENO$ whereas intermediate levels were reported in 1 child (F) and 1 elderly (M) (Figure 5-2).

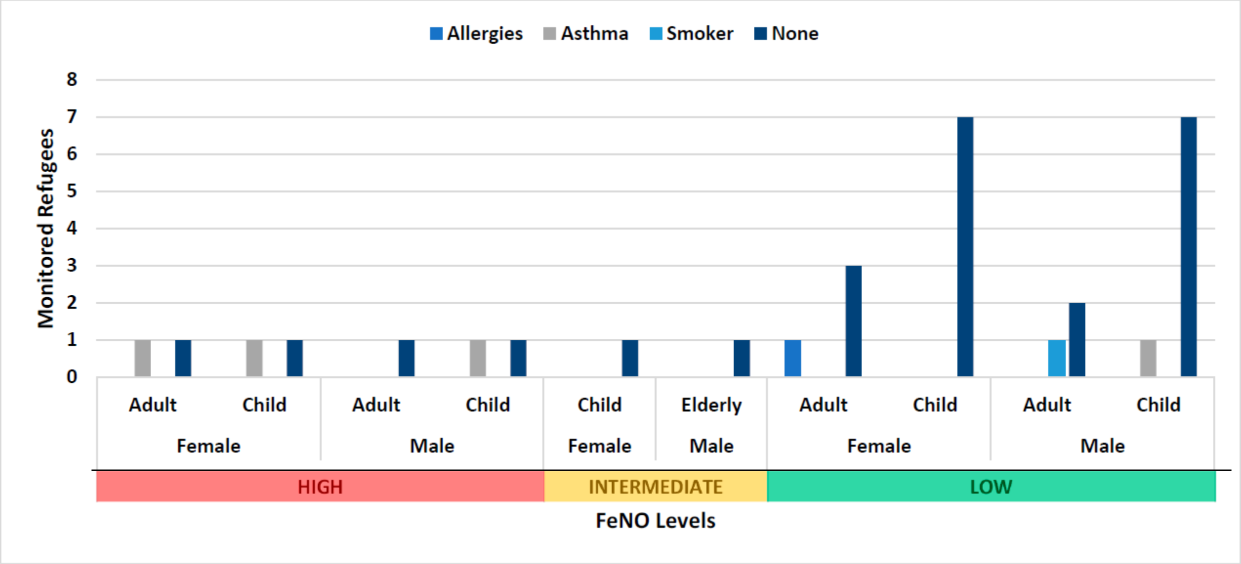


Figure 5-2. Non-permanent $F_ENO$ Results.

The mean $F_ENO$ level for children residing in non-residential shelters was 23.4±4.7 ppb compared to 16.4±2.3 ppb in non-permanent shelters. As for adults, the mean $F_ENO$ level was 18.8±3.1 ppb in non-residential shelters compared to 29.3±5.8 ppb in non-permanent shelters (Figure 5-3).

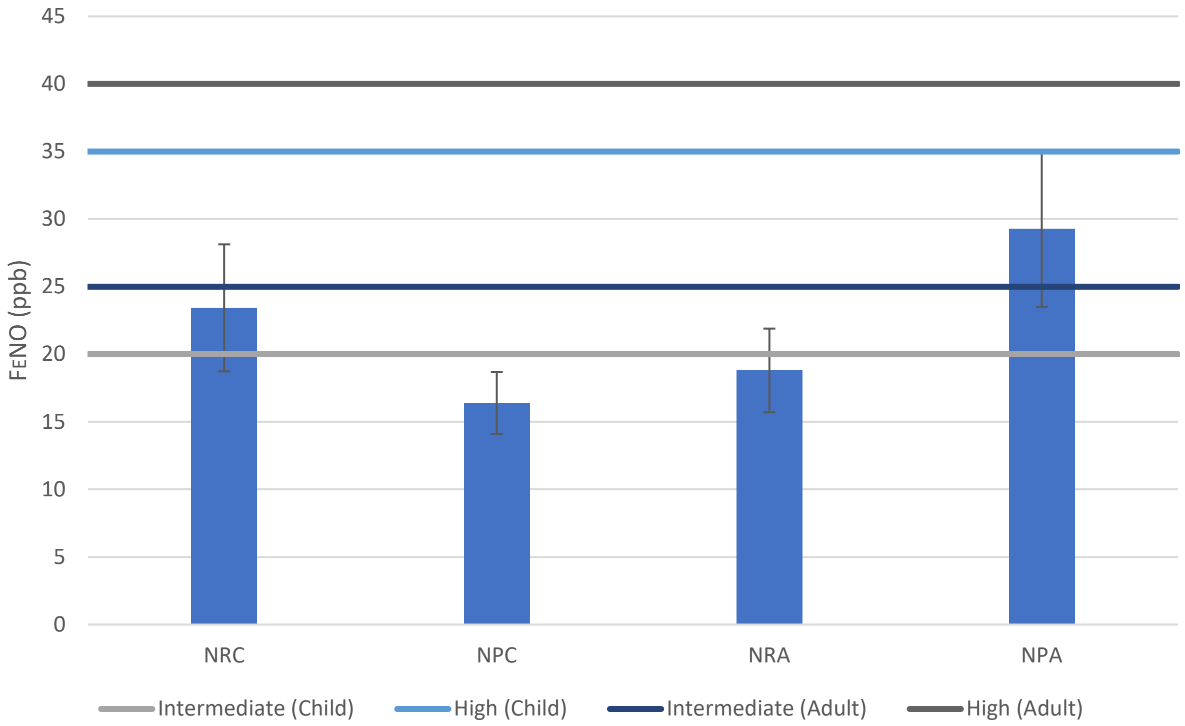


Figure 5-3. FENO Levels. Mean and standard error. NRC (non-residential children); NPC (non-permanent children); NRA (non-residential adults); NPA (non-permanent adults).

The mean FENO level exceeded the intermediate category for children in non-residential shelters and for adults in non-permanent shelters. The difference in the children's age group results could be due to the fact that children residing in non-residential shelters were observed to be spending more time indoors due to the limitation of outdoor activities in such shelters, which included repurposed classrooms. On the other hand, children of non-permanent shelters, which are informal tented settlements established on or near agriculture fields, were observed to be spending more time outdoors. Furthermore, the preceding study revealed that non-residential shelters had the highest mean mould concentration, followed by non-permanent shelters. As for the adult age group, the number of monitored adult females in non-residential shelters was twice that of adult males. Some studies suggested that older males had higher median FeNO levels than females, and others found a negative correlation with female age [203–206]. Nevertheless, although mean levels may indicate a higher susceptibility of children in non-residential shelters and adults in non-permanent shelters, the small sample size and unaccounted-for environmental factors and baseline conditions could not substantiate this conclusion. Further research is required that takes confounding factors into consideration. Although no significant correlation was observed between the age of subjects and FeNO levels ($R^2$ = 0.7%) in both types of shelters, this may have been due to the small sample size.

While the mean levels may indicate a higher susceptibility of children in non-residential shelters and adults in non-permanent shelters, the small sample size and the unaccounted-for environmental factors and baseline conditions could not substantiate this conclusion. Further research is required taking confounding factors into consideration. Although no significant correlation was observed between age of subjects and FENO levels ($R^2$=0.7%) in both types of shelters, this may be due to the small sample size.

Table 5-2 highlights interpretations of FENO levels reported by symptomatic and asymptomatic monitored refugees in both types of shelters.

**Table 5-2. Clinical Interpretation of FENO Levels in Symptomatic and Asymptomatic Refugees.**

| FENO levels | T2 inflammation | Symptomatic | Asymptomatic | Reference |
|---|---|---|---|---|
| Low | Unlikely | 6 | 34 | [188] |
| Intermediate | Likely | 0 | 3 | |
| High | Significant | 6 | 8 | |

The majority of monitored refugees were asymptomatic, as highlighted in Table 2. One of the clinical management guidelines for asymptomatic patients with high and intermediate levels of FENO is to consider high baseline NO production and/or persistent allergen exposure potentially due to subclinical inflammation of lower airways with the absence of symptoms [188,207,208]. Additional confounding factors, such as gender, age, smoking, nutrition, cirrhosis, viruses, and bacterial infections, should also be taken into account when interpreting FENO results [209–211]. Although other shelter types, such as residential shelters, were not assessed, as mentioned, the previous study revealed that non-residential shelters had the highest concentrations of mould, followed by non-permanent shelters [201]. Repetitive long-term exposure to mould and other aeroallergens in these shelter categories could explain the high $F_ENO$ levels observed in asymptomatic subjects [212]. Figure 5-4 depicts the underlying and environmental conditions that lead to the production of $F_ENO$.

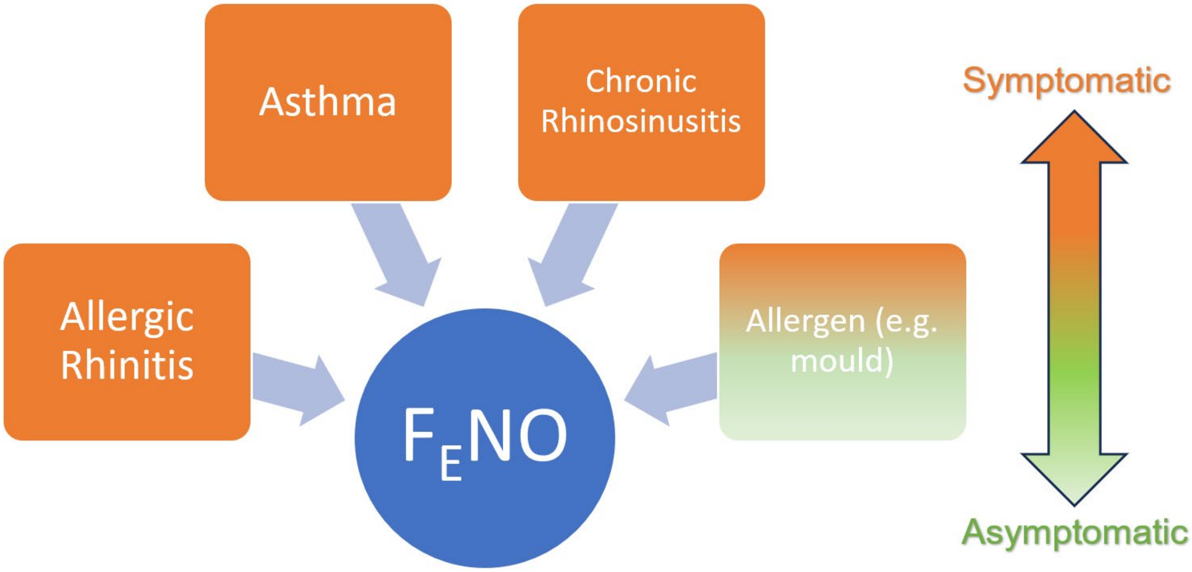


Figure 5-4. Environmental and underlying medical conditions Leading to the production of $F_ENO$ in symptomatic and asymptomatic subjects.

## 5.3. Conclusion, Limitations and Future Research

The findings of this study, although limited, clearly suggest an urgent need to repeat and broaden the study to include residential shelters and an increased sample size to investigate the presence of any significant correlation between $F_ENO$ levels and environmental conditions of shelters. Furthermore, a more inclusive study would benefit refugee health management in establishing a health susceptibility profile of refugees in circumstances where continuous clinical management cannot be maintained. This type of data will not only assist NGOs in the proper deployment of resources and households but can also be used to communicate concerns to policy makers and reduce the rate of hospitalization and additional burden on the host country health system.

Although several environmental factors are impacting refugee wellbeing, further epidemiological studies are needed to determine the quantitative impact (dose–response relationship) of these factors on the health of refugees. Stakeholder meetings, including clinicians, indoor air quality specialists, public specialists, and humanitarian aid and government agencies, should be urgently convened to determine whether indoor air quality is significantly influencing the health and wellbeing of this population. Although FeNO detection holds potential benefits as a non-invasive biomonitoring method, it does have limitations due to previously mentioned confounding factors. Of particular value would be exploring other biomarkers and expanding the biomonitoring capability and application of portable electrochemical sensors and non-invasive methods to facilitate the greater sample size required for statistical robustness in a cost-effective and time efficient manner, while minimising adverse impact on study subjects, particularly the elderly and children.

# Controlling Hazards

## 6. Low-cost Solar-powered Air quality Abatement for Temporary Refugee Shelters: (SWAC & SWAV)

Chapter 4 shed light on indoor environmental conditions of refugee shelters with focus on mould abundance. The limited biomonitoring study in chapter 5 revealed possible impact from persistent allergen exposure in non-residential and non-permanent shelters which had the highest mould concentrations compared to residential shelters and baseline controls. Mould, however, is not the only environmental pollutant affecting refugees' health. Besides cooking activities, kerosene wood stoves used for heating are deployed in main living areas inside ITS (Figure 6-1). The COVID-19 pandemic has further exposed the vulnerability of refugees and displaced populations globally. Studies conducted in refugee settlements including Syrian refugee camps demonstrated that crowdedness and the shortage of personal protective equipment could trigger rapid outbreaks of COVID-19 and therefore requires additional strategies including more access to healthcare services, proper isolation, and frequent testing [203-208]. Similar to HAP, adequate ventilation and efficient filtration are effective in reducing the spread of airborne infectious diseases [209-214].

Informal tented settlements (ITS) are categorized by UNHCR under non-permanent shelters [215-217]. These shelters are built as temporary structures for refugee households and lack design standards for human occupancy [218]. In 2023, there were 3,681 Syrian refugee households with 18,100 individuals of various age groups residing in ITS in the Bar Elias region across the Bekaa valley of Lebanon. The year 2021 witnessed a 5% increase from 2017 in non-permanent shelters and a 4% drop in residential shelters due to evictions and economic impact of the 43% rental cost increase. Additionally, 57% of households lived in substandard, overcrowded, and dangerous conditions whereby all refuges residing in ITS faced a higher risk of susceptibility to extreme weather and hazards [216].

Figure 6-1. Heating in ITS. Kerosene stove serving a living area inside informal tented settlements in the Bar Elias Syrian Refugee camp.

ITS are windowless structures constructed using timber fixed in cement flooring and covered with wood panels and tarpaulin sheets forming the walls and roof (Figure 6-2). Vehicle tires and other heavy material are placed on the roof to prevent movement of tarpaulin sheets. ITS average around 56 $m^2$ (≈603 $ft^2$) in occupiable area with about 2.5 m (≈8 ft) of ceiling height. The structures comprise of 3 to 4 bedrooms averaging up to 15 $m^2$ (≈161 $ft^2$) each, an open kitchen space of about 6 $m^2$, and an attached or detached toilet based on household cultural preferences. Small exhaust fans are installed close to the ceiling and away from sources of combustion and pollution such as kitchens and toilets, resulting in negative pressure being created by unbalanced ventilation. The lack of proper pressurization due to absence of makeup air would direct the airflow from less clean to clean spaces or create back-drafting of combustion gases, potentially leading to a high concentration of contaminants in the occupants' breathing zone [219,220].

Figure 6-2. Non-permanent Shelter Material. Timber and tarpaulin used in informal tented settlements.

While several factors are leading to sub-humanitarian living conditions, including power outages and poor air quality, local government impose constrictions on building adequate shelters for refugees ignoring alternative and cleaner power options such as biogas and solar panels [8,13,216]. Furthermore, Non-Governmental Organizations (NGOs) are focusing more on their WASH programs (water, sanitation, and hygiene) without consideration of ventilation requirements which significantly impact health of refugees, especially vulnerable subgroups (elderly, sick and children). Refugee households should receive sufficient outdoor air to effectively dilute indoor air hazards [221]. Supplemental air cleaning systems help maintain acceptable indoor air quality by physical removal of particles through filtration. Existing solutions, such as residential heating ventilation and air conditioning (HVAC), are costly, difficult to integrate into temporary buildings such as refugee settlements and have high maintenance costs, with high energy consumption [222-225]. This project aims to design and fabricate a prototype device for ITS to provide adequate ventilation to prevent buildup of indoor airborne hazards. Due to power outages and existing energy demand to power existing household appliances, the technology must be autonomously and renewably powered. Furthermore, fabrication materials should also be renewable or at least reusable/recyclable, low cost and easily procured locally. The design should ensure it is possible for local users (non-technical users with basic tools) to maintain and repair, thereby extending the service life. Mindful that they are intended for non-permanent structures, the device should be designed for ease of disassembly and re-assembly [226].

## 6.1. The SWAC Project

The solar-powered window air cleaner (SWAC) concept is designed with the main purpose of introducing outdoor air in an effort to meet ASHRAE standard 62.2 requirements for residential dwellings and to run as an indoor air cleaner during extreme weather conditions and adverse outdoor air quality [221]. As the name implies, the unit is to be wall-mounted at a level relative to an operable window (Figure 6-3).

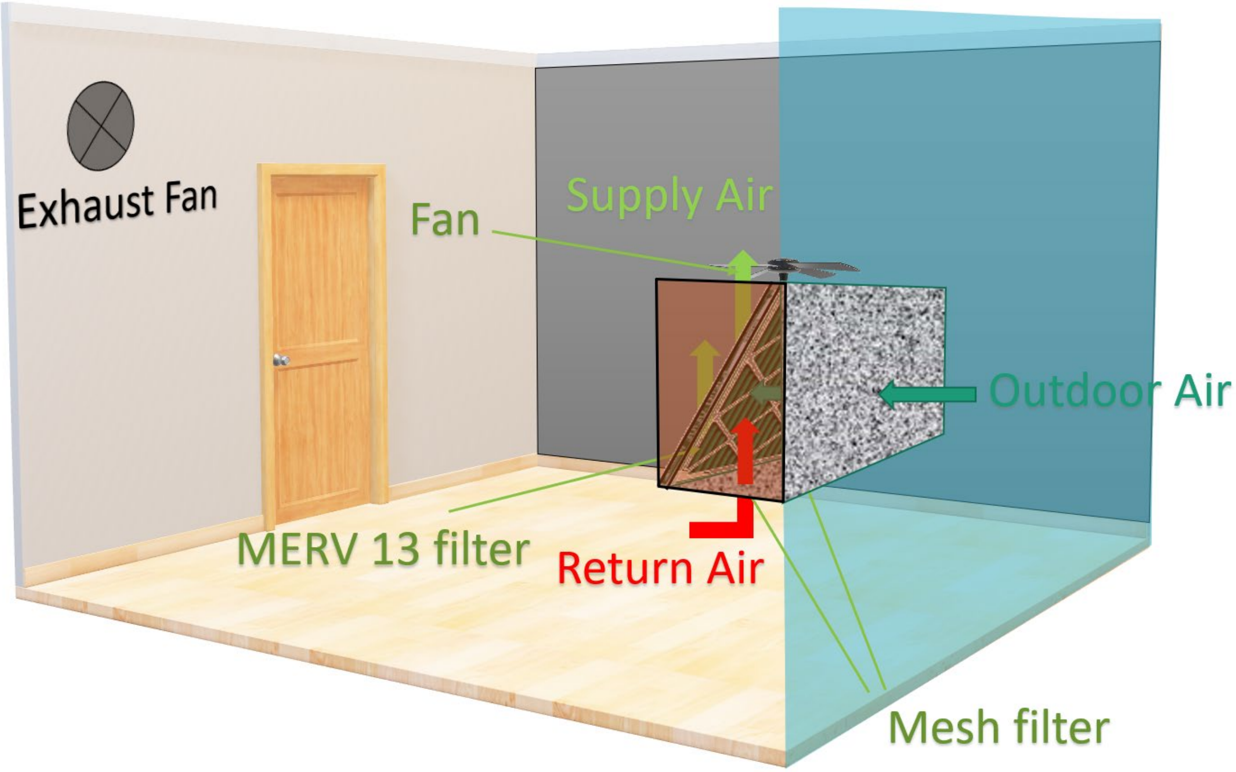


Figure 6-3. Window Unit Concept. Outdoor air is introduced through a mesh filter into a pleated air filter and supplied vertically through an electric fan. When the unit is operated as an indoor air cleaner, the outdoor air side is sealed and return air is drawn through the bottom of the unit.

### 6.1.1. Solar photovoltaic power and DC applications

Solar panels are becoming the most adopted alternative power source in residential and commercial settings [227-229]. Unlike Lebanon, the global increase in solar panel installations has been driven by governmental incentives and the desire to join climate action against energy production through fossil fuel [230-232]. Photovoltaic (PV) panels technology evolved during the past years with the aim to increase efficiency and reduce manufacturing costs [227,228,230]. Silicon is the most utilized material in PV cells manufacturing and the main common types of silicon used are monocrystalline and polycrystalline silicon, with the former having a higher efficiency rating due to the homogeneity of its structure [233-237].

Through a process known as the photovoltaic effect, PV cells convert solar radiation into electricity in the form of a direct current (DC) which is converted into an alternating current (AC) by means of a power inverter to run household and other appliances [229,236,238-244]. Nevertheless, studies have been directed into exploring the use of low voltage DC appliances in buildings and households due to their energy-saving potential and the efficient use of PV panels by reducing loss of power from DC/AC conversion [245-247]. Solar-powered fans, in particular, have been widely used in the agriculture, telecommunication and building industries [248]. Furthermore, the low voltage requirements of vehicles components compared to most household appliances makes PV panels a reliable mobile power source also, evident in its wide adoption in recreational vehicles and personal boats [249-251].

### 6.1.2. Ventilation

Many do-it-yourself (DIY) projects involve the coupling of box fans with air filters as an alternative to expensive portable High Efficiency Particulate Air (HEPA) cleaners [252]. The DIY air cleaners use Minimum Efficiency Reported Value (MERV)-rated pleated air filters, and their configuration was optimized during the COVID-19 pandemic to overcome the pressure drop of higher efficiency filters and to outperform portable HEPA air cleaners' clean air delivery rate (CADR) [253-255]. The majority of these commercial box fans are 20 x 20 inch (50.8 x 50.8 cm) and thus air filters with the same nominal dimensions are often used [253,254]. MERV 13 filters are widely adopted in DIY projects as per ASHRAE's recommendations for their efficiency in the removal of droplet nuclei and other physical pollutants [213,256-260]. The same rating was also used in evaluating removal efficiency of fine and coarse particulate matter in wood stove homes [261]. ASHRAE standard 52.2 published the average removal efficiency of different MERV ratings against 3 particle size ranges, whereby MERV 13 filters have an average efficiency of ≥50% between 0.3 and 1.0 μm (E1), ≥85% between 1.0 and 3.0 μm (E2), and ≥90% between 3.0 and 10.0 μm (E3) [262]. Furthermore, the filtration surface area plays a major role in reducing the pressure drop across the filter, therefore, performance tests were conducted for different configurations of pleat width to determine the best cost versus output benefit [256,263,264].

### 6.1.3. SWAC Material Selection

An online search for commercial box fans revealed an advertised performance of output ranging between 1087 and 3400 cubic meters per hour ($m^3$/hr) which are equivalent to approximately 640 and 2000 cubic feet per minute (cfm). Higher air flows are usually chosen to account for pressure drops resulting from high efficiency filters [253,256,258,264]. Accordingly, a 12 volts (V) electric radiator cooling fan was selected as the DC load for the solar panel to work with a 50.8 x 50.8 x 5.08 cm (nominal), MERV-13 pleated filter (Figure 6-4). The fan manufacturer reported a volumetric air flow output of 1,360 $m^3$/hr (800 cfm). The fan consists of 10 PVC (polyvinyl chloride) blades with an outer diameter of 30.48 cm and includes 4 mounting brackets with 6.4 mm (¼ inch) holes. Since the fan's reported power rating is 80 Watts (W), a slightly higher output was chosen through a 100 W monocrystalline solar panel as the off-grid power source.

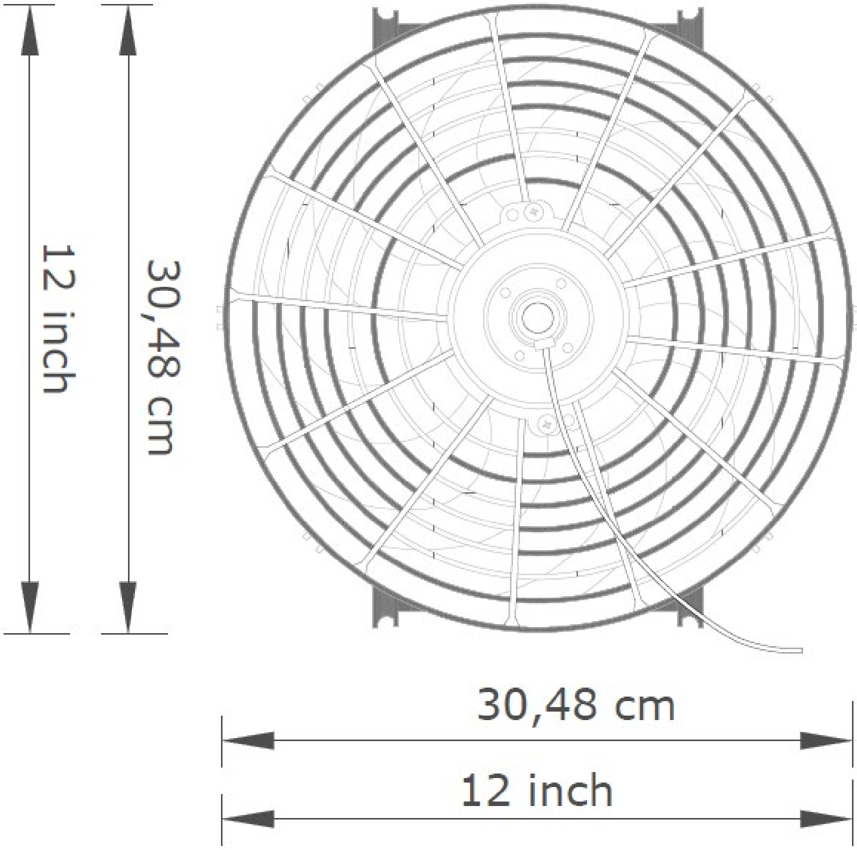


Figure 6-4. Electric Radiator Cooling Fan 12V, 80 W.

### 6.1.3.1. Housing

#### 6.1.3.1.1. FRAME

To maximize air distribution effectiveness, the SWAC unit was designed to either be operated as an outdoor “fresh” air or indoor air cleaning device. Accordingly, the air flow through the filter should be identical in both situations. Hence, the optimal filter position should be diagonal, forming a $45^0$ angle with the opposite corners of the frame and, with both outdoor air intake and recirculated air surface areas being equal. The filter’s dimensions were 49.53 cm x 49.53 cm x 4.45 cm. However, the frame was designed with nominal dimensions to account for variability in commercially available filters. With the length of the filter being 50.8 cm, the opposite adjacent sides should be around 35.9 cm each, and additional 3.59 cm each side to account for an approx. 5 cm filter depth (Figure 6-5).

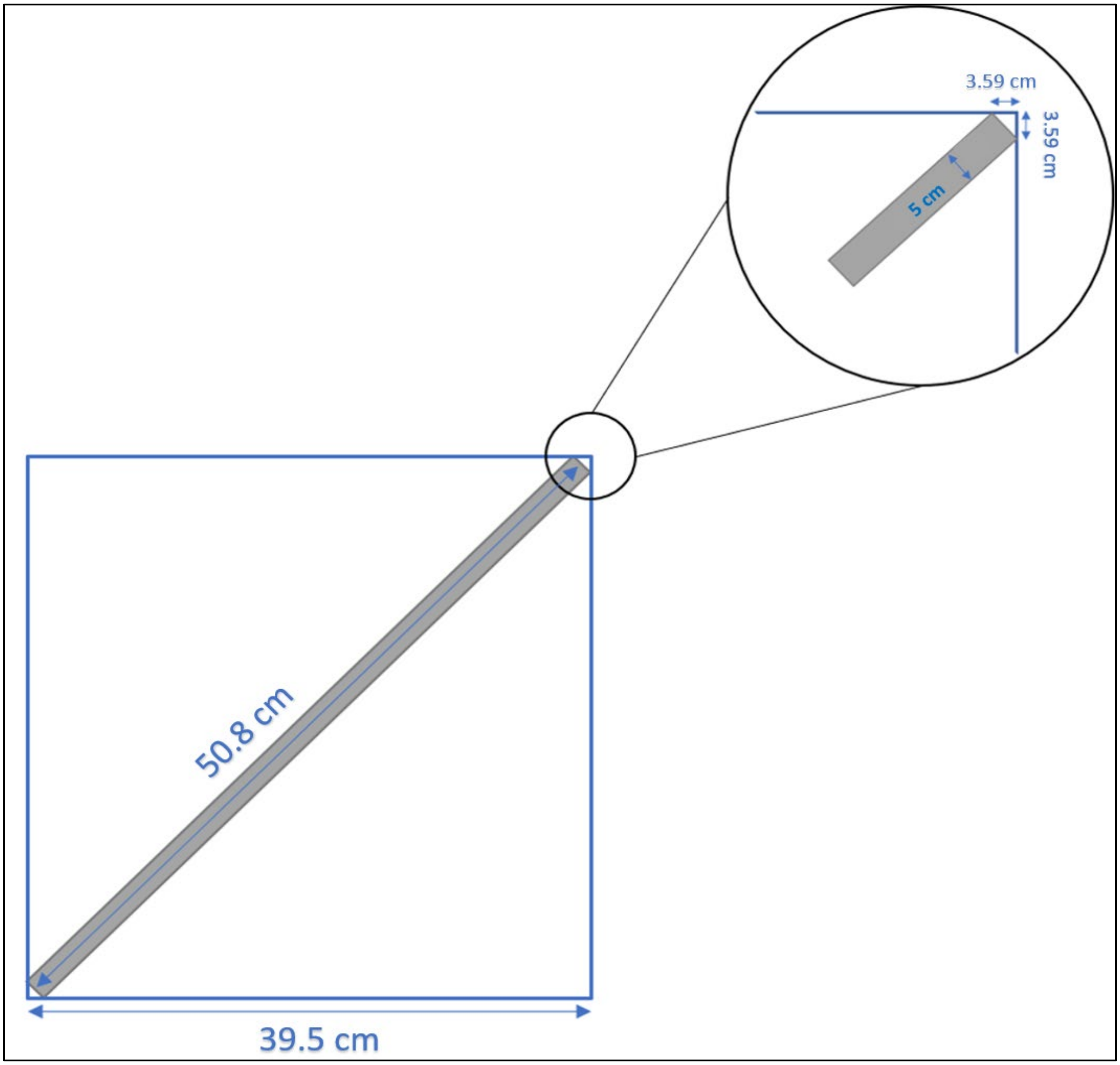


Figure 6-5. Frame Side Adjustments to Account For Filter Nominal Depth.

The frame material was made of zinc-plated steel being lightweight, corrosion resistant, and for affordability and availability [265,266]. The frame structure consisted of punched angled bars perpendicularly connected using 9.5 mm (3/8 inch) hexagonal stainless-steel bolts screwed outwards to maximize filter space and tightened with washers and hexagonal stainless-steel nuts. The hexagonal bolt heads (0.317 cm deep), force the extension of the frame’s front and rear bars by 6.4 mm to accommodate the filter. The electric fan was mounted to 2 flat bars of 39.5 cm, installed alongside the angled bars of the same length (Figure 6-6).

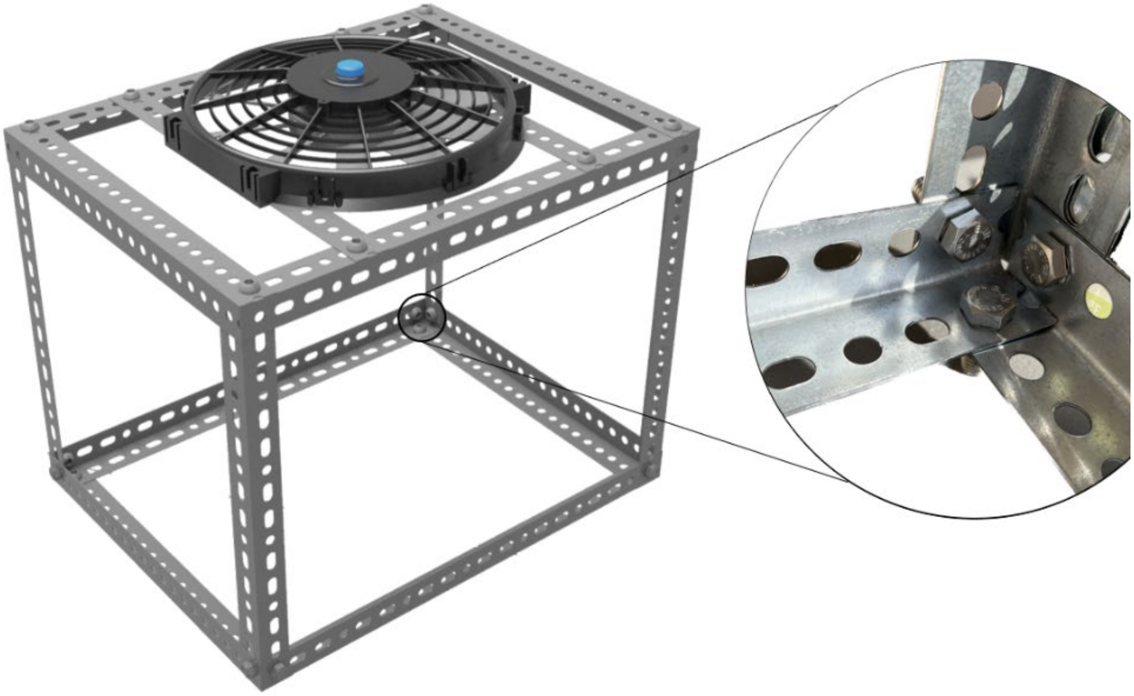


Figure 6-6. SWAC Metal Frame. Punched angled zinc-plated steel bars connected by outward-screwed 9.5 mm hexagonal bolts. The angled bars are extended by 6.4 mm to compensate for the hexagonal bolt heads. The electric fan is mounted on flat bars on the frame’s top.

The SWAC frame is designed to allow for the filter to be installed and replaced outdoors through the rear of the unit. The angled bars sides are 3.5 cm wide which would reduce the rear side opening by 7 cm, making it 6.35 cm narrower than the nominal filter length. Accordingly, flat bars were selected instead of angled bars for the vertical rear sides to allow for unobstructed filter installation and replacement (Figure 6-7). The final outer dimensions of the frame altered by the added thickness of the zinc-plated bars were approximately 52 cm x 40 cm for the front, rear, top and bottom sides, and 40 cm x 40 cm for the left and right sides.

#### 6.1.3.1.2. MESH FILTER

A 52 cm x 40 cm fiberglass mesh screen was selected to cover the rear and bottom sides of the frame for debris, and large particles interception. The recirculated air (bottom) side mesh was installed inside the unit as opposed to the outdoor air mesh installed on the outer edges of the rear side. The fiberglass material was favoured for durability corrosion resistance over metallic materials. An adhesive magnetic roll was installed on the upper and lower sides of the rear mesh cut-out, to facilitate filter replacement and cleaning of the mesh without dismantling the frame. On the base magnetic roll was installed around the mesh with a 2.5 cm x 2.5 cm cut from the corners to account for the bottom hexagonal bolt heads. The magnet strips were reinforced with duct-tape to hold them in place, accounting for poor adhesion of the magnet on the fiberglass mesh material (Figure 6-8).

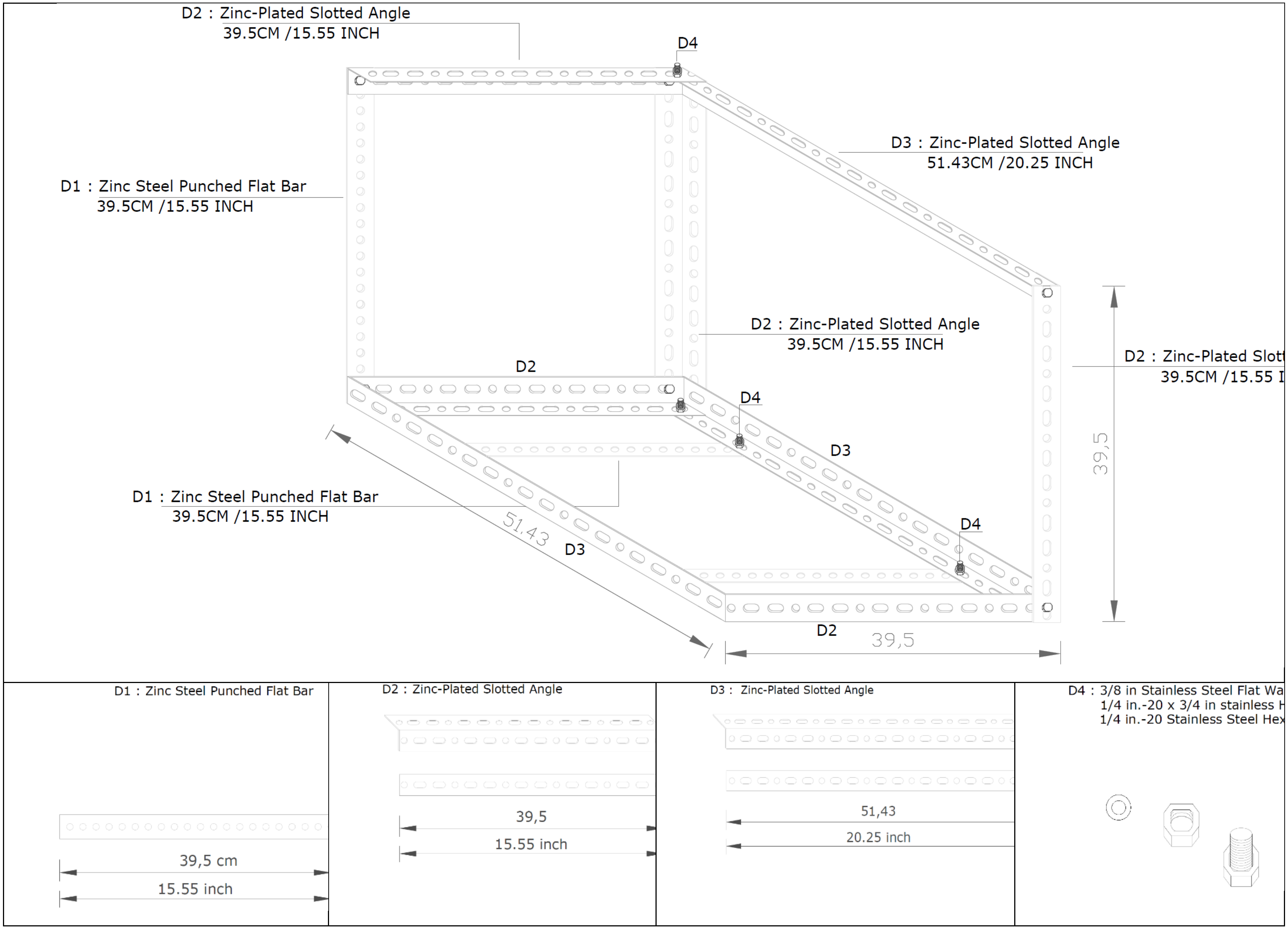


Figure 6-7. SWAC Frame (Upside Down). Dimensions and Components in Inches and Equivalent Centimetres.

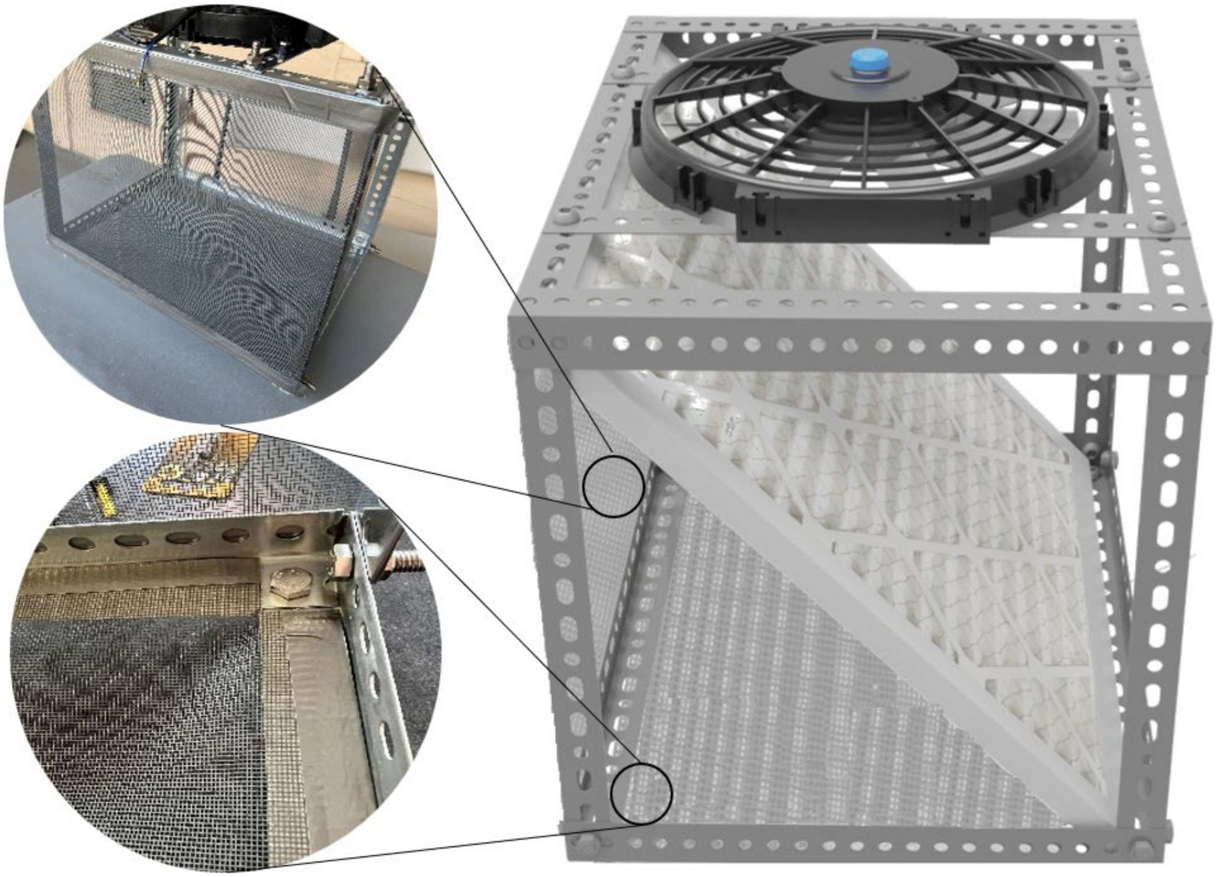


Figure 6-8. SWAC Mesh Filter. Rear mesh filter with adhesive magnet on the top and bottom sides, covered with duct tape. The bottom mesh filter with trimmed corners around the bolts.

#### 6.1.3.1.3. COVER

Cardboard from empty equipment boxes was reused to cover the SWAC frame. A cut-out of the fan circumference was created to form a 53 cm x 41 cm shroud around the fan, extending over the top frame section (Figure 6-9). The side and front covers dimensions were made slightly wider than the top cover to elevate the edges above the top cover, allow it to push firmly against the sides and front cover and limit any gaps. Accordingly, the left and right panels pieces were 42 cm x 42 cm, while the front cover was made 42 cm wide and 53 cm long. Tarpaulin fabric, which is used as shelter material, composed of tightly woven polyethylene, was used to wrap the cardboard panels as a moisture and air barrier, and to provide some protection against physical impact [267-270]. Cardboard was preferred over other materials as it is abundant, affordable and can be customised. Harder materials like wood or plastic are too costly for refugees.

Figure 6-9. Cardboard Panels Covering the Frame Top and Sides.

The tarpaulin surface area was twice that of the covered cardboard section to form an outer and inner layer of tarpaulin material. Duct tape was used to seal the exposed cardboard edges and to close gaps inside the unit between the metal frame and the tarpaulin fabric. Similarly, the inner lining of the fan cut-out was also sealed with duct tape (Figure 6-10).

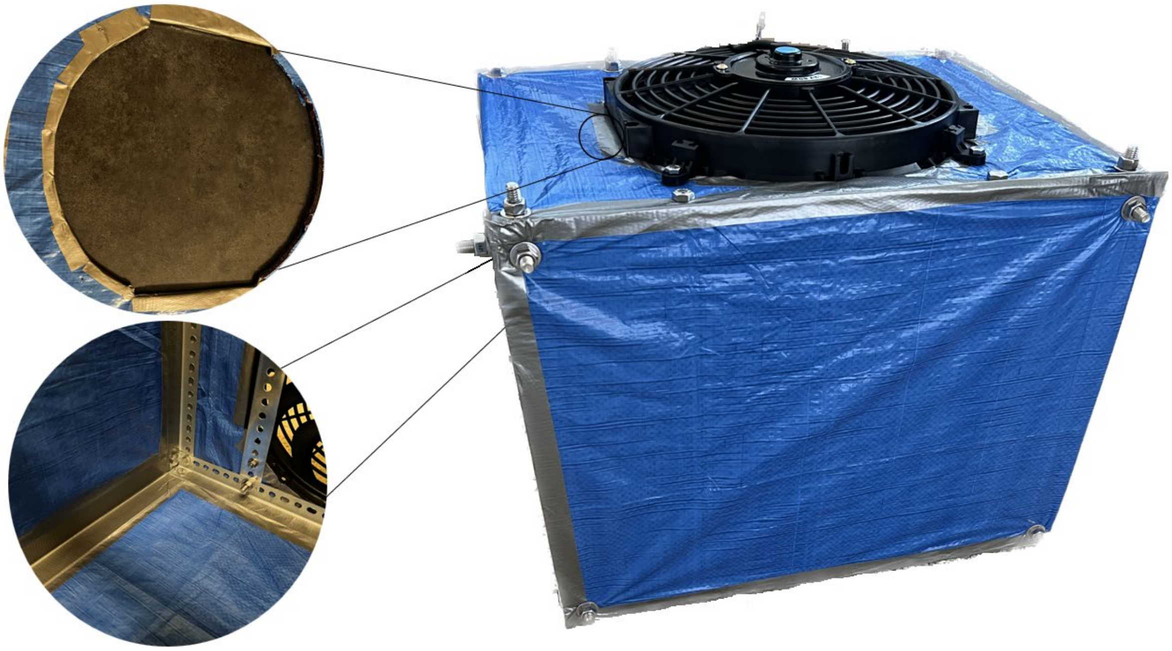
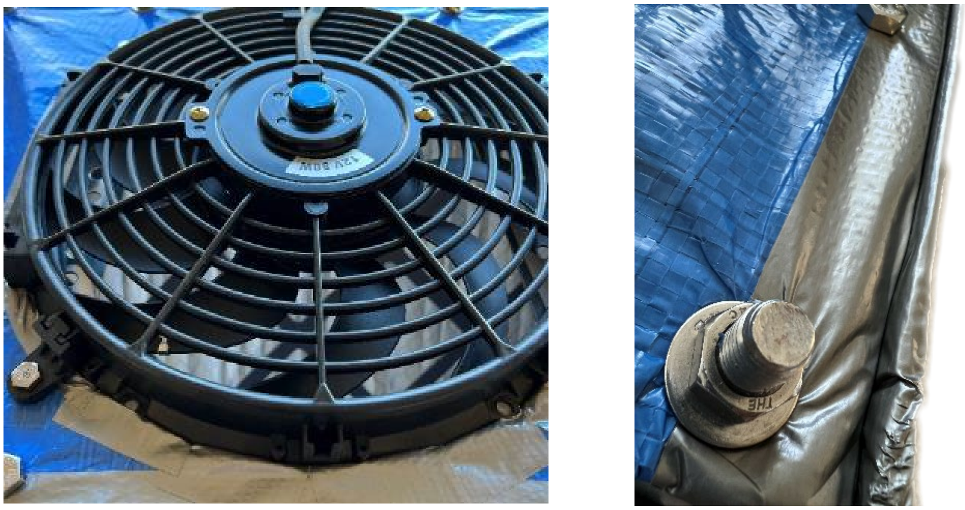


Figure 6-10. SWAC Cover. Duct tape sealing of inner lining of fan top cover, front cover, and frame-tarp gap inside the SWAC unit.

The top shroud was trapped between the fan frame and mounting brackets to further reduce air gaps around the fan. The stainless-steel washers and nuts were tightened to firmly press the covers against the metal frame (Figure 6-11).



(a) (b)

Figure 6-11. Top Cover. (a) Mounting brackets and (b) stainless-steel washers firmly pressing the tarp-covered cardboard against the metal frame and fan cage.

#### 6.1.3.2. Filter

A 1.3 cm rubber foam roll was installed on the left and right sides of the MERV-13 pleated filter to offset gaps created by the actual filter dimensions. The filter was introduced horizontally from the lower rear side of the unit then diagonally adjusted to form a $45^0$ angle with the lower front and upper rear corners. The rubber foam was installed on the upward facing edge of the filter frame to slide over the bolt heads (Figure 6-12).

(a) (b)

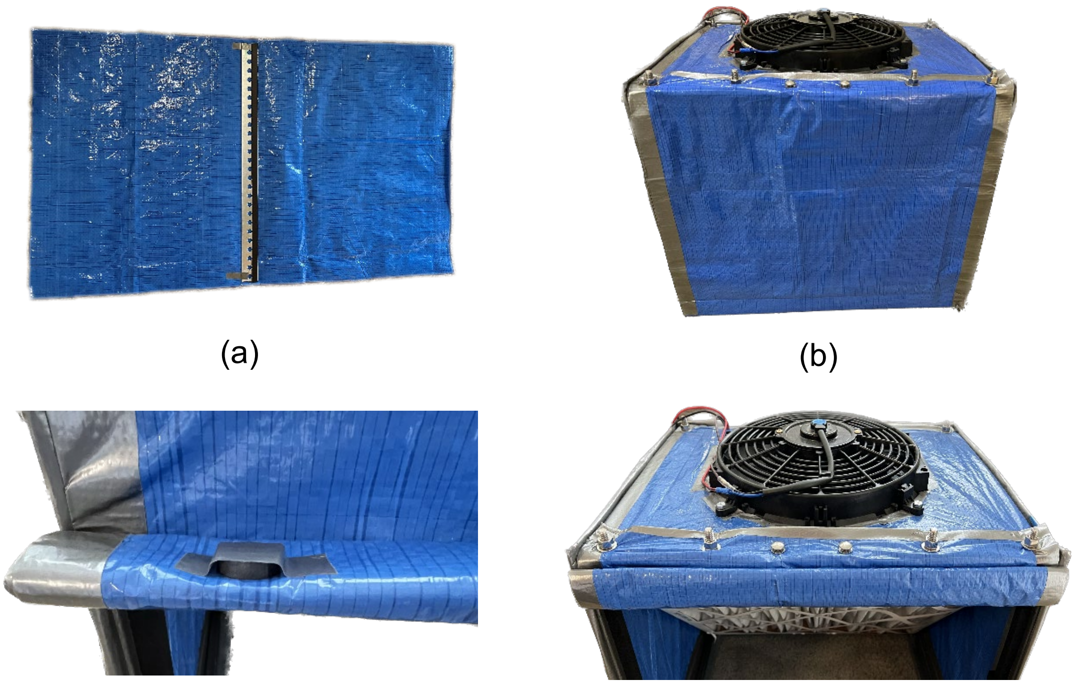
Figure 6-12. MERV Filter. (a) Rubber foam sliding over the bolt head. (b) Tight seal pushing against the covers.

To firmly push the filter frame against the top cover, an 11 cm angled bar piece was installed at the upper rear angled bar and suspended by means of 2 x 7.6 cm (3 inch) bolts through the top cover to adjust the filters position, with hexagonal nuts to level the angled bar piece (Figure 6-13).

(a) (b)

Figure 6-13. Filter Tight Fitting. (a) Angled bar piece installed at the rear to adjust the filter position by means of 7.6 cm bolts and hexagonal nuts. (b) Bolts suspending the angled bar piece through the top cover.

To block outdoor air intake during extreme weather conditions or adverse outdoor air quality and allow indoor air recirculation only, a flap measuring 44.5 cm x 52 cm was installed to overlap with the rear plane of the SWAC unit. The dimensions were chosen to account for overlapping with the top cover rear bolts. Accordingly, the flap was made by cutting an 89 cm x 52 cm tarpaulin sheet and folding it over a 51.43 cm flat bar with a magnetic strip in the middle (Figure 6-14 a). The magnetic strip would allow the flat bar to attract the lower rear angled bar (Figure 6-14 b). The rear flap would be rolled up by being folded by the flat bar's width until reaching the upper rear angled bar. Ceramic disk magnets were taped using duct tape on the edges of the last fold to secure it magnetically to the upper rear angled bar. Similarly, a return air flab was installed at the bottom of the SWAC unit, allowing for manual adjustment during 100% outdoor air, mixed air, or 100% recirculation (Figure 6-14 c and d).



(a)

(b)

(c)

(d)

Figure 6-14. Outdoor Air Flap. (a) Flat bar with a magnetic strip forming the lower edge of the flap. (b) Rear flap closing the outdoor air intake. (c) Ceramic disk magnets taped on the last fold of the rear flap. (d) Rear flap folded and magnetically secured on the upper rear angled bar.

#### 6.1.3.3. Embedded System

A multimeter display was connected to a DC stepless speed controller to monitor power consumption and fluctuations when running on solar power. The fan speed controller has 3 wires, the first is to be connected to the negative power source, the second to be connected to the negative load (fan), while the third is common for both the positive load and power source. The multimeter features an internal shunt and 4 wire screw connectors, 2 to be connected to the power sources and 2 designated for the load. The multimeter and fan speed controller were connected to the fan and power source by means of 14-gauge wires (Figure 6-15).

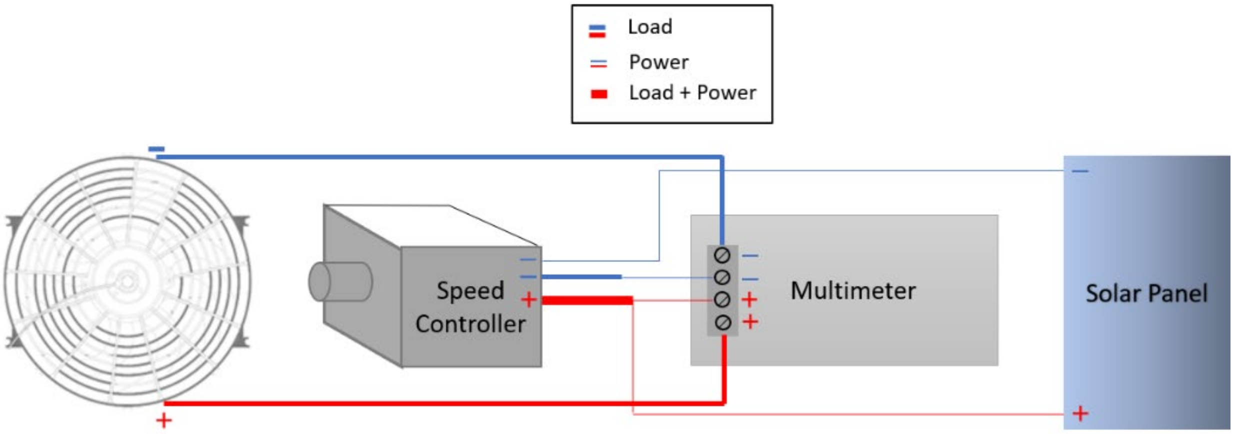
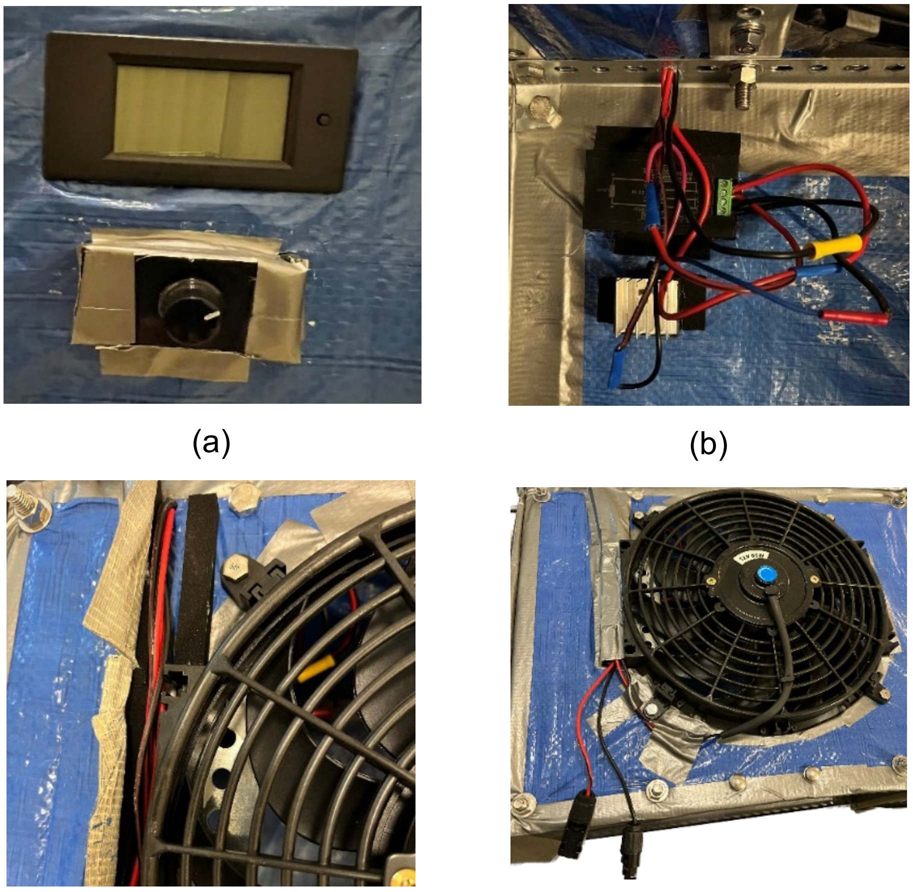


Figure 6-15. Electrical Wiring Diagram. Connections between the fan, multimeter, speed controller, and solar panel.

The display was embedded in the upper right corner of the front cover and the fan speed controller right below it (Figure 6-16 a). Polyethylene-insulated brass wire connectors were used to hold intertwined wires (Figure 6-16 b). The wires were then released to the top cover through a frame hole and trapped between 2 rubber strips alongside the fan, then sealed with duct tape (Figure 6-16 c). MC4 connectors were used to connect to the solar panel (Figure 6-16 d). The purpose of the multimeter was to evaluate correlation between power consumption and output airflow and was not intended to be part of the end user’s SWAC unit.



(a) (b)

(c) (d)

Figure 6-16. SWAC Electric Components. (a) Frontal view of the multimeter display and speed controller. (b) Multimeter display and speed controller embedded inside the front cover. (c) 14-gauge wires connecting the speed controller and multimeter to the fan and power source through the top frame hole alongside the fan. (d) Wires hooked to MC4 connectors.

## 6.2. The SWAV Unit

While the SWAC unit's material selection and optimization were designed to have the capacity to ventilate the total refugee household floor area (56 m$^2$), a second compact and simpler concept was developed to address individual rooms with smaller floor areas. The concept is a solar-powered wall air vent (SWAV) unit which does not require extensive manual assembly as the SWAC unit. However, unlike the SWAC unit, this design aims at treating outdoor air only with no applications for recirculating air.

Accordingly, a 32 cm x 32 cm slotted wall air vent cover was selected with 40 slots measuring 0.64 cm x 10.8 cm each, making the total flow area about 276 cm$^2$ (0.3 square feet). The inner housing of the vent is designed to fit inside a 25.4cm x 25.4 cm duct opening and is wide enough to accommodate 4 x 12 V computer cooling fans, 12 cm diameter each, aligned in parallel to maximize air flow. A cut-to-size MERV8 air filter was placed between the fans and the removable grille and a fiberglass mesh similar to the SWAC unit was affixed to the rear of the vent cover instead of the inside housing to prevent friction with the fan blades due to the negative pressure created by the fans (Figure 6-17).

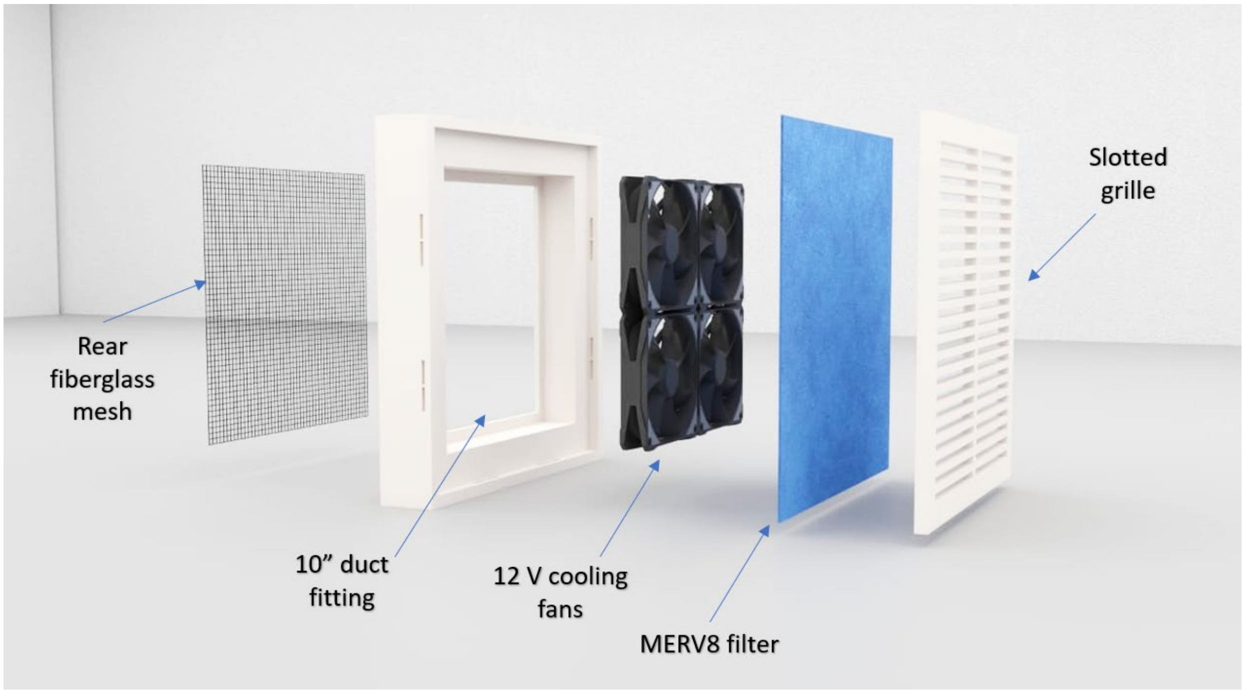


Figure 6-17. SWAV Unit Concept.

The cooling fans were connected to a 4-pin fan hub which in turn was connected to a USB-A adaptor. Other brands exist with direct USB-A connections for external cooling; however, the current concept represents most commonly used cooling fans and would allow for reusing fans from discarded desktop computers. The required power for each fan is 5 W and accordingly a 30 W monocrystalline solar panel featuring a USB inlet was selected to run the SWAV unit (Figure 6-18).

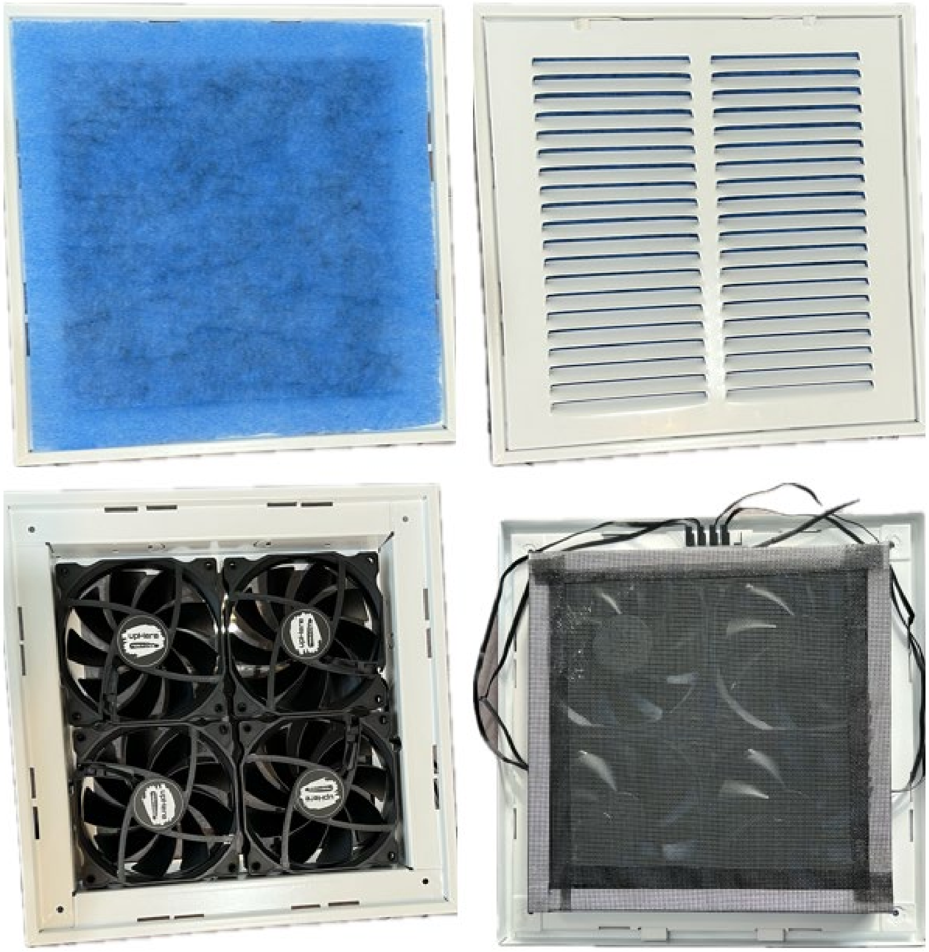


Figure 6-18. Front and Rear Sections of the SWAV unit.

## 6.3. Economic Cost

The average cost of an informal tented shelter is around EUR 1,395 according to Save the Children shelter coordinators. This cost includes site preparation, utilities, infrastructure, and construction (Table 6-1).

**Table 6-1. Estimated Cost of an Informal Tented Shelter in Euro (rounded).**

| **Material/task** | **Estimated Cost (EUR)** |
|---|---|
| Site preparation, construction, and concrete works for the floor. | 185 |
| Latrine, holding tank, and installation | 420 |
| Water tank, stand, and installation | 140 |
| Tent kit and installation | 560 |
| Electrical wiring and equipment | 45 |
| Water taps and accessories | 45 |
| **Total Estimated Cost** | **1,395** |

The SWAC unit provides a hybrid system of air cleaning through filtered forced outdoor air and recirculated indoor air. While the unit does not provide heating and cooling, the closest system to the SWAC function is a residential HVAC unit which costs between EUR 3,500 and EUR 5,000 for the desired space and requires high energy consumption [222,271]. Furthermore, standalone portable air cleaners verified by the Association of Home Appliance Manufacturers (AHAM) can cost between EUR 280 and up to EUR 1,850 to treat the desired space [272]. Table 6-2 outlines the material and total cost of the SWAC and SWAV units. The total cost of the SWAC unit was EUR 185 while the SWAV units cost EUR 50 each. A more cost-effective approach to deploying the SWAV unit would be to connect 4 units servicing individual refugee rooms to a common 100 W solar panel.

**Table 6-2. SWAC And SWAV Unit Material and Total Cost in Euro.**

| **Device** | **Electrical Components** | **Housing and Filter** | **Total** | **Percentage of Total Shelter Cost** |
|---|---|---|---|---|
| **SWAC UNIT** | 92 | 93 | 185 | 13.3% |
| **SWAV UNIT** | 120* | 55* | 175* | 12.5% |
| *Based on 4 units connected to a common 100 w solar panel | | | | |

## 6.4. Performance Testing

### 6.4.1. SWAC Performance

The SWAC unit was connected to the 100 W monocrystalline solar panel to test the fan output with varying solar power. A TSI™ ALNOR® Balometer® capture hood was vertically placed on the fan cover to record the volumetric air flow. A cardboard resembling the fan cover cut-out was installed on the capture hood's opening to offset the dimensions gap of the SWAC unit (Figure 6-19).

Figure 6-19. Capture Hood Setup Over the SWAC Unit.

A total of 30 airflow measurements were collected over a 3-day period during March 2022 in Castro Valley, California, with a recorded solar irradiance 3-day average of 233 $W/m^2$ [273]. The sampling dates were selected to represent sunny days with intermittent clouds to reflect partly cloudy weather and test the unit's performance under suboptimal conditions. The unit was placed inside a detached structure with a 2.5 m (8-foot) ceiling and the solar panel was laid horizontally on the structure's roof.

### 6.4.1.1. Results & Discussion

Airflow was plotted against wattage whereby 3 separate power readings were recorded for each airflow while the unit was running on solar power with a minimum recording of 166 cfm (282 $m^3$/hr) at an average power of 4.53±0.02 W and the highest achieved volumetric airflow being 470 cfm (798.5 $m^3$/hr) corresponding to an average power of 60.77±0.05 W (Figure 6-20). The below plot shows a strong positive correlation ($p<.001$, $R^2 = 0.95$) between airflow and power. A visual smoke test using a smoke pencil with a cotton wick was conducted during the fan's maximum output and did not reveal any air leaks between the metal frame and panels.

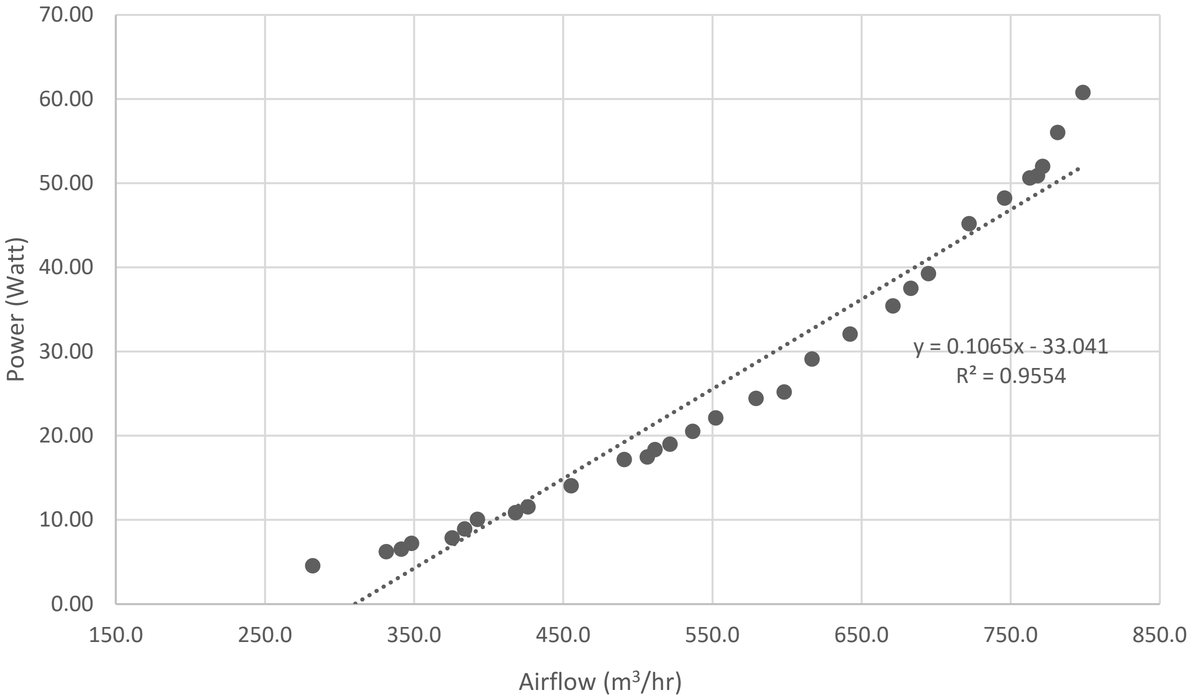


Figure 6-20. Volumetric Airflow Output vs Mean Power Consumption of The SWAC Unit.

Based on ASHRAE standard 62.2 section 4 *"Dwelling-Unit Ventilation"*, the total outdoor air ventilation rate continuously required for an average refugee dwelling-unit of 56 $m^2$ and a total of 6 occupants was 120.6 $m^3$/hr (71 cfm) which is equivalent to 0.88 air changes per hour (ACH), according to the following 2 equations [221]:

Equation 6-1 $$Q_{tot} = 0.03A_{floor} + 7.5(N_{br} + 1)$$

(4-1a; ASHRAE 62.2)

where;

$Q_{tot}$ is the total required ventilation rate, cfm

$A_{floor}$ is the dwelling-unit floor area, $ft^2$

$N_{br}$ is the number of bedrooms (not to be less than 1)

Equation 6-2 ACH = (cfm x 60) / space volume

### 6.4.1.1.1.1. SWAC MIXED AIR VENTILATION

While mixed air is recommended for energy saving and psychrometric control [274-276], the SWAC unit does not provide active temperature conditioning, thus the ventilation air is impacted by the forced outdoor ambient temperature. When outdoor ambient temperatures are extreme during hot or cold days, mixing fresh and recirculated air is of utmost importance, making this SWAC feature beneficial in reducing the impact of extreme cold air during winter to heated spaces. To account for the impact of indoor air mixing, the actual outdoor air ACH was adjusted for air distribution effectiveness using ASHRAE standard 62.1 Table 6-4 “Zone Air Distribution Effectiveness” [69]. The zone air distribution effectiveness factor appropriate for the intended SWAC setup (Figure 6-3) is 0.5, describing the configuration of *“Makeup supply outlet located less than half the length of the space from the exhaust, return or both”*. This configuration accounts for the proximity of the return air bottom intake to the unit’s supply. Accordingly, the air changes of equivalent outdoor air equation becomes [277]:

Equation 6-3 $ACH\_e = (ACH\_oa + ACH\_f) \times E_z$

where;

*ACH_e* is the the air changes of equivalent outdoor air

*ACH_oa* is the the air changes of outdoor air

*ACH_f* is the return air changes adjusted for MERV-13 filter efficiency (ASHAE 52.2 particle size ranges).

$E_z$ is the zone air distribution effectiveness (Table 6-4; ASHRAE 62.1)

Equivalent air changes were calculated based on the ASHRAE standard 52.2 MERV-13 filter efficiency for the 3 particle size ranges (Table 6-2).

### 6.4.1.1.2. SWAC OUTDOOR AIR VENTILATION

To evaluate the unit with 100% outdoor air supply which is a recommended approach to maintain optimal indoor air quality in the absence of energy saving considerations and when outdoor air conditions are favourable [278], the actual outdoor air ACH was adjusted for air distribution effectiveness of 0.8, describing the configuration of *“Makeup supply outlet located more than half the length of the space from the exhaust, return or both”*. Accordingly, the air changes of equivalent outdoor air equation becomes:

Equation 6-4 $ACH\_e = ACH\_oa \times E_z$

Based on this configuration, the fan’s maximum output was equivalent to 4.68 ACH_e while the minimum output was equivalent to 1.65 ACH_e for an average refugee dwelling, exceeding the ASHRAE standard 62.2 requirements by 430% and 87% respectively.

### 6.4.1.1.3. SWAC RECIRCULATED AIR VENTILATION

When the quality of outdoor air is unfavourable due to known nearby sources of contamination such as operating generators, dust and wildfire smoke, the temporary operation of the unit at recirculation mode only would prevent entrainment of contaminants. To evaluate the unit based on recirculation mode only, the same air distribution effectiveness for mixed air was used, and the air changes of equivalent outdoor air equation becomes:

Equation 6-5 $ACH\_e = ACH\_f \times E_z$

Based on this configuration, the fan’s maximum output based on was equivalent to 1.94 ACH_e, while the minimum output was equivalent to 0.68 ACH_e for an average refugee dwelling, which is below the target ACH_e for the E1 particle size distribution. The performance, however, exceeded the E2 and E3 requirements. The minimum air flow required under recirculation mode for E1 is 365 $m^3$/hr (215 cfm) (Table 6-3).

A more accurate evaluation for the SWAC unit as an indoor air cleaner was through establishing the unit’s CADR. The CADR, however, would be evaluated for the room floor area in which the SWAC unit is installed rather than the total ITS floor area. The CADR was established by AHAM in their AC-1-2020 protocol to measure the performance of portable household electric room air cleaners [279]. The aim of the protocol is to provide repeatable test procedures under 3 main particle ranges, dust, cigarette smoke, and pollen. The protocol reports the test chamber dimensions to be 1008 $ft^3$ (28.5 $m^3$). However, a modified AHAM AC-1-2020 protocol originally developed by The Design for Nanomanufacturing Laboratory (DNL) at the University of California Berkeley to evaluate the performance of various MERV-13 filter brands was replicated to calculate the SWAC unit's CADR rating. To assess the unit's performance in laboratory settings, the MC-4 cables were connected to a 12 V socket of a power converter and the power was adjusted to achieve 798.5 $m^3$/hr (470 cfm) which is the maximum output recorded under solar power. The unit was placed in a 9 $m^3$ (320 $ft^3$) hermetic plastic chamber constructed using a PVC pipe frame wrapped with 6-mm-thick plastic sheets which was assembled based on the DNL experimental setup. The setup included an aerosol system to generate NaCl as the surrogate for indoor particulates using a polydisperse constant output atomizer. A condensation particle counter (CPC) (TSI, model 3007, Shoreview, MN, USA), a 16 size channels optical particle sizer (OPS) (TSI, model 3330, Shoreview, MN, USA), and a 13 size channels NanoScan scanning mobility particle sizer (SMPS) (TSI, model 3910, Shoreview, MN, USA) were placed inside the chamber to measure the total particle concentration (particles/cc) of particles between 10 nm to 1 µm, 0.3 µm to 10 µm , and 10 nm to 420 nm, respectively (Figure 6-21). The chamber's air was purged using an air purification device until particle counts dropped below 50 particles/cc after which a 0.1 g/ml NaCl solution was aerosolized inside the chamber allowing the particle concentration to reach 20,000 particles/cc (Figure 6-21) Following particles stabilization for 4 minutes, the SWAC unit was operated until particle concentrations dropped below 50 particles/cc again. The process was repeated 3 times and MATLAB® R2020a was used to analyse the data.

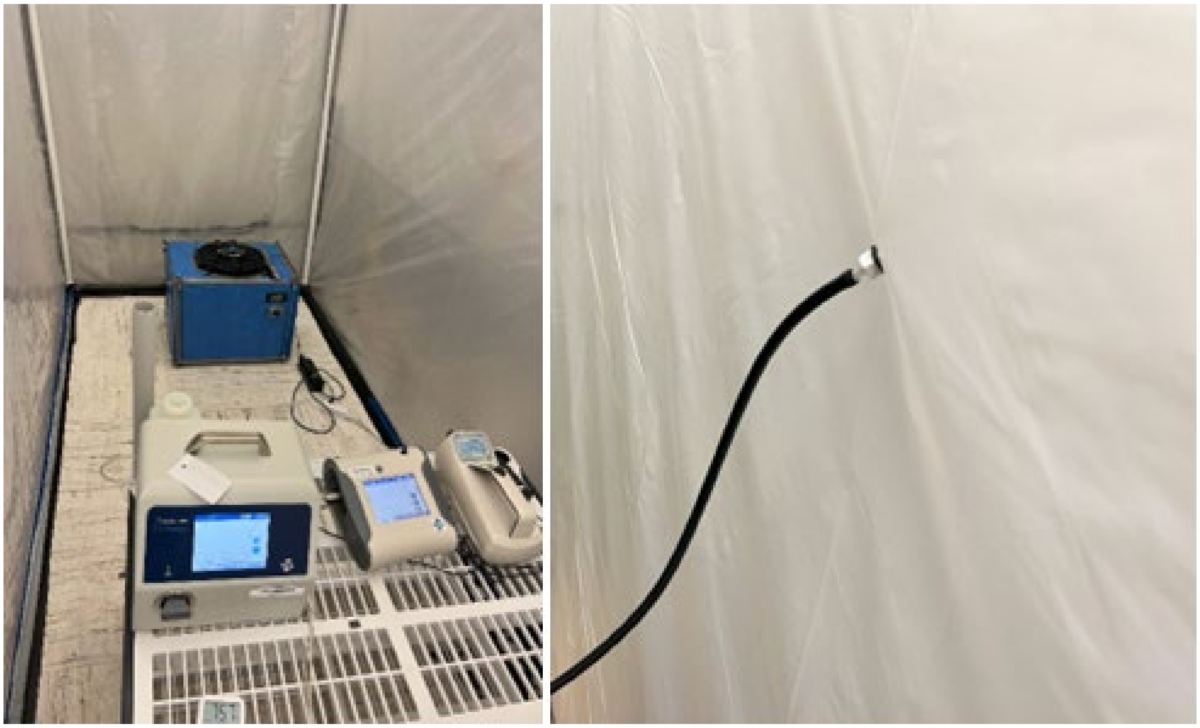


Figure 6-21. SWAC CADR Setup. (Left) SWAC unit inside the CADR testing chamber with the SMPS, OPS, and CPC devices. (Right) 0.1 g/ml NaCl solution aerosolizing hose.

The CADR was calculated using equation 6 below:

Equation 6-6 (AHAM AC-1-2020) $CADR = V * (k_T - k_n)$

where;

$V$ is the volume of the testing chamber in ($ft^3$)
$k_T$ is the total decay rate ($min^{-1}$)
$k_n$ is the natural decay rate ($min^{-1}$)

The average CADR from the triplicate data was calculated to be 114±8.5 (67±5 cfm) which is equivalent to 3.12 ACH for a typical ITS individual room, achieving 95% particle removal in 58 minutes. The effectiveness of this configuration is for the physical removal of suspended particles and does not substitute the dilution effect of outdoor air to mitigate gases such as $CO_2$ and vapours accumulation indoors from building material and anthropogenic activities.

### 6.4.1.1.4. ACOUSTICS

Prolonged exposure to loud noise leads to hearing loss among other adverse health implications [280-282]. Accordingly, to assess noise produced by the fan at different airflow output, 3 sound level measurements for each airflow were collected during the SWAC unit operation using a TSI QUEST SoundPro sound level meter and plotted against airflow. As shown in figure 5-20, sound levels increased with a strong positive correlation with airflow ($p<.001$, $R^2 = 0.97$) which is expected during the production of higher airflow and faster spinning of the fan's motor. The highest recorded measurement was 79.5 decibels (dB) pertaining to the unit's maximum output (Figure 6-22). The recommended 24-hour average sound level for the general population is 70 dB according to the US EPA and WHO [283].

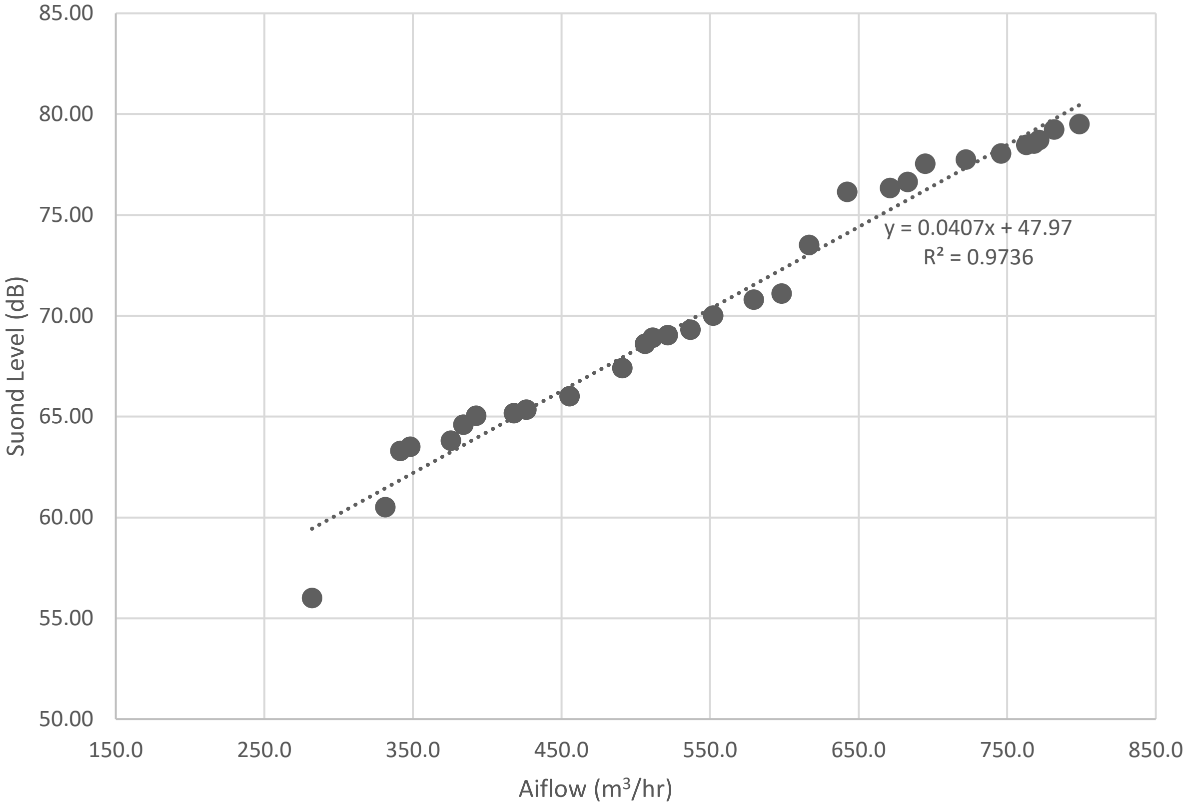


Figure 6-22. Airflow vs Mean Sound Level During SWAC Operation.

The WHO recommended threshold reflects an airflow of 552 $m^3$/hr (325 cfm) with corresponding equivalent air changes of outdoor and mixed air highlighted in table 2. The fan speed controller will allow households to maintain a sound level at or below 70 dB by keeping airflow below 552 $m^3$/hr. Nevertheless, the fan's maximum output should be allowed to flush indoor air when excessive indoor emissions, such as from cooking, cleaning or heating occur. The time required to flush 95% of indoor particles assuming no additional emissions are generated is calculated using equation 5 below [284].

Equation 6-7 $$t_2 - t_1 = -\frac{V}{Q} ln(\frac{C_2}{C_1})$$

where;

$t_2$ is the time required to remove particles, minutes

$t_1$ is the time at initial particle concentration, minutes ($t_1 = 0$)

$V$ is the volume of space, cubic meter ($m^3$)

$Q$ is the airflow in $m^3$/hr

$C_2$ is the final particle concentration

$C_1$ is the initial particle concentration

### 6.4.2. SWAV Performance

A TSI™ VelociCalc® anemometer with a hot wire probe was used to measure air velocity from the SWAV unit during solar power operation over 3 days in Sacramento, California, during the month of October 2023, with a recorded solar irradiance 3-day average of 146 W/$m^2$ [285].The performance testing involved 2 units, the first with the slotted cover and the second with the filter only to evaluate for optimized configuration. To calculate the air flow with the slotted cover, 6 anemometer readings were collected downwind from the slots and the average air velocity was multiplied by the flow area formed by the slots.

#### 6.4.2.1. Results and Discussion

The highest achieved air flow during peak sun hours was 124 $m^3$/hr (73 cfm) which meets the minimum required ACH based on equation 5-4 and a 0.8 effective zone distribution factor. As for performance without the slotted cover, air velocity was measured by placing the anemometer's probe parallel to each fan then multiplying the velocity by the area of the fan to calculate the air flow through the filter, and finally summing the 4 air flows.

The minimum calculated air flow with the filter only was 124 $m^3$/hr (73 cfm) which is equivalent to the maximum output with the slotted cover. The highest achieved output with the filter only was 194 $m^3$/hr (114 cfm), exceeding the target ACH_e for a 15 $m^2$ (161 $ft^2$) room by about 150%. The highest recorded sound level was 63 dB (Table 6-2).

## Table 6-3. SWAC and SWAV Units Performance Summary.

| Device | Output m$^3$/hr (cfm) | Mean Power consumption (W) | OA ACH_e | MA ACH_e | | | RA ACH_e | | | Minimum requirement (ACH) | OA 95% particle removal (minutes) | MA 95% particle removal (minutes) | | | Mean Sound Level (dB) | US EPA recommended threshold (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | E1 | E2 | E3 | E1 | E2 | E3 | | | E1 | E2 | E3 | | |
| SWAC | 282 (166) minimum | 4.53±0.02 | 1.7 | 0.9 | 1.0 | 1.0 | 0.7 | 0.95 | 1.0 | 0.88 $^{A}$ | 109 | 209 | 181 | 176 | 56.0±0.07 | 70.0 (24-hour average) |
| | 552$^{C}$ (325) | 22.1±0.03 | 3.2 | 1.7 | 1.9 | 2.0 | 1.3 | 1.9 | 2.0 | | 56 | 107 | 92 | 90 | 70.0±0.03 | |
| | 798.5 (470) maximum | 60.8±0.05 | 4.7 | 2.4 | 2.8 | 2.9 | 3.12$^{B}$ | | | | 38 | 74 | 64 | 62 | 79.5±0.12 | |
| SWAV | 124$^{D}$ (73) minimum | | 2.7 | | | | | | | 2.7$^{E}$ | 66 | | | | 46±0.03 | |
| | 194 (114) maximum | | 4.2 | | | | | | | | 42 | | | | 63.3±0.03 | |

OA: Outdoor air

MA: Mixed air

RA: Recirculated air

E: Particle Range Efficiency

$^{A}$Based on 6 occupants and 56 m$^2$ (603 ft$^2$) of floor area

$^{B}$Based on CADR rating and coverage of 15 m$^2$ (161 ft$^2$) of floor area

$^{C}$Airflow corresponding to the US EPA recommended sound level threshold

$^{D}$Minimum air flow with filter only and maximum air flow with slotted cover

$^{E}$Based on 6 occupants and 15 m$^2$ (161 ft$^2$) of floor area

## 6.5. Sustainability

To evaluate the SWAC and SWAV units' sustainability, criteria based on the product sustainability index (PSI) model developed by Jawahir et al. (2006) and Zhang et al. (2012) were selected [286,287]. The aim of the PSI is to calculate an aggregate score for 6 sub-indices which are assigned weights and a score reflecting impact. For the purpose of this evaluation, based on the prototype nature of the SWAC and SWAV units and lack of standardization at this phase, no quantitative scoring was attempted, and the selection of the evaluative criteria was based on applicability to circumstantial factors governing the end users. The 6 sub-indices and corresponding evaluative criteria are summarized in Table 6-4.

**Table 6-4. Product Sustainability Index Evaluation. Adopted from Jawahir et al. (2006) and Zhang et al. (2012).**

| Sub-index | Evaluative Criteria |
|---|---|
| Environmental Impact | Environmental effect |
| | Operational safety |
| Societal Impact | Health and Wellness effects |
| | Social impact |
| Functionality | Service life/durability |
| | Ease of use |
| | Maintainability / serviceability |
| | Upgradability |
| | Ergonomics |
| | Reliability |
| | Functional effectiveness |
| Resource utilization and economy | Energy efficiency |
| | Use of renewable source of energy |
| | Material utilization |
| | Installation and training cost |
| | Operational cost |
| Manufacturability | Assembly |
| | Packaging |
| | Transportation |
| | Storage |
| | Disassembly |
| Recyclability | Recyclability |
| | Disposability |
| | Reusability |

### 6.5.1. PSI Impact Evaluation

The environmental impact criteria were evaluated based on operational safety, and toxicological, and emission effects from the SWAC and SWAV units' operation. These criteria were taken into consideration while designing the units as off-grid devices which consume very low voltage and operate with acceptable noise levels while emissions are considered negligeable [288]. Additionally, the positioning of the units is at window level or higher which should be out of reach of children.

The social impact is reflected by the primary aim of the units which is to improve indoor air quality in an underserved population. The health and wellness effect, however, cannot be fully evaluated at this phase since improvement in medical conditions and reported symptoms was not assessed after the deployment of the units and the verification and validation of the units were based on design performance only.

As for functionality, while a typical useful life of a solar panel is up to 25 years [289] the units' durability is highly dependent on other electrical components such as computer or radiator fans used which cannot be standardized in order to facilitate resourcing. Moreover, both units are upgradable from an output and filtration efficiency which require higher capacity solar panels. From an ergonomic perspective, filter replacement can be performed in a standing upright position in both units and no awkward body movements or work above the shoulders is required. Reliability and functional effectiveness are inherent in the fact that the units are the only present mechanical solutions to mitigate indoor pollutants and their performance was verified by the output air flow.

With respect to resource utilization and economy, both units consume low energy and are fully operated by solar power. The current design requires resourcing several components for the frame assembly and electrical system. The SWAC unit's frame and cover are made from 3 main materials (zinc-plated steel, tarpaulin and cardboard). Despite the ease of materials resourcing, future designs can promote homogeneity of structural materials to further simplify assembly and installation. Apart from the initial capital cost to assemble the unit, additional operational cost is mainly for filter replacement and potentially for repairing the tarpaulin-covered carboard panels in the event of physical damage.

The units’ components are mainly compact in volume and stackable during packaging, storage and transportation. Assembling resourced materials on-site is the more favourable approach for logistics and transportation as none of the units require controlled environments or power tools during assembly and disassembly.

While the only consumable components are the air filters, both units are assembled using recyclable materials, from the frame materials to electrical components [290-293]. Those materials can be easily segregated from proper disposal and recycling. Furthermore, the units can outlive the shelters they are deployed in due to the temporary state of those shelters. Accordingly, the units can be relocated to other temporary structures or serve new occupants and the ease of disassembly ensures proper storage for future deployment if warranted.

## 6.6. Comparison With Existing Solutions

Compared to existing commercial devices the SWAC and SWAV units offer an economic, functional, and sustainable solution in light of the temporary status of the shelters. In additional to low operational costs, the maintenance cost for the SWAC and SWAV units is very low with minimal technical requirements compared to residential HVAC units which require high technical expertise and incur high cost of maintenance and repair [222,271]. Similarly, although portable air cleaners consume less energy than HVAC units, repairing the units entails technical expertise [274]. Table 6-5 summarizes the comparative features of the SWAC and SWAV units.

**Table 6-5. SWAC and SWAV Units Comparison to Other Solutions.**

| Solution | Functionality | Filtration (particulate) | Power Consumption | Maintenance (cost/technical) | Approximate Cost (EUR) | Reference |
|---|---|---|---|---|---|---|
| SWAC | Outdoor air and Indoor air treatment (Mixed air ventilation) | MERV-13 | Solar | Low/Low | 185 | |
| SWAV | Outdoor air treatment | MERV-8 | Solar | Low/Low | 175 | |
| Residential HVAC | Outdoor air and Indoor air treatment (Mixed air ventilation) including air conditioning and heating | MERV-7 (typical) to 13 | Grid | High/High | 3,500 – 5,000 | [222,271] |
| Portable Air Cleaners | Indoor air treatment | HEPA | Grid | Medium/High | 280 – 1,350 | [274] |

## 6.7. Conclusion, Limitations and Design Improvement

This study presented 2 prototype sustainable ventilation solutions, the SWAC and SWAV units, to mitigate poor air quality in Syrian refugee shelters. The 2 devices powered with solar panels, exceeded ventilation requirements set forth by the ASHRAE standard for residential dwelling-units.

While both units were designed to introduce outdoor air and filter recirculated air, they do not provide heating nor cooling for indoor spaces. Controlling psychrometric parameters such as temperature and relative humidity is not only required for thermal comfort but also to maintain environmental conditions which impact indoor emissions and microbial activity [294-296]. Accordingly, future designs should include means for thermal and moisture control while keeping the solution’s overall cost lower than commercially available systems to ease the sourcing of material in different geographical locations. Maintenance requirements must also be taken into consideration with the limited technical capabilities of the target user.

Furthermore, future designs should also account for additional filtration phases such as active carbon filters to mitigate indoor VOC and other gaseous emissions and evaluate the performance of the SWAC unit with additional pressure drop imposed by multiple filters.

# 7. Conclusion

The massive influx of Syrian refugees to Lebanon was met with various challenges mainly due to the lack of preparedness of the hosting country which had been suffering from and ongoing economic and political crisis for several years. Lebanon is adjacent to conflict zones and subject to regular domestic political and social unrest, resulting in issues with dissemination of aid to refugees and lack of economic investment to improve shelters and stakeholder conditions. The number of refugees has increased globally since the start of the Syrian civil war in 2010. As of June 2023, over 108 million people were displaced forcibly worldwide resulting mainly from violence, conflicts, and persecution. Over 50% of the globally displaced population consists of Syrians (19%), Ukrainians (16%), and Afghans (16%), and 76% of the globally displaced population are hosted by low and middle-income countries [297]. While the case of Syrian refugees was not necessarily unique in light of global events which lead to the displacement of other populations in different continents, it presented an opportunity for research in the field of environmental health following the industrial hygiene approach of anticipation, recognition, evaluation, and control of hazards. The controls were further verified by design calculation and partially validated with CADR testing. The following diagram summarizes the phases of this research:

| | |
|---|---|
| Anticipation | • Syrian Refugee popultion deployment in Lebanon and vulnerability.<br>• Environmental research in similar settings. |
| Recognition | • Pilot study to identify exisiting environmental pollutants in refugee settlements in Lebanon. |
| Evaluation | • Fungal exposure in Syrian refugee settlements in Lebanon.<br>• Biomonitoring potential effects of environemtnal exposure. |
| Control | • SWAC and SWAV units design and development. |
| Verification and Validation | • Performance testing of SWAC and SWAV units.<br>• CADR testing of SWAC unit |

The demographic profile of Syrian refugees along with health surveys specific to this population and previous environmental health studies related to indoor environmental quality have shed light on anticipated hazards associated with the living conditions of refugee households. This was reflected in inadequate shelters, poor sanitation and hygiene, reported existing medical conditions, susceptibility of certain age groups, and imposed restrictions and financial constraints.

Following an initial investigation conducted at 2 refugee camps in Lebanon in an attempt to recognize indoor environmental pollutants potentially impacting refugees' health, a follow up research to further investigate fungal exposure in Syrian refugee settlements revealed several significant associations between categories of shelter and mould concentrations and has further established strong associations between certain mould types and shelter conditions. The aim of the fungal exposure study was to identify environmental risks associated with Syrian refugee shelters in Lebanon, focusing on indoor mould populations based on initial findings form the pilot study, and for NGOs to present local authorities and policy makers with scientific evidence of alarming nature and address a public health concern which may add to the existing burden on the national health system.

Several studies and international agencies including WHO have recommended remediating the sources of moisture and dampness to prevent microbial growth [42,298,299]. Knowing that the shelters conditions in which Syrian refugees are residing are potential sources of diseases related to mould exposure, the restrictions imposed by the Lebanese government and the lack of funding for adequate housing has put the refugee population at risk whereby the vulnerable subpopulation such as children, women, the elderly, and immunocompromised individuals are at an even higher risk of developing respiratory and other diseases. Nevertheless, studies have also demonstrated that long term exposure to mould also leads to adverse health effects even for normal individuals [114,299,300]. Thus, in addition to chronic medical conditions reported by the older age group of this population, it is of utmost importance to investigate the emerging health effects in refugee settlements in Lebanon especially for the young age group which constitutes more than 50% of the refugee population, due to the fact that newborn children up until the age of about 14 years of refugee families who fled the war in 2010 were born into these camps.

Non-invasive biomonitoring of pulmonary inflammation was conducted to further evaluate environmental hazards. While biomonitoring was limited to non-residential and non-permanent shelters, it provided some insight regarding existing respiratory conditions and the possibility to implement minimally invasive methods to establish susceptibility profiles in Syrian refugees amid limited access to healthcare. The clinical interpretation of $F_ENO$ results suggested possible persistent exposure to allergens in addition to significant type 2 inflammation in some subjects. These findings warrant the need to expand the study and investigate other biomarkers and attempt to correlate findings with environmental conditions to evaluate if a dose-response relationship exists.

The design and development of the SWAC and SWAV units as sustainable technologies running on solar power attempted at a minimum to supplement for residential ventilation requirements in informal tented refugee settlements by mechanically forcing outdoor air into occupied spaces. In addition to supplying outdoor air, the SWAC unit also aimed at mitigating indoor pollutants build-up including but not limited to particulates and airborne microorganisms generated from building material and human activity through filtration of recirculated indoor air. Local government restrictions, budget constraints of NGOs, and expenditure prioritization of households, however, pose a great challenge on establishing adequate infrastructure and appropriate living environments for refugees. Accordingly, the SWAC and SWAV units were designed to use commercially available, reusable, and affordable material ensuring low initial and eventually reasonable maintenance cost compared with most suitable solutions currently available on the market [301-303].

The SWAC unit's performance evaluation met the ASHRAE standard 62.2 requirements at the minimum output when operated as a mixed air unit with 50% outdoor air using the most stringent particle range for ASHRAE standard 52.2 MERV-13 filter efficiency, which demonstrates the effectiveness of this solution even during periods of low solar irradiance. The unit's CADR value was also derived at the maximum airflow rate and delivered 3.12 ACH for a typical ITS room. The SWAV unit also met the equivalent outdoor air target at the minimum output for individual refugee rooms with maximum occupancy while running on solar power. Further evaluation should include computational fluid dynamics (CFD) simulation of particles reduction based on the output of both devices. Additionally, CFD modelling would suggest proper positioning and deployment of the devices inside the shelters. Nevertheless, these proposed controls do not compensate for adequate shelter design which is of utmost importance especially when purposed for human occupancy even for temporary use. While ventilation would promote adequate indoor air quality, shelters should be erected with durable and low chemical-emitting materials. These structures should maintain proper pressurization and thermal comfort to supplement other sustainable efforts.

In conclusion, this study provided an insight on the environmental conditions surrounding Syrian refugees in Lebanon and suggested a phased approach to address these conditions in order to fill the gap in quantitative environmental research in displaced populations. Accordingly, the research aimed at examining the population demographics in an attempt to identify vulnerable subgroups and to anticipate the impact of recognized environmental exposure based on the refugees reported health profiles. The research also demonstrated that a combination of environmental sampling and minimally invasive biomonitoring can be used as evaluative criteria for exposure. Finally, sustainable low-cost and effective technologies were developed to mitigate for adverse indoor environmental quality and help alleviate the well-being of refugee households. The agonising choices made by refugee households to leave their homes or countries can alone impact their mental health. If other displacement-related hazards were not addressed, illnesses will emerge or aggravate to further reduce the quality of life of these populations. Thus, environmental health research in displaced populations is crucial to assist stakeholders with controlling exposures and reducing the risk of health degradation. The progressive approach adopted in this research, although conducted with focus on Syrian refugees, can be replicated in other displaced or underserved populations globally. Cooperation, collaboration and international investment from humanitarian agencies and policy makers is imperative to provide proper accommodations for the refugees to protect their health and wellbeing.

# References

References

1. Lambert, H. Temporary refuge from war: customary international law and the Syrian conflict. *International and Comparative Law Quarterly* **2017**, *66*, 723, DOI 10.1017/S0020589317000124. Available online: https://search.proquest.com/docview/1909748652.

2. UNHCR 3RP Regional Refugee & Resilience Plan 2017-2018. **2017**.

3. UNHCR - Refugee Statistics. Available online: https://www.unhcr.org/refugee-statistics/download/?url=2bxU2f (Accessed on 17/12/ 2022).

4. Syria Regional Refugee Response. Available online: https://data2.unhcr.org/en/situations/syria/location/71 (Accessed on April 13, 2022).

5. Lebanese Ministry of Public Health Statistical Bulletin 2019.

6. Where we work. Available online: https://www.unrwa.org/where-we-work/lebanon.

7. Blanchet, K.; Fouad, F.M.; Pherali, T. Syrian refugees in Lebanon: the search for universal health coverage. *Confl Health* **2016**, *10*, 12, DOI 10.1186/s13031-016-0079-4.

8. Amnesty International Lebanon: Agonizing choices: Syrian refugees in need of health care in Lebanon. *Policy File* **2014**.

9. John Hopkins Bloomberg School of Public Health; Mèdecins Du Monde; International Medical Corps; American University of Beirut; UNHCR; Humanitarian Aid and Civil Protection Syrian refugee and Affected Host Population Health Access Survey in Lebanon. **2015**.

10. El-Khatib, Z.; Scales, D.; Vearey, J.; Forsberg, B.C. Syrian refugees, between rocky crisis in Syria and hard inaccessibility to healthcare services in Lebanon and Jordan. *Conflict and Health* **2013**, *7*, 6–8.

11. Regional Refugees and Resilience Plan Regional Strategic Overview. *Al - Ahram Weekly* **2017** Available online: https://search.proquest.com/docview/1884990887.

12. Syrian Regional Refugee Response. Available online: https://data2.unhcr.org/en/situations/syria/location/71.

13. Sanyal, R. A no-camp policy: Interrogating informal settlements in Lebanon. *Geoforum* **2017**, *84*, 117–125.

14. Smith, K.R.; Bruce, N.; Balakrishnan, K.; Adair-Rohani, H.; Balmes, J.; Chafe, Z.; Dherani, M.; Hosgood, H.D.; Mehta, S.; Pope, D.; Rehfuess, E. Millions dead: how do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. *Annual review of public health* **2014***, 35*, 185–206.

15. Lim, S.S.; Vos, T.; Flaxman, A.D.; Danaei, G.; Shibuya, K.; Adair-Rohani, H.; AlMazroa, M.A.; Amann, M.; Anderson, H.R.; Andrews, K.G. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The lancet* **2012***, 380*, 2224–2260.

16. Prüss-Ustün, A.; Corvalán, C. *Preventing Disease through Healthy Environments,* World Health Organization: Geneva, 2016; pp. 147.

17. Ezzati, M. Methodology for assessment of environmental burden of disease -Annex 4.1 Annex 4.1: Comparative Risk Assessment in the Global Burden of Disease Study and the Environmental Health Risks Global Programme on Evidence for Health Policy World Health Organization. *Methodology for assessment of Environmental burden of disease* **2000**, 31–49.

18. Bruce, N.; Perez-Padilla, R.; Albalak, R.; World Health Organization. Dept. of Protection of the Human Environment The health effects of indoor air pollution exposure in developing countries. **2002** Available online: http://www.who.int/iris/handle/10665/67496.

19. WHO Regional Office for Europe *WHO Guidelines for Indoor Air Quality : Selected Pollutants,* WHO Regional Office for Europe: Europe, 2010;.

20. World Health Organization Burning opportunity: clean household energy for health, sustainable development, and wellbeing of women and children. *Who* **2016**, 113.

21. World Health Organization Evaluating household energy and health interventions. **2008**.

22. Hoseini, M.; Nabizadeh, R.; Delgado-Saborit, J.M.; Rafiee, A.; Yaghmaeian, K.; Parmy, S.; Faridi, S.; Hassanvand, M.S.; Yunesian, M.; Naddafi, K. Environmental and lifestyle factors affecting exposure to polycyclic aromatic hydrocarbons in the general population in a Middle Eastern area. *Environmental pollution (1987)* **2018***, 240*, 781–792.

23. Hood, E. Dwelling Disparities: How Poor Housing Leads to Poor Health. *Environmental Health Perspectives* **2005***, 113*, A311–A317, DOI 10.1289/ehp.113-a310. Available online: https://www.jstor.org/stable/3436233.

24. Nen, O.A.S.; Fisk, W.J.; Mendell, M.J. Association of Ventilation Rates and CO 2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings. *Indoor Air* **1999***, 1*, 226–252.

25. Qi Zheng; Lee, D.; Lee, S.; Jeong Tai Kim; Kim, S. A Health Performance Evaluation Model of Apartment Building Indoor Air Quality. *Indoor &#43; built environment* **2011**, *20*, 26–35.

26. US Environmental Protection Agency Report to Congress on Indoor Air Quality, Volume II: Assessment and Control of Indoor Air Pollution. **1989**, 250.

27. Wei, W.; Ramalho, O.; Mandin, C. Indoor air quality requirements in green building certifications. *Building and environment* **2015**, *92*, 10–19.

28. Rios, J.L.d.M.; Boechat, J.L.; Gioda, A.; Santos, C.Y.d.; Aquino Neto, F.R.d.; Lapa e Silva, J.R. Symptoms prevalence among office workers of a sealed versus a non-sealed building: Associations to indoor air quality. *Environment international* **2009**, *35*, 1136–1141.

29. Tong, Z.; Chen, Y.; Malkawi, A.; Adamkiewicz, G.; Spengler, J.D. Quantifying the impact of traffic-related air pollution on the indoor air quality of a naturally ventilated building. *Environment international* **2016**, *89-90*, 138–146.

30. Spengler, J.D.; Chen, Q. INDOOR AIR QUALITY FACTORS IN DESIGNING A HEALTHY BUILDING. *Annual review of energy and the environment* **2000**, *25*, 567–600.

31. US Environmental Protection Agency Indoor Air Quality Tools for Schools: Reference Guide. *United States Environmental Protection Agency* **2009**, 98.

32. Spaul, W.A. Building-related factors to consider in indoor air quality evaluations. *Journal of allergy and clinical immunology* **1994**, *94*, 385–389.

33. Krieger, J.; Higgins, D.L. Housing and health: Time again for public health action. *American Journal of Public Health* **2002**, *92*, 758–768.

34. Uhde, E.; Salthammer, T. Impact of reaction products from building materials and furnishings on indoor air quality—A review of recent advances in indoor chemistry. *Atmospheric environment (1994)* **2007**, *41*, 3111–3128.

35. Meklin, T.; Hyvärinen, A.; Toivola, M.; Reponen, T.; Koponen, V.; Husman, T.; Taskinen, T.; Korppi, M.; Nevalainen, A. Effect of Building Frame and Moisture Damage on Microbiological Indoor Air Quality in School Buildings. *AIHA journal* **2003**, *64*, 108–116.

36. El-Sharif, N.; Abdeen, Z.; Qasrawi, R.; Moens, G.; Nemery, B. Asthma prevalence in children living in villages, cities and refugee camps in Palestine. *The European respiratory journal* **2002**, *19*, 1026–1034.

37. Abu Mourad, T.A. Palestinian refugee conditions associated with intestinal parasites and diarrhoea: Nuseirat refugee camp as a case study. *Public health (London)* **2004**, *118*, 131–142.

38. Al-Khatib, I.A.; Arafat, R.N.; Musmar, M. Housing environment and women's health in a Palestinian refugee camp. *International journal of environmental health research* **2005**, *15*, 181–191.

39. Bonner, P.C.; Schmidt, W.; Belmain, S.R.; Oshin, B.; Baglole, D.; Borchert, M. Poor Housing Quality Increases Risk of Rodent Infestation and Lassa Fever in Refugee Camps of Sierra Leone. *The American journal of tropical medicine and hygiene* **2007**, *77*, 169–175.

40. Shultz, A.; Omollo, J.O.; Burke, H.; Qassim, M.; Ochieng, J.B.; Weinberg, M.; Feikin, D.R.; Breiman, R.F. Cholera Outbreak in Kenyan Refugee Camp: Risk Factors for Illness and Importance of Sanitation. *AMERICAN JOURNAL OF TROPICAL MEDICINE AND HYGIENE* **2009**, *80*, 640–645.

41. Plog, B.A.; Niland, J.; Quinlan, P. *Fundamentals of Industrial Hygiene,* 5th ed.; National Safety Council Itasca, IL: 1996;.

42. World Health Organization, (. WHO guidelines for indoor air quality; dampness and mould. *Scitech Book News* **2009**, *33*.

43. Moriske, D.H.; Szewzyk, D.R. *Guidelines for Indoor Air Hygiene in School Buildings,* Federal Environment Agency (UBA): Berlin, 2008;.

44. WHO DEVELOPMENT OF WHO GUIDELINES FOR INDOOR AIR QUALITY Development of WHO Guidelines for Indoor Air Quality Report on a Working Group Meeting. *World Health Organization Regional Office for Europe* **2006**, 1–27.

45. US Consumer Product Safety Commission *Indoor Air Pollution: An Introduction for Health Professionals,* DIANE Publishing: 1996;.

46. World Health Organization *WHO guidelines for indoor air quality: selected pollutants,* World Health Organization. Regional Office for Europe: 2010;.

47. Particulate Matter (PM) Pollution. Available online: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM.

48. Esworthy, R. Air Quality: EPA's 2013 Changes to the Particulate Matter (PM) Standard. *Congressional Research Service* **2013**, 6.

49. Kelly, F.J.; Fussell, J.C. Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter. *Atmospheric Environment* **2012**, *60*, 504–526.

50. Perrone, M.G.; Gualtieri, M.; Consonni, V.; Ferrero, L.; Sangiorgi, G.; Longhin, E.; Ballabio, D.; Bolzacchini, E.; Camatini, M. Particle size, chemical composition, seasons of the year and urban, rural or remote site origins as determinants of biological effects of particulate matter on pulmonary cells. *Environmental Pollution* **2013**, *176*, 215–227.

51. Kim, K.; Kabir, E.; Kabir, S. A review on the human health impact of airborne particulate matter. *Environment International* **2015**, *74*, 136–143.

52. Invernizzi, G.; Ruprecht, A.; Mazza, R.; Rossetti, E.; Sasco, A.; Nardini, S.; Boffi, R. Particulate matter from tobacco versus diesel car exhaust: an educational perspective. *Tobacco Control* **2004**, *13*, 219 LP – 221.

53. Brook, R.D.; Rajagopalan, S.; Pope, 3., C Arden; Brook, J.R.; Bhatnagar, A.; Diez-Roux, A.V.; Holguin, F.; Hong, Y.; Luepker, R.V.; Mittleman, M.A.; Peters, A.; Siscovick, D.; Smith, J., Sidney C; Whitsel, L.; Kaufman, J.D. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation (New York, N.Y.)* **2010**, *121*, 2331–2378.

54. Hong, C.; Goldberg, M.; Villeneuve, P. A Systematic Review of the Relation Between Long-term Exposure to Ambient Air Pollution and Chronic Diseases. *Reviews on Environmental Health* **2008**, *23*, 243.

55. World Health Organization (WHO) *Air Quality Guidelines for Europe Second Edition,* 2nd Editio ed.; World Health Organization Regional Office for Europe: Copenhagen, 2000;.

56. Brauer, M.; Amann, M.; Burnett, R.T.; Cohen, A.; Dentener, F.; Ezzati, M.; Henderson, S.B.; Krzyzanowski, M.; Martin, R.V.; Van Dingenen, R.; van Donkelaar, A.; Thurston, G.D. Exposure Assessment for Estimation of the Global Burden of Disease Attributable to Outdoor Air Pollution. *Environmental Science & Technology* **2012**, *46*, 652–660.

57. Leon Hsu, H.; Mathilda Chiu, Y.; Coull, B.A.; Kloog, I.; Schwartz, J.; Lee, A.; Wright, R.O.; Wright, R.J. Prenatal Particulate Air Pollution and Asthma Onset in Urban Children. Identifying Sensitive Windows and Sex Differences. *Am J Respir Crit Care Med* **2015**, *192*, 1052.

58. Fang, Y.; Naik, V.; Horowitz, L.W.; Mauzerall, D.L. Air pollution and associated human mortality: the role of air pollutant emissions, climate change and methane concentration increases from the preindustrial period to present. *Atmos. Chem. Phys.* **2013**, *13*, 1377–1394.

59. Pope, C.A.; Ezzati, M.; Dockery, D.W. Fine-Particulate Air Pollution and Life Expectancy in the United States. *New England Journal of Medicine* **2009**, *360*, 376–386.

60. Araujo, J.A. Particulate air pollution, systemic oxidative stress, inflammation, and atherosclerosis. *Air Quality, Atmosphere & Health* **2011**, *4*, 79–93.

61. Cachon, B.F.; Firmin, S.; Verdin, A.; Ayi-Fanou, L.; Billet, S.; Cazier, F.; Martin, P.J.; Aissi, F.; Courcot, D.; Sanni, A.; Shirali, P. Proinflammatory effects and oxidative stress within human bronchial epithelial cells exposed to atmospheric particulate

matter (PM2.5 and PM>2.5) collected from Cotonou, Benin. *Environmental Pollution* **2014**, *185*, 340–351.

62. World Health Organization (WHO) air quality guidelines (AQGs) and estimated reference levels (RLs). Available online: https://www.eea.europa.eu/publications/status-of-air-quality-in-Europe-2022/europes-air-quality-status-2022/world-health-organization-who-air (Accessed on 8 August 2024).

63. Visser, M.J.; de Wit-Bos, L.; Palmen, N.; Bos, P.; NAT; M&amp;V Overview of Occupational Exposure Limits within Europe. **2014**.

64. Guais, A.; Brand, G.; Jacquot, L.; Karrer, M.; Dukan, S.; Grévillot, G.; Molina, T.J.; Bonte, J.; Regnier, M.; Schwartz, L. Toxicity of carbon dioxide: a review. *Chemical research in toxicology* **2011**, *24*, 2061–2070.

65. Abolhassani, M.; Guais, A.; Chaumet-Riffaud, P.; Sasco, A.J.; Schwartz, L. Carbon dioxide inhalation causes pulmonary inflammation. *American Journal of Physiology - Lung Cellular and Molecular Physiology* **2009**, *296*, 657–665.

66. Permentier, K.; Vercammen, S.; Soetaert, S.; Schellemans, C. Carbon dioxide poisoning: a literature review of an often forgotten cause of intoxication in the emergency department. *Int J Emerg Med* **2017**, *10*, 1–4.

67. Lang-Yona, N.; Levin, Y.; Dannemiller, K.C.; Yarden, O.; Peccia, J.; Rudich, Y. Changes in atmospheric CO2 influence the allergenicity of Aspergillus fumigatus. *Global Change Biology* **2013**, *19*, 2381–2388, DOI 10.1111/gcb.12219. Available online: http://onlinelibrary.wiley.com/doi/10.1111/gcb.12219/abstract.

68. Anonymous Indoor air quality: biological contaminants. Report on a WHO meeting, DENMARK, Jan 1, 1990; , pp. 1–67.

69. ASHRAE *Standard 62.1-2016 - Ventilation for Acceptable Indoor Air Quality,* American Society of Heating, Refrigerating and Air-Conditioning Engineers: Atlanta, GA, 2016; pp. 56.

70. National Institute for Occupational Safety and Health (NIOSH) *NIOSH POCKET GUIDE TO CHEMICAL HAZARDS DEPARTMENT OF HEALTH AND HUMAN SERVICES Centers for Disease Control and Prevention National Institute for Occupational Safety and Health,* Department of Health and Human Services: 2007;.

71. Burnett, R.T.; Cakmak, S.; Raizenne, M.E.; Stieb, D.; Vincent, R.; Krewski, D.; Brook, J.R.; Philips, O.; Ozkaynak, H. The Association between Ambient Carbon Monoxide Levels and Daily Mortality in Toronto, Canada. *Journal of the Air &amp; Waste Management Association (1995)* **1998**, *48*, 689–700.

72. Jaffe, L.S. Ambient Carbon Monoxide And Its Fate in the Atmosphere. *Journal of the Air Pollution Control Association* **2012**, *18*, 534–540.

73. Comrie, A.C.; Diem, J.E. Climatology and forecast modeling of ambient carbon monoxide in Phoenix, Arizona. *Atmospheric Environment* **1999***, 33*, 5023.

74. Fauci, G.L.; Weiser, G.; Steiner, I.P.; Shavit, I. Carbon monoxide poisoning in narghile (water pipe) tobacco smokers. *Canadian journal of emergency medicine* **2012***, 14*, 57–59.

75. Hampson, N.B., MD; Hauff, N.M., BE Carboxyhemoglobin levels in carbon monoxide poisoning: do they correlate with the clinical picture? *The American journal of emergency medicine* **2008***, 26*, 665–669.

76. Cuinica, L.G.; Cruz, A.; Abreu, I.; da Silva, J.C.G.E. Effects of atmospheric pollutants (CO, O3, SO2) on the allergenicity of Betula pendula, Ostrya carpinifolia, and Carpinus betulus pollen. *International Journal of Environmental Health Research* **2015***, 25*, 312–321.

77. Thomassen, Ø; Brattebø, G.; Rostrup, M. Carbon monoxide poisoning while using a small cooking stove in a tent. *The American journal of emergency medicine* **2004***, 22*, 204–206.

78. Li, C.; Kang, S.; Chen, P.; Zhang, Q.; Guo, J.; Mi, J.; Basang, P.; Luosang, Q.; Smith, K.R. Personal PM2.5 and indoor CO in nomadic tents using open and chimney biomass stoves on the Tibetan Plateau. *Atmospheric environment (1994)* **2012***, 59*, 207–213.

79. US Environmental Protection Agency FACT SHEET NATIONAL AMBIENT AIR QUALITY STANDARDS FOR CARBON MONOXIDE -FINAL RULE. **2011**.

80. Meng, Z. Oxidative Damage of Sulfur Dioxide on Various Organs of Mice: Sulfur Dioxide Is a Systemic Oxidative Damage Agent. *Inhalation Toxicology* **2003***, 15*, 181–195.

81. Johns, D.O.; Linn, W.S. A review of controlled human SO2 exposure studies contributing to the US EPA integrated science assessment for sulfur oxides. *Inhalation toxicology* **2011***, 23*, 33–43.

82. Shapiro, R. Genetic effects of bisulfite (sulfur dioxide). *Mutation Research/Reviews in Genetic Toxicology* **1977***, 39*, 149–175.

83. Wang, X.; Du, J.; Cui, H. Sulfur dioxide, a double-faced molecule in mammals. *Life Sciences* **2014***, 98*, 63–67.

84. Solé, D.; Camelo-Nunes, I.C.; Wandalsen, G.F.; Pastorino, A.C.; Jacob, C.; Gonzalez, C.; Wandalsen, N.F.; Filho, N.; Fischer, G.B.; Naspitz, C.K. Prevalence of symptoms of asthma, rhinitis, and atopic eczema in Brazilian adolescents related to exposure to gaseous air pollutants and socioeconomic status. *Journal of Investigational Allergology and Clinical Immunology* **2007***, 17*, 6.

85. AnonymousRisk and exposure assessment for the review of the primary National Ambient Air Quality Standard for sulfur oxides. *Risk and exposure assessment for the review of the primary national ambient air quality standard for sulfur oxides* **2018** Available online: https://purl.fdlp.gov/GPO/gpo107154.

86. Riedel, F.; Krämer, M.; Scheibenbogen, C.; Rieger, C.H.L. Effects of $SO_2$ exposure on allergic sensitization in the guinea pig. *Journal of Allergy and Clinical Immunology* **1988***, 82*, 527–534.

87. Devalia, J.L.; Rusznak, C.; Herdman, M.J.; Trigg, C.J.; Davies, R.J.; Tarraf, H. Effect of nitrogen dioxide and sulphur dioxide on airway response of mild asthmatic patients to allergen inhalation. *The Lancet* **1994***, 344*, 1668–1671.

88. Sheppard, D.; Wong, W.S.; Uehara, C.F.; Nadel, J.A.; Boushey, H.A. Lower Threshold and Greater Bronchomotor Responsiveness of Asthmatic Subjects to Sulfur Dioxide. *American Review of Respiratory Disease* **1980***, 122*, 873–878.

89. US Environmental Protection Agency (EPA) FACT SHEET PROPOSED DECISION PRIMARY NATIONAL AMBIENT AIR QUALITY STANDARD FOR SULFUR OXIDES ACTION. **2018**, 1–3.

90. National Research Council *Acute Exposure Guideline Levels for Selected Airborne Chemicals,* National Academies Press: Washington, D.C., 2012;.

91. Gauderman, W.J.; Avol, E.; Lurmann, F.; Kuenzli, N.; Gilliland, F.; Peters, J.; McConnell, R. Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide. *Epidemiology* **2005***, 16*, 737–743.

92. PERSHAGEN, G.; RYLANDER, E.; NORBERG, S.; ERIKSSON, M.; NORDVALL, S.L. Air Pollution Involving Nitrogen Dioxide Exposure and Wheezing Bronchitis in Children. *International Journal of Epidemiology* **1995***, 24*, 1147–1153.

93. GARRETT, M.; HOOPER, M.; HOOPER, B.; ABRAMSON, M. Respiratory Symptoms in Children and Indoor Exposure to Nitrogen Dioxide and Gas Stoves. *American Journal of Respiratory and Critical Care Medicine* **1998***, 158*, 891–895.

94. Belanger, K.; Gent, J.F.; Triche, E.W.; Bracken, M.B.; Leaderer, B.P. Association of Indoor Nitrogen Dioxide Exposure with Respiratory Symptoms in Children with Asthma. *American Journal of Respiratory and Critical Care Medicine* **2006***, 173*, 297–303.

95. Primary National Ambient Air Quality Standards (NAAQS) for Nitrogen Dioxide. Available online: https://www.epa.gov/no2-pollution/primary-national-ambient-air-quality-standards-naaqs-nitrogen-dioxide (Accessed on 13 December 2023).

96. World Health Organization (WHO) *Indoor air quality: organic pollutants. Reports on a WHO meeting, Berlin (West), 23-27 August 1987,* WHO Regional Office for Europe (EURO reports and studies ; 111: Copenhagen, 1989;.

97. Technical Overview of Volatile Organic Compounds. Indoor Air Quality (IAQ). Available online: https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds#3.

98. Xu, J.; Szyszkowicz, M.; Jovic, B.; Cakmak, S.; Austin, C.C.; Zhu, J. Estimation of indoor and outdoor ratios of selected volatile organic compounds in Canada. *Atmospheric environment (1994)* **2016**, *141*, 523–531.

99. Sofuoglu, S.C.; Aslan, G.; Inal, F.; Sofuoglu, A. An assessment of indoor air concentrations and health risks of volatile organic compounds in three primary schools. *International journal of hygiene and environmental health* **2011**, *214*, 36–46.

100. Cheng, M.; Brown, S.K. VOCS IDENTIFIED IN AUSTRALIAN INDOOR AIR AND PRODUCT EMISSION ENVIRONMENTS, 2005; , pp. 23–7.

101. Brown, S.K.; Sim, M.R.; Abramson, M.J.; Gray, C.N. Concentrations of Volatile Organic Compounds in Indoor Air – A Review. *Indoor Air* **1994**, *4*, 123–134.

102. Wang, S.; Ang, H.M.; Tade, M.O. Volatile organic compounds in indoor environment and photocatalytic oxidation: State of the art. *Environment International* **2007**, *33*, 694–705.

103. Mølhave, L.; Clausen, G.; Berglund, B.; Ceaurriz, J.; Kettrup, A.; Lindvall, T.; Maroni, M.; Pickering, A.C.; Risse, U.; Rothweiler, H.; Seifert, B.; Younes, M. Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations*. *Indoor Air* **1997**, *7*, 225–240.

104. Mølhave, L.; Bach, B.; Pedersen, O.F. Human reactions to low concentrations of volatile organic compounds. *Environment International* **1986**, *12*, 167–175.

105. Norbäck, D.; Björnsson, E.; Janson, C.; Widström, J.; Boman, G. Asthmatic symptoms and volatile organic compounds, formaldehyde, and carbon dioxide in dwellings. *Occupational and Environmental Medicine* **1995**, *52*, 388 LP – 395.

106. U.S. Environmental Protection Agency Benzene. *U.S. Environmental Protection Agency* **2012**, 1–5.

107. ATSDR Toxicological Profile for Benzene. *Agency for Toxic Substances and Disease Registry (ATSDR)* **2007**, 438.

108. Bahadar, H.; Mostafalou, S.; Abdollahi, M. Current understandings and perspectives on non-cancer health effects of benzene: A global concern. *Toxicology and Applied Pharmacology* **2014**, *276*, 83–94.

109. Moore, D.; Robson, G.D.; Trinci, A.P.J. *21st Century Guidebook to Fungi with CD,* Cambridge University Press: 2011;.

110. Burge, H.A. The fungi: How they grow and their effects on human health. *Heating, Piping and Air Conditioning* **1997***, 69*.

111. Kazemian, N.; Pakpour, S.; Milani, A.S.; Klironomos, J. Environmental factors influencing fungal growth on gypsum boards and their structural biodeterioration: A university campus case study. *PLoS ONE* **2019***, 14*, e0220556, DOI 10.1371/journal.pone.0220556. Available online: https://search.proquest.com/docview/2268093898.

112. Storey, E.; Dangman, K.H.; Schenck, P.; Debernardo, R.L.; Chin, Y.S.; Bracker, A.; Hodgson, M.J. *Guidance for Clinicians on the Recognition and Management of Health Effects related to Mold Exposure and Moisture Indoors,* University of Connecticut Health Center. Division of Occupational and Environmental Medicine. Center for Indoor Environments and Health: Farmington, CT, 2004;.

113. Verdier, T.; Coutand, M.; Bertron, A.; Roques, C. A review of indoor microbial growth across building materials and sampling and analysis methods. *Building and environment* **2014***, 80*, 136–149.

114. William J Rea; Nancy Didriksen; Theodore R Simon; Yaqin Pan; Ervin J Fenyves; Bertie Griffiths Effects of toxic exposure to molds and mycotoxins in building-related illnesses. *Archives of environmental health* **2003***, 58*, 399–405 Available online: http://www.ncbi.nlm.nih.gov/pubmed/15143852.

115. Burge, H.A. Allergens and other air pollutants. *Monaldi archives for chest disease = Archivio Monaldi per le malattie del torace* **1994***, 49*, 373–374.

116. GRANT, C.; HUNTER, C.A.; FLANNIGAN, B.; BRAVERY, A.F. The Moisture Requirements of Molds Isolated from Domestic Dwellings. *International Biodeterioration* **1989***, 25*, 259–284, DOI 10.1016/0265-3036(89)90002-X.

117. Mendell, M.J.; Mirer, A.G.; Cheung, K.; Tong, M.; Douwes, J. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence. *Environmental health perspectives* **2011***, 119*, 748–756.

118. Caillaud, D.; Leynaert, B.; Keirsbulck, M.; Nadif, R.; Roussel, S.; Ashan-Leygonie, C.; Bex, V.; Bretagne, S.; Caillaud, D.; Colleville, A.C.; Frealle, E.; Ginestet, S.; Lecoq, L.; Leynaert, B.; Nadif, R.; Oswald, I.; Reboux, G.; Bayeux, T.; Fourneau, C.; Keirsbulck, M. Indoor mould exposure, asthma and rhinitis: Findings from systematic reviews and recent longitudinal studies. *European Respiratory Review* **2018***, 27*.

119. Quansah, R.; Jaakkola, M.S.; Hugg, T.T.; Heikkinen, S.A.M.; Jaakkola, J.J.K. Residential Dampness and Molds and the Risk of Developing Asthma: A Systematic Review and Meta-Analysis. *PLOS ONE* **2012***, 7*, e47526.

120. Santry, I.W. Hydrogen sulfide in sewers. *Journal (Water Pollution Control Federation)* **1963**, 1580–1588.

121. Tomar, M.; Abdullah, T.H. Evaluation of chemicals to control the generation of malodorous hydrogen sulfide in waste water. *Water Res* **1994***, 28*, 2545–2552.

122. Reiffenstein, R.J.; Hulbert, W.C.; Roth, S.H. *Toxicology of hydrogen sulfide,* Annual Reviews 4139 El Camino Way, PO Box 10139, Palo Alto, CA 94303-0139, USA: 1992; pp. 109–134.

123. AnonymousBS ISO 16000-20:2014: Indoor air. Detection and enumeration of moulds. Determination of total spore count. **2014** Available online: https://bsol.bsigroup.com/en/Bsol-Item-Detail-Page/?pid=000000000030273491.

124. EPA Indoor air - Part 11: Determination of the emission of volatile organic compounds from building products and furnishing - Sampling, storage of samples and preparation of test specimens. **2011**.

125. EPA Indoor air - Part 5: Sampling strategy for volatile organic compounds (VOCs). **2011**.

126. British Standards Institution BSI Standards Publication Gas detectors -Electrical apparatus for the detection of carbon monoxide in domestic premises. **2018**.

127. British Standards Institution BS ISO 16000-18:2011. Indoor air Part 18: Detection and enumeration of moulds -Sampling by impaction. **2011**, 29p.

128. Abdel-Salam, M.M. Seasonal variation in indoor concentrations of air pollutants in residential buildings. *J Air Waste Manage Assoc* **2021***, 71*, 761–777.

129. Stock, T.H.; Morandi, M.T.; Afshar, M.; Chung, K.C. Evaluation of the use of diffusive air samplers for determining temporal and spatial variation of volatile organic compounds in the ambient air of urban communities. *J Air Waste Manage Assoc* **2008***, 58*, 1303–1310.

130. Xia, X.; Hopke, P.K. Seasonal variation of 2-methyltetrols in ambient air samples. *Environ Sci Technol* **2006***, 40*, 6934–6937.

131. Biran, A.; Schmidt, W.; Zeleke, L.; Emukule, H.; Khay, H.; Parker, J.; Peprah, D. Hygiene and sanitation practices amongst residents of three long-term refugee camps in Thailand, Ethiopia and Kenya. *TROPICAL MEDICINE & INTERNATIONAL HEALTH* **2012***, 17*, 1133–1141.

132. Habib, R.R.; Basma, S.H.; Yeretzian, J.S. Harboring illnesses: On the association between disease and living conditions in a Palestinian refugee camp in Lebanon. *INTERNATIONAL JOURNAL OF ENVIRONMENTAL HEALTH RESEARCH* **2006***, 16*, 99–111.

133. Habib, R.R.; Mahfoud, Z.; Fawaz, M.; Basma, S.H.; Yeretzian, J.S. Housing quality and ill health in a disadvantaged urban community. *Public health (London)* **2009***, 123*, 174–181.

134. Cronin, A.A.; Shrestha, D.; Spiegel, P.; Gore, F.; Hering, H. Quantifying the burden of disease associated with inadequate provision of water and sanitation in selected sub-Saharan refugee camps. *JOURNAL OF WATER AND HEALTH* **2009***, 7*, 557–568.

135. Cronin, A.A.; Shrestha, D.; Cornier, N.; Abdalla, F.; Ezard, N.; Aramburu, C. A review of water and sanitation provision in refugee camps in association with selected health and nutrition indicators - the need for integrated service provision. *JOURNAL OF WATER AND HEALTH* **2008***, 6*, 1–13.

136. Benka-Coker, M.L.; Tadele, W.; Milano, A.; Getaneh, D.; Stokes, H. A case study of the ethanol CleanCook stove intervention and potential scale-up in Ethiopia. *Energy for sustainable development : the journal of the International Energy Initiative* **2018***, 46*, 53–64.

137. Albadra, D.; Vellei, M.; Coley, D.; Hart, J. Thermal comfort in desert refugee camps: An interdisciplinary approach. *Building and environment* **2017***, 124*, 460–477.

138. Stephanie Everaerts; Katrien Lagrou; Kristina Vermeersch; Lieven J Dupont; Bart M Vanaudenaerde; Wim Janssens Aspergillus fumigatus Detection and Risk Factors in Patients with COPD-Bronchiectasis Overlap. *International Journal of Molecular Sciences* **2018***, 19*, 523, DOI 10.3390/ijms19020523. Available online: https://search.proquest.com/docview/2014800442.

139. Armstrong-James, D.; Meintjes, G.; Brown, G.D. A neglected epidemic: fungal infections in HIV/AIDS. *Trends in Microbiology* **2014***, 22*, 120–127.

140. KIRKPATRICK, C.H. Fungal Infections in HIV Patients. *Annals of the New York Academy of Sciences* **2018***, 616*, 461–468.

141. Durden, F.M.; Elewski, B. Fungal infections in HIV-infected patients. *Seminars in cutaneous medicine and surgery* **1997***, 16*, 200—212.

142. DOWNS, S.; MITAKAKIS, T.; MARKS, G.; CAR, N. ; BELOUSOVA, E.; LEÜPPI, J.; XUAN, W.E.I.; DOWNIE, S.; TOBIAS, A.; PEAT, J. Clinical Importance of Alternaria Exposure in Children. *American Journal of Respiratory and Critical Care Medicine* **2001***, 164*, 455–459.

143. British Standards Institution BS EN ISO 16000-19: 2014. Indoor air Part 19: Sampling strategy for moulds. **2014**.

144. Thermo Fisher Scientific Series 10-800. Instruction Manual. Single Stage Viable Sampler. **2009**.

145. British Standards Institution BS ISO 16000-17:2008. Indoor air Part 17: Detection and enumeration of moulds — Culture-based method. **2009**.

146. Yamamoto, N.; Hospodsky, D.; Dannemiller, K.C.; Nazaroff, W.W.; Peccia, J. Indoor Emissions as a Primary Source of Airborne Allergenic Fungal Particles in Classrooms. *Environmental science &amp; technology* **1900***, 49*, 5098–5106, DOI 10.1021/es506165z. Available online: http://dx.doi.org/10.1021/es506165z.

147. Watanabe, T. *Pictorial atlas of soil and seed fungi : morphologies of cultured fungi and key to species,* 3rd ed.; CRC Press/Taylor & Francis: Boca Raton, 2010;.

148. Sciortino, C.V. *Atlas of clinically important fungi,* John Wiley & Sons, Incorporated: Hoboken, New Jersey, 2017;.

149. ASTM International F2659 − 10: Standard Guide for Preliminary Evaluation of Comparative Moisture Condition of Concrete , Gypsum Cement and Other Floor Slabs and Screeds Using a Non-Destructive Electronic Moisture Meter. **2016***, 10*, 1–6.

150. Lennartsson, P.R.; Taherzadeh, M.J.; Edebo, L. Rhizopus. In *Encyclopedia of Food Microbiology (Second Edition)*; Batt, C.A.; Tortorello, M.L., Eds.; Academic Press: Oxford, 2014; pp. 284–290.

151. Sircar, G.; Bhattacharya, S.G. 221 Allergenic Significance of Airborne Rhizopus Stolonifer (ehrenb.) Vuill, a Common Bread Mold. *The World Allergy Organization Journal* **2012***, 5*, S73–S90, DOI 10.1097/01.WOX.0000411978.49685.7f. Available online: https://explore.openaire.eu/search/publication?articleId=od______267::6d167f475ca2f294a680e537cce4e397.

152. Hurraß, J.; Heinzow, B.; Aurbach, U.; Bergmann, K.; Bufe, A.; Buzina, W.; Cornely, O.A.; Engelhart, S.; Fischer, G.; Gabrio, T.; Heinz, W.; Herr, C.E.W.; Kleine-Tebbe, J.; Klimek, L.; Köberle, M.; Lichtnecker, H.; Lob-Corzilius, T.; Merget, R.; Mülleneisen, N.; Nowak, D.; Rabe, U.; Raulf, M.; Seidl, H.P.; Steiß, J.; Szewszyk, R.; Thomas, P.; Valtanen, K.; Wiesmüller, G.A. Medical diagnostics for indoor mold exposure. *International journal of hygiene and environmental health* **2017***, 220*, 305–328.

153. Kuhn, D.M.; Ghannoum, M.A. Indoor Mold, Toxigenic Fungi, and *Stachybotrys chartarum* : Infectious Disease Perspective. *Clinical Microbiology Reviews* **2003***, 16*, 144–172.

154. Jones, R.; Recer, G.M.; Hwang, S.A.; Lin, S. Association between indoor mold and asthma among children in Buffalo, New York. *Indoor Air* **2011***, 21*, 156–164.

155. Rea, W.J.; Didriksen, N.; Simon, T.R.; Pan, Y.; Fenyves, E.J.; Griffiths, B. Effects of Toxic Exposure to Molds and Mycotoxins in Building-Related Illnesses. *Archives of environmental health* **2003***, 58*, 399–405.

156. Laura Escriva; Guillermina Font; Lara Manyes; Houda Berrada Studies on the Presence of Mycotoxins in Biological Samples: An Overview. **2017**, *9*, 251, DOI 10.3390/toxins9080251. Available online: https://search.proquest.com/docview/1940272980.

157. Bloom, E.; Bal, K.; Nyman, E.; Must, A.; Larsson, L. Mass spectrometry-based strategy for direct detection and quantification of some mycotoxins produced by Stachybotrys and Aspergillus spp. in indoor environments. *Appl Environ Microbiol* **2007**, *73*, 4211–4217, DOI 10.1128/AEM.00343-07.

158. Simoni, M.; Lombardi, E.; Berti, G.; Rusconi, F.; La Grutta, S.; Piffer, S.; Petronio, M.G.; Galassi, C.; Forastiere, F.; Viegi, G. Mould/dampness exposure at home is associated with respiratory disorders in Italian children and adolescents: the SIDRIA-2 Study. *Occupational and Environmental Medicine* **2005**, *62*, 616 LP – 622.

159. Müller, A.; Lehmann, I.; Seiffart, A.; Diez, U.; Wetzig, H.; Borte, M.; Herbarth, O. Increased incidence of allergic sensitisation and respiratory diseases due to mould exposure: Results of the Leipzig Allergy Risk children Study (LARS)11Following a presentation given as part of the International Congress on Environmental Health and the 4. *International Journal of Hygiene and Environmental Health* **2002**, *204*, 363–365.

160. Bellanger, A.-.; Reboux, G.; Roussel, S.; Grenouillet, F.; Didier-Scherer, E.; Dalphin, J.-.; Millon, L. Indoor fungal contamination of moisture-damaged and allergic patient housing analysed using real-time PCR. *Letters in Applied Microbiology* **2009**, *49*, 260–266.

161. Birgitte, A.; C, F.J.; Ib, S.; S, R.I.; S, L.L. Associations between Fungal Species and Water-Damaged Building Materials. *Applied and Environmental Microbiology* **2011**, *77*, 4180–4188.

162. Alfieri, P.V.; Correa, M.V. Analysis of biodeterioration wood estate: use different techniques to obtain images. *Matéria* **2018**, *23*, DOI 10.1590/s1517-707620180002.0409. Available online: https://explore.openaire.eu/search/publication?articleId=dedup_wf_001::8ee4ef1ea6015b68ecba2a74838bde6e.

163. Hyvarinen, A.; Meklin, T.; Vepsalainen, A.; Nevalainen, A. Fungi and actinobacteria in moisture-damaged building materials - concentrations and diversity. *Int Biodeterior Biodegrad* **2002**, *49*, 27–37, DOI 10.1016/S0964-8305(01)00103-2.

164. U.S. Department of Housing and Urban Development Assessing Housing Durability: A Pilot Study. **2001**.

165. Dacquisto, D.J.; Crandell, J.H.; Lyons, J. BUILDING MOISTURE AND DURABILITY: Past, Present, and Future. **2004**.

166. Albadra, D.; Kuchai, N.; Acevedo-De-los-Ríos, A.; Rondinel-Oviedo, D.; Coley, D.; da Silva, C.F.; Rana, C.; Mower, K.; Dengel, A.; Maskell, D.; Ball, R.J. Measurement and analysis of air quality in temporary shelters on three continents. *Building and Environment* **2020**, *185*, 107259.

167. American Conference of Governmental Industrial Hygienists *Bioaerosols: Assessment and Control,* ACGIH: 1999;.

168. Centers for Disease Control and Prevention (CDC) 2018 Fourth National Report on Human Exposure to Environmental Chemicals. **2018**.

169. WHO Regional Office for Europe Human biomonitoring: facts and figures. **2015**, 88.

170. Sexton, K.; Needham, L.L.; Pirkle, J.L. Human Biomonitoring of Environmental Chemicals. *Source: American Scientist* **2004**, *92*, 38.

171. Hanson, N.; Halling, M.; Norin, H. Biomarkers for Environmental Monitoring Suggestions for Norwegian monitoring programs. *Om Miljødirektoratet* **2013**.

172. National Research Council Biological markers in environmental health research. Committee on Biological Markers of the National Research Council. *Environmental Health Perspectives* **1987**, *74*, 3–9.

173. Lam, P.K.S.; Gray, J.S. The use of biomarkers in environmental monitoring programmes. *Marine Pollution Bulletin* **2003**, *46*, 182–186, DOI 10.1016/S0025-326X(02)00449-6. Available online: https://www.sciencedirect.com/science/article/pii/S0025326X02004496.

174. Paredi, P.; Kharitonov, S.A.; Barnes, P.J. Analysis of Expired Air for Oxidation Products. *American Journal of Respiratory and Critical Care Medicine* **2002**, *166*, S31–S37.

175. Horvath, I.; Loukides, S.; Wodehouse, T.; Kharitonov, S.A.; Cole, P.J.; Barnes, P.J. Increased levels of exhaled carbon monoxide in bronchiectasis: a new marker of oxidative stress. *Thorax* **1998**, *53*, 867 LP – 870.

176. Uasuf, C.G.; Jatakanon, A.; James, A.; Kharitonov, S.A.; Wilson, N.M.; Barnes, P.J. Exhaled carbon monoxide in childhood asthma. *The Journal of Pediatrics* **1999**, *135*, 569–574.

177. Nathan, C.; Xie, Q. Nitric oxide synthases: Roles, tolls, and controls. *Cell* **1994**, *78*, 915–918.

178. Taylor, D.R.; Pijnenburg, M.W.; Smith, A.D.; Jongste, J.C.D. Exhaled nitric oxide measurements: clinical application and interpretation. *Thorax* **2006**, *61*, 817.

179. Kelekci, S.; Sen, V.; Yolbas, I.; Uluca, Ü; Tan, I.; Gürkan, M.F. FeNO levels in children with asthma and other diseases of the lung. *Eur Rev Med Pharmacol Sci* **2013***, 17*, 3078–3082.

180. Pignatti, P.; Visca, D.; Loukides, S.; Märtson, A.; Alffenaar, J.C.; Migliori, G.B.; Spanevello, A. A snapshot of exhaled nitric oxide and asthma characteristics: Experience from high to low income countries. *Pulmonology* **2022***, 28*, 44–58.

181. Tang, K.; Shao, X.; Liu, F.; Zhu, B.; Dong, Z.; Xu, W.; Yang, Q. Correlation between nitric oxide content in exhaled breath condensate and the severity of acute respiratory distress syndrome. *International Journal of Clinical and Experimental Pathology* **2017***, 10*, 7350.

182. Nguyen-Thi-Bich, H.; Duong-Thi-Ly, H.; Thom, V.T.; Pham-Thi-Hong, N.; Dinh, L.D.; Le-Thi-Minh, H.; Craig, T.J.; Duong-Quy, S. Study of the correlations between fractional exhaled nitric oxide in exhaled breath and atopic status, blood eosinophils, FCER2 mutation, and asthma control in Vietnamese children. *Journal of Asthma and Allergy* **2016***, 9*, 163–170.

183. Brzozowska, A.; Majak, P.; Jerzyńska, J.; Smejda, K.; Bobrowska-Korzeniowska, M.; Stelmach, W.; Koczkowska, M.; Stelmach, I. Exhaled nitric oxide correlates with IL-2, MCP-1, PDGF-BB and TIMP-2 in exhaled breath condensate of children with refractory asthma. *Advances in Dermatology and Allergology/Postępy Dermatologii i Alergologii* **2015***, 32*, 107–113.

184. Fahy, J.V. Type 2 inflammation in asthma—present in most, absent in many. *Nature Reviews Immunology* **2015***, 15*, 57–65.

185. Dunican, E.M.; Fahy, J.V. The role of type 2 inflammation in the pathogenesis of asthma exacerbations. *Annals of the American Thoracic Society* **2015***, 12*, S144–S149.

186. Busse, W.W.; Kraft, M.; Rabe, K.F.; Deniz, Y.; Rowe, P.J.; Ruddy, M.; Castro, M. Understanding the key issues in the treatment of uncontrolled persistent asthma with type 2 inflammation. *European Respiratory Journal* **2021***, 58*.

187. Kosoy, I.; Lew, E.; Ledanois, O.; Derrickson, W. Characterization of uncontrolled, severe asthma patients with type 2 inflammation (T2): results from a physician survey across countries from Latin American, Eurasian Middle East regions and China. *Journal of Asthma* **2022***, 59*, 1021–1029, DOI 10.1080/02770903.2021.1895208. Available online: https://doi.org/10.1080/02770903.2021.1895208.

188. CIRCASSIA Clinical Guidelines for The Interpretation of FeNO Levels. **2020**.

189. Centre of Excellence in Severe Asthma Inflammation Biomarkers In the assessment and management of severe asthma – tools and Interpretation. **2019**.

190. Chiappori, A.; De Ferrari, L.; Folli, C.; Mauri, P.; Riccio, A.M.; Canonica, G.W. Biomarkers and severe asthma: a critical appraisal. *Clinical and Molecular Allergy* **2015***, 13*, 20, DOI 10.1186/s12948-015-0027-7. Available online: https://doi.org/10.1186/s12948-015-0027-7.

191. DWEIK, R.A.; BOGGS, P.B.; ERZURUM, S.C.; IRVIN, C.G.; LEIGH, M.W.; LUNDBERG, J.O.; OLIN, A.; PLUMMER, A.L.; TAYLOR, D.R. An Official ATS Clinical Practice Guideline: Interpretation of Exhaled Nitric Oxide Levels (FeNO) for Clinical Applications. *American journal of respiratory and critical care medicine* **2011***, 184*, 602–615, DOI 10.1164/rccm.9120-11ST. Available online: https://www.ncbi.nlm.nih.gov/pubmed/21885636.

192. UNHCR Health access and utilization survey among Syrian refugees in Lebanon. **2022**.

193. Kakaje, A.; Alhalabi, M.M.; Alyousbashi, A.; Ghareeb, A.; Hamid, L.; Al-Tammemi, A.B. Smoking habits and the influence of war on cigarette and shisha smoking in Syria. *Plos one* **2021***, 16*, e0256829.

194. Oda, A.; Beukeboom, C.; Bridekirk, J.; Bayoumi, A.; Hynie, M. Examining trends of cigarette smoking amongst Syrian refugees during their first two years in Canada. *Journal of Immigrant and Minority Health* **2021***, 23*, 640–645.

195. Kheirallah, K.A.; Cobb, C.O.; Alsulaiman, J.W.; Alzoubi, A.; Hoetger, C.; Kliewer, W.; Mzayek, F. Trauma exposure, mental health and tobacco use among vulnerable Syrian refugee youth in Jordan. *Journal of public health (Oxford, England)* **2020***, 42*, e343–e351, DOI 10.1093/pubmed/fdz128. Available online: https://search.proquest.com/docview/2315973573.

196. Kutluk, T.; Koç, M.; Öner, İ; Babalıoğlu, İ; Kirazlı, M.; Aydın, S.; Ahmed, F.; Köksal, Y.; Tokgöz, H.; Duran, M. Cancer among syrian refugees living in Konya Province, Turkey. *Conflict and health* **2022***, 16*, 1–10.

197. Government of Lebanon and United Nations Lebanon Crisis Response Plan 2017–2020 (2018 Update). **2018**.

198. Li, Y.; Feng, L.; Chen, B.; Kim, H.; Yi, S.; Guo, Y.L.; Wu, C. Association of urban particle numbers and sources with lung function among children with asthma or allergies. *The Science of the total environment* **2016***, 542*, 841–844, DOI 10.1016/j.scitotenv.2015.10.098. Available online: http://www.ncbi.nlm.nih.gov/pubmed/26556748.

199. Lin, L.; Tsai, M.; Chen, M.; Ng, S.; Hsieh, C.; Lin, C.; Lu, F.L.; Hsieh, W.; Chen, P. Childhood exposure to phthalates and pulmonary function. *The Science of the total environment* **2018***, 615*, 1282–1289.

200. CIRCASSIA NIOX VERO Airway Inflammation Monitor. User Manual. *Mena Report* **2016**.

201. Alaouie, M.; Troisi, G.M.; Saliba, N.; Shaib, H.; Hajj, R.; El Hajj, R.; Malak, S.; Jakarian, C.; Jaafar, W. Fungal Exposure and Shelter Assessment in Syrian Refugee Settlements in Lebanon. *Aerobiology* **2023***, 1*, 19–36.

202. National Institute for Health and Care Excellence Asthma: diagnosis, monitoring and chronic asthma management. *Published: November 29,* **2017**, March.

203. Fouad, F.M.; McCall, S.J.; Ayoub, H.; Abu-Raddad, L.J.; Mumtaz, G.R. Vulnerability of Syrian refugees in Lebanon to COVID-19: quantitative insights. *Conflict and Health* **2021***, 15*, 1–6.

204. Banik, R.; Rahman, M.; Hossain, M.M.; Sikder, M.T.; Gozal, D. COVID-19 pandemic and Rohingya refugees in Bangladesh: what are the major concerns? *Global Public Health* **2020***, 15*, 1578–1581.

205. Barua, A.; Karia, R.H. Challenges faced by Rohingya refugees in the COVID-19 pandemic. *Annals of Global Health* **2020***, 86*.

206. Truelove, S.; Abrahim, O.; Altare, C.; Lauer, S.A.; Grantz, K.H.; Azman, A.S.; Spiegel, P. The potential impact of COVID-19 in refugee camps in Bangladesh and beyond: A modeling study. *PLoS medicine* **2020***, 17*, e1003144.

207. Gilman, R.T.; Mahroof-Shaffi, S.; Harkensee, C.; Chamberlain, A.T. Modelling interventions to control COVID-19 outbreaks in a refugee camp. *BMJ global health* **2020***, 5*, e003727.

208. Kluge, H.H.P.; Jakab, Z.; Bartovic, J.; d'Anna, V.; Severoni, S. Refugee and migrant health in the COVID-19 response. *The Lancet* **2020***, 395*, 1237–1239.

209. Bahnfleth, W. Epidemic Task Force Core Recommendations. *ASHRAE J* **2021***, 63*, 8–9.

210. William Bahnfleth PHD, P.E.; Degraw, J. Reducing Airborne Infectious Aerosol Exposure. *ASHRAE J* **2021***, 63*, 18–21.

211. Morawska, L. Droplet fate in indoor environments, or can we prevent the spread of infection? *Indoor air* **2006***, 16*, 335–347.

212. Memarzadeh, F.; Xu, W. Role of air changes per hour (ACH) in possible transmission of airborne infections. *Building Simulation* **2012***, 5*, 15–28.

213. Conlan, W.H. Building Readiness Plan for SARS-CoV-2. *ASHRAE J* **2020***, 62*, 72–74.

214. Burroughs, H.E.; Hansen, S.J. *Managing Indoor Air Quality,* Fairmont Press: 2004;.

215. UNHCR; UNICEF; Inter-Agency Coordination; WFP VASyR 2019. Vulnerability Assessment of Syrian Refugees in Lebanon. **2019**.

216. Inter-agency coordination Lebanon; UNHCR; WFP; UNICEF VASyR 2021 Vulnerability Assessment of Syrian Refugees in Lebanon. **2021**.

217. Inter-Agency Coordination; UNHCR; WFP; UNICEF VASyR 2020 Vulnerability Assessment of Syrian Refugees in Lebanon. **2020**.

218. Kikano, F.; Fayazi, M.; Lizarralde, G. Understanding Forms of Sheltering by (and for) Syrian Refugees in Lebanon, 7th i-Rec Conference 2015: Reconstruction and Recovery in Urban Contexts, , 2015International Information and Research for Reconstruction (i-Rec) Conference: 2015; .

219. Mudarri, D.H. Building codes and indoor air quality. *US EPA* **2010**.

220. The Inside Story: A Guide to Indoor Air Quality. Available online: https://www.epa.gov/indoor-air-quality-iaq/inside-story-guide-indoor-air-quality (Accessed on 30/4/ 2022).

221. ASHRAE ANSI/ASHRAE Standard 62.2-2016, Ventilation and Acceptable Indoor Air Quality in Residential Buildings. **2016**.

222. Liu, G.; Xiao, M.; Zhang, X.; Gal, C.; Chen, X.; Liu, L.; Pan, S.; Wu, J.; Tang, L.; Clements-Croome, D. A review of air filtration technologies for sustainable and healthy building ventilation. *Sustainable Cities and Society* **2017***, 32*, 375–396, DOI 10.1016/j.scs.2017.04.011. Available online: https://www.sciencedirect.com/science/article/pii/S221067071630734X.

223. McDonald, E.; Cook, D.; Newman, T.; Griffith, L.; Cox, G.; Guyatt, G. Effect of air filtration systems on asthma: a systematic review of randomized trials. *Chest* **2002***, 122*, 1535–1542.

224. Azimi, P.; Zhao, D.; Stephens, B. Estimates of HVAC filtration efficiency for fine and ultrafine particles of outdoor origin. *Atmospheric environment (1994)* **2014***, 98*, 337–346, DOI 10.1016/j.atmosenv.2014.09.007. Available online: https://dx.doi.org/10.1016/j.atmosenv.2014.09.007.

225. Zhao, D.; Azimi, P.; Stephens, B. Evaluating the long-term health and economic impacts of central residential air filtration for reducing premature mortality associated with indoor fine particulate matter (PM2. 5) of outdoor origin. *International journal of environmental research and public health* **2015***, 12*, 8448–8479.

226. British Standards Institute BS 8887-3:2018: Design for manufacture, assembly, disassembly and end-of-life processing (MADE). **2018**.

227. Smith, A.B. Environmental Activism in the Form of Residential Solar Panels and the Resulting Conflicts of the 21st Century Recent Development. *Envtl & Energy L & Pol'y J* **2008***, 3*, 330–334 Available online: https://heinonline.org/HOL/P?h=hein.journals/eener3&i=334

https://heinonline.org/HOL/PrintRequest?handle=hein.journals/eener3&collection=0&div=21&id=334&print=section&sction=21.

228. Hale, B.; Kramer, S.W. Installation of solar panels in a residential setting: A feasibility study for a Southern US City.

229. Andrei, H.; Dogaru-Ulieru, V.; Chicco, G.; Cepisca, C.; Spertino, F. Photovoltaic applications. *J Mater Process Technol* **2007***, 181*, 267–273, DOI https://doi.org/10.1016/j.jmatprotec.2006.03.043. Available online: https://www.sciencedirect.com/science/article/pii/S092401360600183X.

230. Lan, H.; Gou, Z.; Cheng, B. Regional difference of residential solar panel diffusion in Queensland, Australia. *null* **2020***, 15*, 13–25, DOI 10.1080/15567249.2020.1736214. Available online: https://doi.org/10.1080/15567249.2020.1736214.

231. Liu, X.; O'Rear, E.G.; Tyner, W.E.; Pekny, J.F. Purchasing vs. leasing: A benefit-cost analysis of residential solar PV panel use in California. *Renewable Energy* **2014***, 66*, 770–774, DOI https://doi.org/10.1016/j.renene.2014.01.026. Available online: https://www.sciencedirect.com/science/article/pii/S096014811400055X.

232. H. Matsuo; K. Kobayashi; Y. Sekine; M. Asano; Lin Wenzhong Novel solar cell power supply system using the multiple-input DC-DC converter, - INTELEC - Twentieth International Telecommunications Energy Conference (Cat. No.98CH36263), 1998; , pp. 797–802.

233. Dobrzański, L.A.; Szczęsna, M.; Szindler, M.; Drygała, A. Electrical properties mono-and polycrystalline silicon solar cells. *Solar Cells* **2013***, 59*, 67–74.

234. Stutenbaeumer, U.; Mesfin, B. Equivalent model of monocrystalline, polycrystalline and amorphous silicon solar cells. *Renewable Energy* **1999***, 18*, 501–512, DOI https://doi.org/10.1016/S0960-1481(98)00813-1. Available online: https://www.sciencedirect.com/science/article/pii/S0960148198008131.

235. Taşçıoğlu, A.; Taşkın, O.; Vardar, A. A Power Case Study for Monocrystalline and Polycrystalline Solar Panels in Bursa City, Turkey. *International Journal of Photoenergy* **2016***, 2016*, 1–7, DOI 10.1155/2016/7324138. Available online: https://www.airitilibrary.com/Publication/alDetailedMesh?DocID=P20170302001-201612-201703020023-201703020023-753-759.

236. Alaaeddin, M.H.; Sapuan, S.M.; Zuhri, M.Y.M.; Zainudin, E.S.; AL- Oqla, F.M. Photovoltaic applications: Status and manufacturing prospects. *Renewable and Sustainable Energy Reviews* **2019***, 102*, 318–332, DOI https://doi.org/10.1016/j.rser.2018.12.026. Available online: https://www.sciencedirect.com/science/article/pii/S1364032118308219.

237. Nogueira, C.E.C.; Bedin, J.; Niedzialkoski, R.K.; de Souza, S.N.M.; das Neves, J.C.M. Performance of monocrystalline and polycrystalline solar panels in a water

pumping system in Brazil. *Renewable and Sustainable Energy Reviews* **2015**, *51*, 1610–1616, DOI https://doi.org/10.1016/j.rser.2015.07.082. Available online: https://www.sciencedirect.com/science/article/pii/S1364032115007297.

238. A. Cellatoglu; K. Balasubramanian Renewable energy resources for residential applications in coastal areas: A modular approach, - 2010 42nd Southeastern Symposium on System Theory (SSST), 2010; , pp. 340–345.

239. Goebel, C.; Cheng, V.; Jacobsen, H. Profitability of Residential Battery Energy Storage Combined with Solar Photovoltaics. *Energies* **2017**, *10*, 976, DOI 10.3390/en10070976. Available online: https://search.proquest.com/docview/2316073789.

240. A. Trubitsyn; B. J. Pierquet; A. K. Hayman; G. E. Gamache; C. R. Sullivan; D. J. Perreault High-efficiency inverter for photovoltaic applications, - 2010 IEEE Energy Conversion Congress and Exposition, 2010; , pp. 2803–2810.

241. Yuvarajan, S.; Yu, D.; Xu, S. A novel power converter for photovoltaic applications. *J Power Sources* **2004**, *135*, 327–331.

242. G. C. Giaconia; G. Fiscelli; F. L. Bue; A. Di Stefano; D. La Cascia; R. Miceli Integration of distributed on site control actions via combined photovoltaic and solar panels system, - 2009 International Conference on Clean Electrical Power, 2009; , pp. 171–177.

243. Keskin Arabul, F.; Arabul, A.Y.; Kumru, C.F.; Boynuegri, A.R. Providing energy management of a fuel cell–battery–wind turbine–solar panel hybrid off grid smart home system. *Int J Hydrogen Energy* **2017**, *42*, 26906–26913, DOI https://doi.org/10.1016/j.ijhydene.2017.02.204. Available online: https://www.sciencedirect.com/science/article/pii/S0360319917308303.

244. Mandal, S.; Singh, D. Real time data acquisation of solar panel using arduino and further recording voltage of the solar panel. *International Journal of Instrumentation and Control Systems* **2017**, *7*, 15–25.

245. Garbesi, K. Catalog of DC appliances and power systems. **2012**.

246. E. Rodriguez-Diaz; M. Savaghebi; J. C. Vasquez; J. M. Guerrero An overview of low voltage DC distribution systems for residential applications, - 2015 IEEE 5th International Conference on Consumer Electronics - Berlin (ICCE-Berlin), 2015; , pp. 318–322.

247. Rauf, S.; Wahab, A.; Rizwan, M.; Rasool, S.; Khan, N. Application of Dc-grid for Efficient use of solar PV System in Smart Grid. *Procedia Computer Science* **2016**, *83*, 902–906, DOI https://doi.org/10.1016/j.procs.2016.04.182. Available online: https://www.sciencedirect.com/science/article/pii/S1877050916302150.

248. Mekhilef, S.; Saidur, R.; Safari, A. A review on solar energy use in industries. *Renewable and Sustainable Energy Reviews* **2011**, *15*, 1777–1790, DOI 10.1016/j.rser.2010.12.018. Available online: https://www-sciencedirect-com.libproxy.berkeley.edu/science/article/pii/S1364032110004533.

249. Rivers, C. Solar on the move: Providing power to mobile abodes. *ReNew: Technology for a Sustainable Future* **2014**, 50–55 Available online: https://www-jstor-org.libproxy.berkeley.edu/stable/renetechsustfutu.126.50.

250. Muszyńska-Jeleszyńska, D. The use of solar technology on vessels for development of water tourism and recreation - Bydgoszcz Water Tram case study. *AIP Conference Proceedings* **2018**, *2040*, 070011, DOI 10.1063/1.5079132. Available online: https://aip.scitation.org/doi/abs/10.1063/1.5079132.

251. Lundmark, S.T.; Alatalo, M.; Thiringer, T.; Grunditz, E.A.; Mellander, B.E. Vehicle components and configurations. *Systems Perspectives on Electromobility* **2013**, 22–32.

252. Srikrishna, D. Price-performance comparison of HEPA air purifiers and lower-cost MERV 13/14 filters with box fans for filtering out SARS-Cov-2 and other particulate aerosols in indoor community settings. *medRxiv* **2021**.

253. Srikrishna, D. Can 10× cheaper, lower-efficiency particulate air filters and box fans complement High-Efficiency Particulate Air (HEPA) purifiers to help control the COVID-19 pandemic? *Sci Total Environ* **2022**, 155884.

254. Dal Porto, R.; Kunz, M.N.; Pistochini, T.; Corsi, R.L.; Cappa, C.D. Characterizing the performance of a do-it-yourself (DIY) box fan air filter. *Aerosol Science and Technology* **2022**, *56*, 564–572.

255. A variation on the “box fan with merv 13 filter” air cleaner. Available online: https://www.texairfilters.com/a-variation-on-the-box-fan-with-merv-13-filter-air-cleaner/ (Accessed on April 13, 2022).

256. Zaatari, M.; Novoselac, A.; Siegel, J. The relationship between filter pressure drop, indoor air quality, and energy consumption in rooftop HVAC units. *Build Environ* **2014**, *73*, 151–161, DOI https://doi.org/10.1016/j.buildenv.2013.12.010. Available online: https://www.sciencedirect.com/science/article/pii/S0360132313003661.

257. Zhang, J.; Huntley, D.; Fox, A.; Gerhardt, B.; Vatine, A.; Cherne, J. Study of Viral Filtration Performance of Residential HVAC Filters. *ASHRAE journal* **2020**, *62*, 26–32 Available online: https://search.proquest.com/docview/2435559184.

258. Stephens, B.; Siegel, J.A. Ultrafine particle removal by residential heating, ventilating, and air-conditioning filters. *Indoor air* **2013**, *23*, 488–497, DOI 10.1111/ina.12045. Available online: https://api.istex.fr/ark:/67375/WNG-4B6L6B2V-L/fulltext.pdf.

259. Faulkner, C.A.; Castellini, J.E.; Zuo, W.; Lorenzetti, D.M.; Sohn, M.D. Investigation of HVAC operation strategies for office buildings during COVID-19 pandemic. *Building and environment* **2022**, *207*, 108519, DOI 10.1016/j.buildenv.2021.108519. Available online: https://dx.doi.org/10.1016/j.buildenv.2021.108519.

260. Bahnfleth, W. Epidemic Task Force Core Recommendations. *ASHRAE J* **2021**, *63*, 8–9.

261. McNamara, M.L.; Thornburg, J.; Semmens, E.O.; Ward, T.J.; Noonan, C.W. Reducing indoor air pollutants with air filtration units in wood stove homes. *Science of The Total Environment* **2017**, *592*, 488–494, DOI //doi.org/10.1016/j.scitotenv.2017.03.111. Available online: http://www.sciencedirect.com/science/article/pii/S004896971730623X.

262. ASHRAE ANSI/ASHRAE Standard 52.2-2017. Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size. **2017** Available online: https://global.ihs.com/doc_detail.cfm?gid&#61;IFZOBFAAAAAAAAAA&amp;input_doc_number&#61;ASHRAE 52.2 ADD C.

263. Ben-David, T.; Waring, M.S. Interplay of ventilation and filtration: Differential analysis of cost function combining energy use and indoor exposure to PM2.5 and ozone. *Build Environ* **2018**, *128*, 320–335, DOI https://doi.org/10.1016/j.buildenv.2017.10.025. Available online: https://www.sciencedirect.com/science/article/pii/S0360132317304833.

264. Hubbard, J.A.; Wiemann, D.K.; McKenzie, B.B. High Air-Flow Aerosol Filtration Testing. *Sandia National Laboratories* **2018**.

265. Marder, A.R. The metallurgy of zinc-coated steel. *Progress in Materials Science* **2000**, *45*, 191–271, DOI https://doi.org/10.1016/S0079-6425(98)00006-1. Available online: https://www.sciencedirect.com/science/article/pii/S0079642598000061.

266. Biddulph, C. Zinc electroplating. *Products Finishing* **2012**, *1*, 106.

267. Rodriguez, J.; Chocron, I.S.; Martinez, M.A.; Sanchez-Galvez, V. High strain rate properties of aramid and polyethylene woven fabric composites. *Composites Part B: Engineering* **1996**, *27*, 147–154.

268. Omodara, M.A.; Montross, M.D.; McNeill, S.G. Water vapor permeability of bag materials used during bagged corn storage. *Agricultural Engineering International: CIGR Journal* **2021**, *23*.

269. Papiernik, S.K.; Yates, S.R. Effect of Environmental Conditions on the Permeability of High Density Polyethylene Film To Fumigant Vapors. *Environmental science & technology* **2002**, *36*, 1833–1838, DOI 10.1021/es011252i. Available online: http://dx.doi.org/10.1021/es011252i.

270. Heding, N.; Jeilsø, K. *Improved tarpaulin materials for rain protection of small chip piles,* Frederiksberg, 1988;.

271. How Much Does A New HVAC System Cost? Available online: https://www.forbes.com/home-improvement/hvac/new-hvac-system-cost/ (Accessed on 24/02/ 2023).

272. CERTIFIED ROOM AIR CLEANERS - AHAM Verified. Available online: https://www.ahamdir.com/room-air-cleaners/ (Accessed on 24/02/ 2023).

273. Solar Radiation Data. Available online: https://solcast.com/data-for-researchers (Accessed on 30 March 2023).

274. Mendell, M.J.; Apte, M.G. Balancing energy conservation and occupant needs in ventilation rate standards for Big Box stores and other commercial buildings in California. Issues related to the ASHRAE 62.1 Indoor Air Quality Procedure. **2010**, DOI 10.2172/1213550. Available online: https://www.osti.gov/servlets/purl/1213550.

275. SeppĘnen, O. Ventilation Strategies for Good Indoor Air Quality and Energy Efficiency. *International Journal of Ventilation* **2008***, 6*, 297–306, DOI 10.1080/14733315.2008.11683785. Available online: https://www.tandfonline.com/doi/abs/10.1080/14733315.2008.11683785.

276. Persily, A.K.; Emmerich, S.J. Indoor air quality in sustainable, energy efficient buildings. *HVAC&R Research* **2012***, 18*, 4–20, DOI 10.1080/10789669.2011.592106. Available online: https://doi.org/10.1080/10789669.2011.592106.

277. ASHRAE Epidemic Task Force Building Readiness. *ASHRAE* **2022**.

278. Improving Indoor Air Quality. Available online: https://www.epa.gov/indoor-air-quality-iaq/improving-indoor-air-quality (Accessed on 26 November 2023).

279. Association of Home Appliance Manufacturers AHAM AC-1-2020: Method for measuring performance of portable household electric room air cleaners. **2020**.

280. Sliwinska-Kowalska, M.; Davis, A. Noise-induced hearing loss. *Noise and Health* **2012***, 14*, 274.

281. Hong, O.; Kerr, M.J.; Poling, G.L.; Dhar, S. Understanding and preventing noise-induced hearing loss. *Disease-a-month* **2013***, 59*, 110–118.

282. Ding, T.; Yan, A.; Liu, K. What is noise-induced hearing loss? *Br J Hosp Med* **2019***, 80*, 525–529.

283. Hammer Monica, S.; Swinburn Tracy, K.; Neitzel Richard, L. Environmental Noise Pollution in the United States: Developing an Effective Public Health Response.

*Environ Health Perspect* **2014***, 122*, 115–119, DOI 10.1289/ehp.1307272. Available online: https://doi.org/10.1289/ehp.1307272.

284. Centers for Disease Control and Prevention Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care facilities, 1994. *MMWr* **1994***, 43*, 1–132.

285. Solar Radiation Data. Available online: https://solcast.com/data-for-researchers (Accessed on 22 October 2023).

286. Jawahir, I.S.; Wanigarathne, P.C.; Wang, X. Chapter 12. Product design and manufacturing processes for sustainability. In *Mechanical Engineers' Handbook. Manufacturing and Management*; Kutz, M., Ed.; JOHN WILEY & SONS, INC.: 2006; pp. 414–443.

287. Zhang, X.; Lu, T.; Shuaib, M.; Rotella, G.; Huang, A.; Feng, S.C.; Rouch, K.; Badurdeen, F.; Jawahir, I.S. A metrics-based methodology for establishing product sustainability index (ProdSI) for manufactured products, Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, University of California at Berkeley, Berkeley, USA, May 23-25, 2012, Springer: 2012; , pp. 435–441.

288. Shin, J.; Park, J.; Park, N. A method to recycle silicon wafer from end-of-life photovoltaic module and solar panels by using recycled silicon wafers. *Solar Energy Mater Solar Cells* **2017***, 162*, 1–6, DOI 10.1016/j.solmat.2016.12.038. Available online: https://www.sciencedirect.com/science/article/pii/S0927024816305591.

289. Chowdhury, M.S.; Rahman, K.S.; Chowdhury, T.; Nuthammachot, N.; Techato, K.; Akhtaruzzaman, M.; Tiong, S.K.; Sopian, K.; Amin, N. An overview of solar photovoltaic panels' end-of-life material recycling. *Energy Strategy Reviews* **2020***, 27*, 100431.

290. Takagi, T.; Iwata, S.; Iseki, Y. Material Recycling Technologies for Closed-Loop Recycle System of Cross Flow Fan, 2005 4th International Symposium on Environmentally Conscious Design and Inverse Manufacturing, IEEE: 2005; , pp. 308–309.

291. Çelik, C.; Arslan, C.; Arslan, F. Recycling of waste electrical cables. *Material Science & Engineering International Journal* **2019***, 3*, 107–111.

292. Dudek, F.J.; Daniels, E.J.; Nagy, Z.; Zaromb, S.; Yonco, R.M. Electrolytic Separation and Recovery in Caustic of Steel and Zinc from Galvanized Steel Scrap. *Sep Sci Technol* **1990***, 25*, 2109–2131.

293. Seki, S.; Osakada, F.; Yoshioka, T. Developments in an industry-led R&D program for recycling PVC products in Japan. *Journal of Material Cycles and Waste Management* **2014***, 16*, 385–397.

294. Wang, Y.; Wang, H.; Tan, Y.; Liu, J.; Wang, K.; Ji, W.; Sun, L.; Yu, X.; Zhao, J.; Xu, B. Measurement of the key parameters of VOC emissions from wooden furniture, and the impact of temperature. *Atmos Environ* **2021***, 259*, 118510.

295. Zhou, C.; Zhan, Y.; Chen, S.; Xia, M.; Ronda, C.; Sun, M.; Chen, H.; Shen, X. Combined effects of temperature and humidity on indoor VOCs pollution: Intercity comparison. *Build Environ* **2017***, 121*, 26–34.

296. Norbäck, D. Subjective indoor air quality in schools–the influence of high room temperature, carpeting, fleecy wall materials and volatile organic compounds (VOC). *Indoor Air* **1995***, 5*, 237–246.

297. Figures at a glance. Available online: https://www.unhcr.org/us/about-unhcr/who-we-are/figures-glance (Accessed on February 2, 2024).

298. Jaakkola, Maritta S., MD, PhD; Quansah, R., PhD; Hugg, T.T., PhD; Heikkinen, S.A.M., BSc; Jaakkola, Jouni J.K., MD, PhD Association of indoor dampness and molds with rhinitis risk: A systematic review and meta-analysis. *Journal of allergy and clinical immunology* **2013***, 132*, 1099–1110.e18.

299. Institute of Medicine (U.S.) Committee on Damp Indoor Spaces and Health *Damp indoor spaces and health,* 2004;.

300. Zhang, X.; Sahlberg, B.; Wieslander, G.; Janson, C.; Gislason, T.; Norback, D. Dampness and moulds in workplace buildings: Associations with incidence and remission of sick building syndrome (SBS) and biomarkers of inflammation in a 10year follow-up study. *Science of the Total Environment* **2012***, 430*, 75–81, DOI 10.1016/j.scitotenv.2012.04.040.

301. Gupton Jr, W. *HVAC controls: Operation and maintenance,* CRC Press: 2001;.

302. Martin, M.A.; Durfee, D.J.; Hughes, P.J. Comparing maintenance costs of geothermal heat pump systems with other HVAC systems in Lincoln Public Schools: Repair, service, and corrective actions, Oak Ridge National Lab.(ORNL): Oak Ridge, TN (United States), Jun 19, 1999; .

303. Wang, L. Modeling and Simulation of HVAC Faulty Operations and Performance Degradation due to Maintenance Issues. **2013** Available online: https://explore.openaire.eu/search/result?id=od325::c86b4b1a1441dd5f62fa1a0cf1a74fc0.

# Appendix

## Thesis Publications

aerobiology

Article

# Fungal Exposure and Shelter Assessment in Syrian Refugee Settlements in Lebanon

Malek Alaouie, Gera M. Troisi, Najat Saliba, Houssam Shaib, Rayan Hajj, Rawan El Hajj,
Sandy Malak, Carla Jakarian and Wiaam Jaafar

MDPI

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Article

# Fungal Exposure and Shelter Assessment in Syrian Refugee Settlements in Lebanon

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**Abstract:** Over 1 million Syrian refugees have fled war to seek asylum in Lebanon. The population has been placed in substandard conditions which could lead to adverse health effects, particularly in vulnerable subgroups, notably due to evident chronic dampness and inadequate ventilation potentially leading to indoor mold growth. To investigate whether the types and conditions of Syrian refugee shelters influence indoor mold populations, a cross-sectional indoor environmental study was performed in 4 provinces of Lebanon. Accordingly, a total of 80 refugee households and 20 host population households (baseline) were selected. Mold air sampling and moisture measurements of shelter material were performed in residential, non-residential, and non-permanent shelters. Results revealed that although non-residential shelters had the highest mean total indoor count (1112 CFU/m$^3$), *Aspergillus*, *Stachybotrys*, and *Penicillium* spp. were strongly associated with non-permanent shelters ($p < 0.001$). Additionally, occupancy was found to be strongly associated with *Cladosporium* ($p < 0.05$), *Ulocladium* ($p < 0.05$), and *Stachybotrys* spp. ($p < 0.001$). As for shelter conditions, the highest total indoor count (1243 CFU/m$^3$) was reported in unfinished structures. These findings suggest that shelter category, condition and occupancy significantly influence indoor mold concentrations, increasing respiratory health risks for Syrian refugees in Lebanon.

**Keywords:** refugee; conflict; shelter; mold; dampness; occupancy; environmental exposure; indoor air quality

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## 1. Introduction

The Syrian war has relocated over 10 million Syrian refugees of which 7.5 million are displaced internally. By 2016, the number of Syrian refugees registered with the United Nations High Commissioner for Refugees (UNHCR) in Lebanon, exceeded 1 million (equivalent to 25% of the local population), making it the third largest refugee population globally. Nevertheless, in 2017, Lebanon became the second largest Syrian refugee-hosting country after Turkey and maintained this position through 2022 [1–3].

As of June 2018, the distribution of Syrian refugees across the 4 major provinces in Lebanon, was 36% in Bekaa, 26.2% in Beirut, 25.8% in Northern Lebanon, and 12.1% in Southern Lebanon. About 47.5% of refugees are males and 52.5% are females with children under the age of 17 accounting for 55.5% of the population. The 222,695 refugee households reside in urban, suburban and rural areas [1,3,4]. While 70% of refugees live in apartments and rented rooms, 16% of households live in temporary structures known as informal tented settlements (IS), 5% reside in unfinished buildings and 9% as annexed structures to existing houses. Moreover, 44% of refugee households have 5 or more people sharing one bedroom [5]. A similar crowding occurs in neighboring countries accommodating Syrian refugees. Within the Za'atari camp in Jordan, for example, the needs of refugees have already surpassed the camp's capacity, leading to sanitation problems and limited access to medical care [6].

Lebanon is adjacent to conflict zones and subject to regular domestic political and social unrest, resulting in issues with the dissemination of aid to refugees and a lack of economic investment to improve shelters and stakeholder conditions. Syrian refugees in Lebanon accordingly lack essential services relating to access to drinking water and sanitation, due partially to budget constraints of non-governmental humanitarian organizations and restrictions on the establishment of larger refugee camps imposed by the Lebanese government which put the refugee population at risk whereby the vulnerable subpopulation such as children, women, the elderly and immunocompromised individuals are at an even higher risk of developing respiratory and other diseases [7,8].

Building codes are developed to promote occupants' health by setting construction quality and structural integrity standards [9]. Structurally unsound units and poorly designed low-cost housing can lead to susceptibility to environmental, sanitary, and severe weather conditions [10–12]. Building products are a source of hazardous emissions and structural defects can promote pollutants pathway within dwellings [13,14]. Previous studies related to housing conditions and health in Middle East refugee camps have shown strong associations between poor housing quality and respiratory illnesses, such as asthma prevalence in children and women's health. Before the Syrian war, humanitarian research focused on internally displaced and asylum-seeking Palestinian refugees. For example, the ISAAC study in 2000, revealed that schoolchildren from refugee camps were at significantly greater risk of asthma than those from neighbouring villages and cities in Palestine [15]. In 2001, a study of 1625 households in the Gaza Strip found that the quality of environmental health and hygiene significantly influenced the occurrence of parasitic infections and dysentery particularly among children aged 1–4 [16]. A study at another Palestinian refugee camp, revealed a strong association between women's health and unhealthy housing conditions from overcrowding, inadequate ventilation and poor hygiene [17]. The clinical association between microbiological exposure and incidence of allergies, asthma, respiratory and immunological conditions in refugee camps is well recognized [18–20], but it should be borne in mind that refugees are exposed to mixtures containing volatile chemicals (including pesticides and cleaning chemicals), suspended particulates as well as airborne immunogens and pathogens, which together exacerbate health impacts. Naturally, it is very difficult to attribute causality to the exposure of a single entity and disease, and there is a paucity of research due to limited resources and local politics [21].

Natural ventilation, which is the main method adopted in refugee settlements, uses pressure differences between the indoor and outdoor air to create air exchange without mechanical intervention, thus reducing energy cost. Mechanical ventilation on the other hand, requires electrical consumption to adjust temperature and control humidity [22,23]. Both methods have their drawbacks, nevertheless. Natural ventilation in urban settings, for instance, introduces harmful pollutants from the untreated outdoor air and does not contribute to dilution of indoor contaminants concentration which according to the US EPA may be 2 to 5 times and in some cases 100 times more concentrated than outdoor air [22,24,25]. Furthermore, HVAC systems are potential sources of pollutants contributing to microbial growth resulting in condensation from heat exchange [26]. However, ventilation is not the only contributing factor to indoor air quality, building material can also be a potential source of toxicity and a medium for microbial and fungal growth [13,14,26–28].

Mold are eukaryotic microorganisms which grow filaments called hyphae [29]. They pertain to the kingdom Fungi and fall into 3 main common groups which are Zygomycetes, Basidiomycetes, and Ascomycetes, the group which contains the main fungi that colonize building materials [30]. Fungal mould growth is a major concern for architects and structural engineers which is a housing epidemic that leads to undesirable changes in the structural characteristics of buildings [31]. Fungi are ubiquitous in nature, they can be parasitic or symbiotic, however, most fungi are saprophytic, absorbing nutrients from decaying material. In indoor environments, materials such as wood, paper, paint, insulation, and dust are suitable for fungal growth. [32] These bio-receptive materials allow the growth of fungi such as *Alternaria*, *Stachybotrys*, *Cladosporium*, *Penicillium*, and *Aspergillus* spp. [33,34]. Mould growth also depends on certain environmental conditions such as temperature and relative humidity (RH%). Mould usually favor temperatures between 15 and 30 °C, however, some species grow below or above this range [32]. As for relative humidity (RH%), a range between 30% and 50% should be maintained for a healthy indoor air (ASHRAE standard 62.1 recommends 30 and 65% RH [35]) as fungal growth and dust mite infestations occur above 50% RH [36]. Although fungal spores can travel passively through environments, indoor fungal presence is mainly attributed to moisture, and growth can occur on material with water activity varying between $< 0.8$ and $> 0.98$ [37].

In 2004, the Damp Indoor Spaces and Health Committee of the Institute of Medicine (IOM) reviewed and summarized the scientific evidence for relationships between indoor air exposure and the development and exacerbations of asthma. It concluded among several studies sufficient evidence of an association between damp indoor exposure and certain respiratory health outcomes, but insufficient evidence of an association between the presence of mold and the onset of asthma [38–40]. Conversely, the World Health Organization (WHO) concluded the level of evidence was sufficient to suggest causality for asthma development and “almost” sufficient for the exacerbation of asthma irrespective of age group [21]. Although several studies have focused on refugee health in relation to the built environment [41–48], none have investigated the evidence for correlations between categories and conditions of settlements, and the type and prevalence of airborne mold knowing that vulnerable and immunosuppressed individuals (children, the elderly, HIV patients, pregnant women, and patients on immunosuppressive medication) account for more than 60% of the Syrian refugee population which put them “at risk” from health effects from exposure to elevated levels of pathogenic fungi [49–53]. Such information is vital to refugee management for planning locations and types of settlements according to season, resources, refugee demographics (composition and proportion of vulnerable groups) and refugee health status. The aim of this study is thus to investigate correlations between mold concentrations and the categories, structural conditions, occupancy and moisture content of Syrian refugee shelters to evaluate the influence of each of these factors on total indoor mold counts and abundance of specific mold genera.

## 2. Materials and Methods

### 2.1. Population Data

An original sample size representing the total number of registered refugee households by UNHCR was calculated to be 97 and rounded to 100 households with a 95% confidence interval and a 10% error margin. Access to refugee households was limited by geographical, logistical, and communication challenges. Consent for accessing the shelters was obtained on the same day of sampling by each head of household. The sample size was accordingly reduced to 80 refugee households due to these limitations. While random selection was the method of recruitment, only Syrian refugee households residing in the identified settlements were selected since other nationalities were also present, however, did not share the current humanitarian and socio-political profile of refugees governed by forced displacement and constricted temporary residency. Furthermore, an effort was made to obtain a close representation of shelter classifications under residential, non-residential, and non-permanent shelters (Table 1). Settlements were selected from four Lebanese governorates using the beneficiaries’ database of Save the Children in Lebanon. Households were anonymized and referenced as per Save the Children’s internal Memoranda of Understanding established with the beneficiaries.

**Table 1.** Distribution of Sampled Refugee Households ($n = 80$).

| Governorate | Area | No. Households | Residential | Non-Residential | Non-Permanent |
|---|---|---|---|---|---|
| Beirut | Bourj Hammoud | 20 | 20 | | |
| Bekaa | Bar Elias | 20 | 2 | | 18 |
| South | Abra | 20 | 7 | 13 | |
| North | Biret Akkar | 20 | | 20 | |

The selected sample included non-residential (41.25%), non-permanent (22.5%), and residential (36.25%) households. Non-residential households included classrooms, garages, and storerooms; residential households included rented apartments and rooms in multi-family buildings, while non-permanent households were informal tented settlements, composed of detached structures made from timber, plywood ceilings and walls, draped with cloth and plastic sheets (Figure 1). The floor area of these structures was approximately 45 m$^2$ for single-family households and 100 m$^2$ for multi-family households. The average occupancy per household in all refugee shelters was 6 persons and children accounted for more than 50% of the selected population. As for the control group, 20 residential standard apartments were selected from the host population, representing indoor baseline conditions, whereby 10 apartments were located in Beirut and 10 in Mount Lebanon. Accordingly, the total sample size was 100 households with a 4:1 refugee to baseline control ratio. The cross-sectional study covering sampling and moisture assessment was performed in the spring season (May 2019).

**Figure 1.** (**Left**) Aerial views of the Bourj Hammoud neighborhood in Beirut. (**Right**) and informal tented settlements in the Bekaa Bar Elias region.

The selected households were naturally ventilated through windows in residential and non-residential shelters, while non-permanent shelters (informal settlements) relied on natural air infiltration through structural gaps and guided exhaust from small wall-mounted fans. Shelters were further categorized based on structures such as concrete or wood, and on conditions such as "Standard", "Damaged", "Unfinished", or "Visible Mold" (Table 2). Standard shelters are mainly residential apartments with intact structural integrity. Damaged shelters, on the other hand, are any type of shelter that has cracks in walls and/or ceilings, and/or a leaking roof. Unfinished shelters were rooms lacking insulation, floor tiles and/or paint primer. The presence of visible mold patches was considered evidence of fungal growth on building surfaces.

**Table 2.** Shelter Condition.

| Shelter Category | Standard | Damaged | Unfinished | Visible Mold |
|---|---|---|---|---|
| Residential<br>$n = 29$ | 5 | 1 | 4 | 19 |
| Non-residential<br>$n = 33$ | | 13 | 20 | |
| Non-permanent<br>$n = 18$ | | | | 18 |

### 2.2. Mold Air Sampling and Enumeration

A walkthrough inspection was performed in every household prior to sampling [54]. Photographs of building structural integrity and conditions were taken, including visible mold growth. Most shelters consisted of a single room and adjacent connected cooking area and a shared toilet with low or absent interior walls. Images of visible mold growth typically seen on residential and informal settlement walls and ceilings are shown in Figures 2 and 3.

**Figure 2.** Examples of evident sporadic (**left**) and concentrated (**right**) mold growth on residential shelters ceilings.

**Figure 3.** Example of mold growth on the ceiling (**left**) and wall (**right**) wood panels inside informal settlements.

An Andersen N6 single-stage impactor, consisting of 400 precision holes of 0.65 µm cut-off diameter was placed on a tripod in the middle of the selected room at 1.5 m above the ground [55]. The impactor was connected to a Zefon® pump adjusted to 28.3 Liter per minute (L/min) with 9 mm Sabouraud dextrose agar media plates placed inside the impactor to collect samples. A total of 2 samples were taken for 5 min and another 2 for 2.5 min according to ISO standard methods (ISO 16000-17) [56,57]. An ambient outdoor and a blank sample were collected to establish the ambient baseline concentrations for each monitoring exercise. Control (field blank) samples were processed alongside samples and treated in an identical manner for quality control [56]. Samples were incubated at 25 °C on the day of collection and observed for colony growth at 24, 48, 72 and 96 h. Enumeration was performed before the overgrowth of colonies. Positive hole correction to calculate a probable count from the total raw count (assuming multiple particles can impact the same hole) was applied to total counts before conversion to colony-forming units per cubic meter ($\mathrm{CFU/m^3}$) [56,57]. Positive hole correction was calculated using the following formula:

$$\mathrm{Pr} = \mathrm{N}\,[1/\mathrm{N} + 1/\mathrm{N} - 1 + 1/\mathrm{N} - 2 + \ldots 1/\mathrm{N} - \mathrm{r} + 1]$$

where;

Pr is the expected number of viable particles to produce 'r' positive holes.

N is the total number of holes which is 400 in the case of the Andersen N6 single-stage impactor.

Sampled volumes at 5 and 2.5 min were 141.5 L and 70.75 L, respectively. The concentration of colony-forming units per cubic meter of air $C_I$ was calculated for each sample according to the following formula [57]:

$$C_I = \frac{n_{\mathrm{CFU}}}{V_I}$$

where;

$n_{CFU}$ is the total number of colony-forming units on the agar plates.

$V_I$ is the total sampling volume, in cubic metres.

To calculate the total concentration of molds in each location, the 4 sampled volumes (2 × 141.5 L and 2 × 70.75 L) were added, as per the following formula:

$$C_I = \frac{n1_{\mathrm{CFU}} + n2_{\mathrm{CFU}} + n3_{\mathrm{CFU}} + n4_{\mathrm{CFU}}}{V_{I1} + V_{I2} + V_{I3} + V_{I4}}$$

The indoor/outdoor ratio (i/o) was calculated by dividing the total indoor count by the total outdoor count after positive hole correction adjustment.

### 2.3. Identification of Mold/Fungi

For the identification of indoor mold genera, a sample from distinctive colonies on the Sabouraud dextrose agar was taken by means of an inoculating loop and placed on alcohol covering the center of the microscopic slide. A total of 3 drops of lactophenol cotton blue were used to stain the fungal culture and a cover slip was placed over the sample. Slides were gently heated before microscopic examination at 100, 40 and 20× magnification to identify mold genera. Microscopic structures were identified using the Atlas of Clinically Important Fungi and the Pictorial Atlas of Soil and Seed Fungi [58–60]. Enumeration of specific mold type was reported as $\mathrm{CFU/m^3}$, for the purpose of establishing possible correlations between mold genera, and type and conditions of shelters.

### 2.4. Moisture Content

The moisture content of shelter material was determined using a Tramex® non-destructive moisture meter using a scale of 5–30% moisture for wood structures and 0–100% scale for concrete structures. For concrete structures, an average of three readings was taken for study locations around windows, on shelter floors and walls adjacent to frequently damp environments (e.g., bathrooms and kitchens). For informal settlements, moisture was measured on wood structures (e.g., beams and ceiling panels). Readings were collected once the device was firmly placed against the structure and moved around until the highest reading was recorded [61].

### *2.5. Data Analysis*

Descriptive statistics were used to determine the percentages of each mold present within a household. Analysis of variance (ANOVA) was used to determine the statistical significance of any differences between mean mold concentration, indoor/outdoor (I/O) mold ratio and total indoor count (TIC), among different types of shelters. ANOVA was also used to determine the statistical significance of any difference between the above-mentioned variables among different observed shelter conditions.

Barlett's test for equality of variances was used to account for unequal sample sizes.

Pearson correlation was used to determine associations between moisture content in concrete for residential and non-residential shelters, and wood for non-permanent shelters and the following parameters:

- Concentration of different mold types
- I/O ratio
- Total indoor count
- Occupancy

The adjusted *p*-value for all parts was determined using a regression test. The significant model with high $R^2$ and adjusted $R^2$ was considered the final one.

To account for outliers in the selected sample, non-parametric analysis using the Kruskal–Wallis test was conducted to determine the correlation between TIC and type of shelter.

Similarly, robust regression was used to determine the correlation between TIC and occupancy.

## 3. Results and Discussion

### *3.1. Mold Concentration*

*Aspergillus*, *Cladosporium*, *Penicillium*, and *Rhizopus* spp. were the most prominent genera in the 3 shelter categories and baseline households (Figure 4). The results revealed that non-permanent shelters had the highest concentrations of *Stachybotrys* (8.6 CFU/$m^3$), *Aspergillus* (64 CFU/$m^3$), *Penicillium* (223.4 CFU/$m^3$), *Pithomyces* (7.5 CFU/$m^3$) and *Ulocladium* (3.9 CFU/$m^3$) spp., indicating that the shelter structure influenced the abundance of these genera. Furthermore, *Cladosporium* and *Alternaria* spp. ($p < 0.01$) were more abundant in non-residential compared to non-permanent and residential shelters, and significantly higher than baseline households. A final regression model ($R^2$ = 56.32%) established between types of shelter and the most abundant mold genera revealed a significant association ($p < 0.001$) with *Aspergillus*, *Penicillium*, and *Stachybotrys* spp., which may be considered as predictors of informal architecture and design.

*Rhizopus* spp. was higher in non-residential shelters compared to other categories, followed by controls, however, no significant association was found. The presence of *Rhizopus* in control households may indicate that seasonal and psychometric factors influence airborne concentrations, more than building material [62,63]. Additionally, despite the low concentrations of *Candida* spp. in all types of shelters, controls were found to have the highest counts and no significant association with refugee shelters. As seen with *Rhizopus* spp., *Candida* spp. abundance was attributed to factors unrelated to building structure, such as indoor emissions and/or human activity [58].

Health effects attributed to mold exposure include fungal infections, allergic rhinitis, asthma, hypersensitivity pneumonitis, interstitial lung disease, bronchopulmonary aspergillosis, allergic fungal sinusitis, and organic dust toxic syndrome. The illnesses and symptoms caused by such exposure range from flu-like syndromes and congestion to interstitial or cavitary pneumonia and fibrosis [32,64–66]. Furthermore, some of the identified genera, particularly Aspergillus and *Penicillium* spp., produce secondary mycotoxins such as aflatoxins and ochratoxins which can cause adverse health effects in exposed humans [67–69]. Table 3 summarizes major symptoms and diseases associated with mold exposure, adopted from Storey et al. (2004) Guidance for Clinicians [32]:

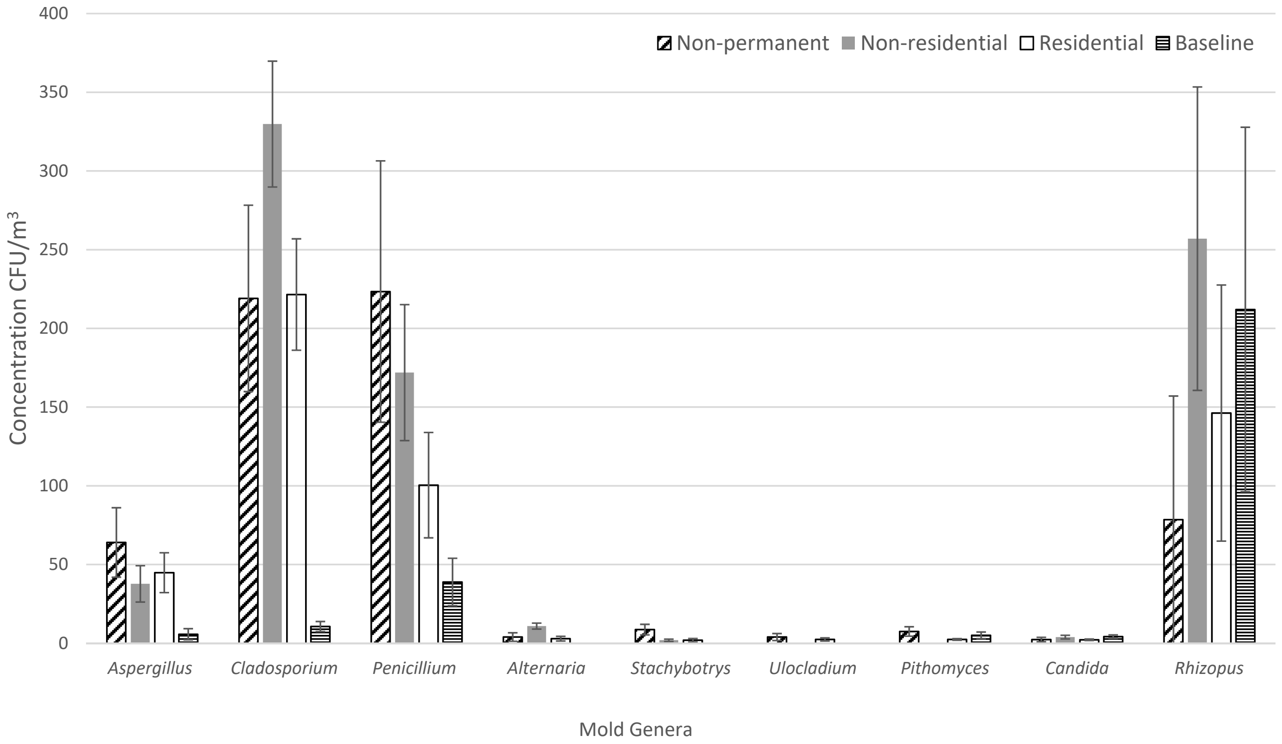


**Figure 4.** Indoor mold by type of shelter, mean concentrations (±std. error). Non-permanent (*n* = 18); non-residential (*n* = 33); residential (*n* = 29); baseline households (*n* = 20).

**Table 3.** Clinical Outcomes of Mold Exposure.

| **Health Effects** | **Illness/Symptoms** |
|---|---|
| Fungal Infections | Flu-like syndrome, interstitial or cavitary pneumonia, meningoencephalitis, tinea cruris, corporis, and pedis. |
| Allergic Rhinitis and Asthma | Upper airway: clear rhinorrhea, nasal congestion, sneezing, post-nasal drip with sore throat, coughing, and hoarseness.<br>Lower airway: bronchospasm, chest tightness, and shortness of breath. |
| Hypersensitivity Pneumonitis and Interstitial Lung Disease | Extrinsic allergic alveolitis, farmer's lung, Japanese summer-house, cryptogenic fibrosing alveolitis, idiopathic pulmonary fibrosis. |
| Bronchopulmonary Aspergillosis | Eosinophilic pneumonia, mucous plugs, or asthma exacerbations. |
| Allergic Fungal Sinusitis | Polyposis |
| Allergic Dermatitis | Dryness, pruritus, and skin rashes. |
| Irritation | Cough, skin irritation, and burning or itching of the eyes and nose. |
| Organic Dust Toxic Syndrome | Flu-like syndrome with prominent respiratory symptoms and fever. |

Simoni et al. (2005) reported a strong correlation between early childhood mold exposure and the onset of respiratory disorders and asthma, more evident in children than adolescents [70]. Furthermore, the Leipzig Allergy Risk Children Study (LARS) suggested a significant association between respiratory tract infection and exposure to *Penicillium* spores > 100 CFU/$m^3$, and between allergic rhinitis and exposure to *Aspergillus* > 100 CFU/$m^3$ in 200 children aged 36 months [71].

The majority (67%) of identified mold genera are commonly found in air samples of moisture-damaged dwellings and in bulk samples of water-damaged building material [72,73]. Damaged structures had the highest concentrations of *Aspergillus* and *Alternaria* spp. ($p < 0.05$) compared to standard, unfinished and visibly mold-infested shelters. *Cladosporium* spp. was highest and equally abundant in damaged and unfinished shelters and lowest in standard shelters ($p < 0.001$). Compared to standard, damaged and visible mold-infested shelters, unfinished shelters had the highest concentrations of *Penicillium* and *Rhizopus* spp., however, this was not statistically significant (Figure 5).

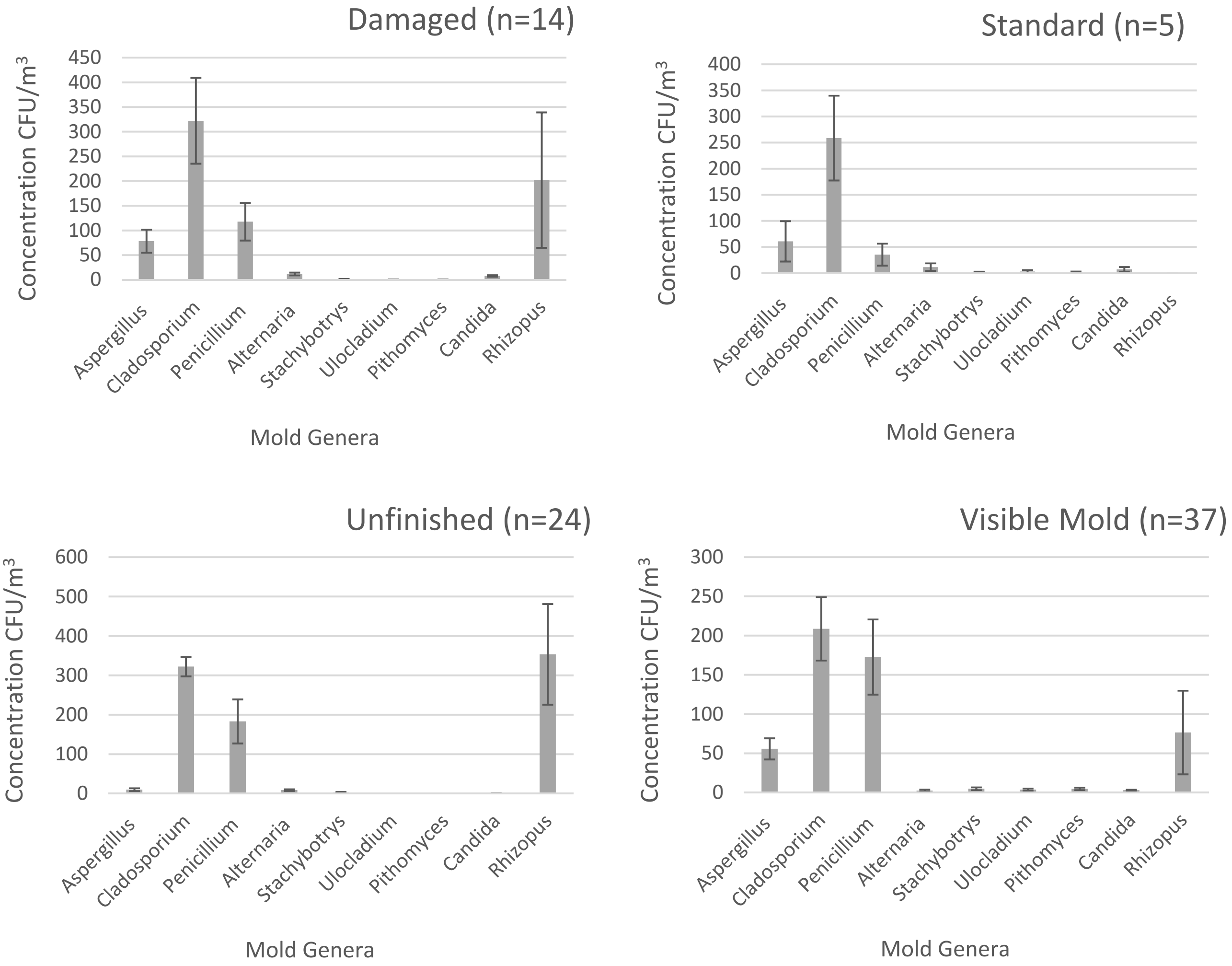


**Figure 5.** Indoor Mold Abundance by Shelter Condition (mean ± std. error).

Among the 9 identified fungal genera, only *Cladosporium* ($p < 0.05$), *Stachybotrys* ($p < 0.001$), and *Ulocladium* ($p < 0.05$) spp. were significantly associated with occupancy (Table 4).

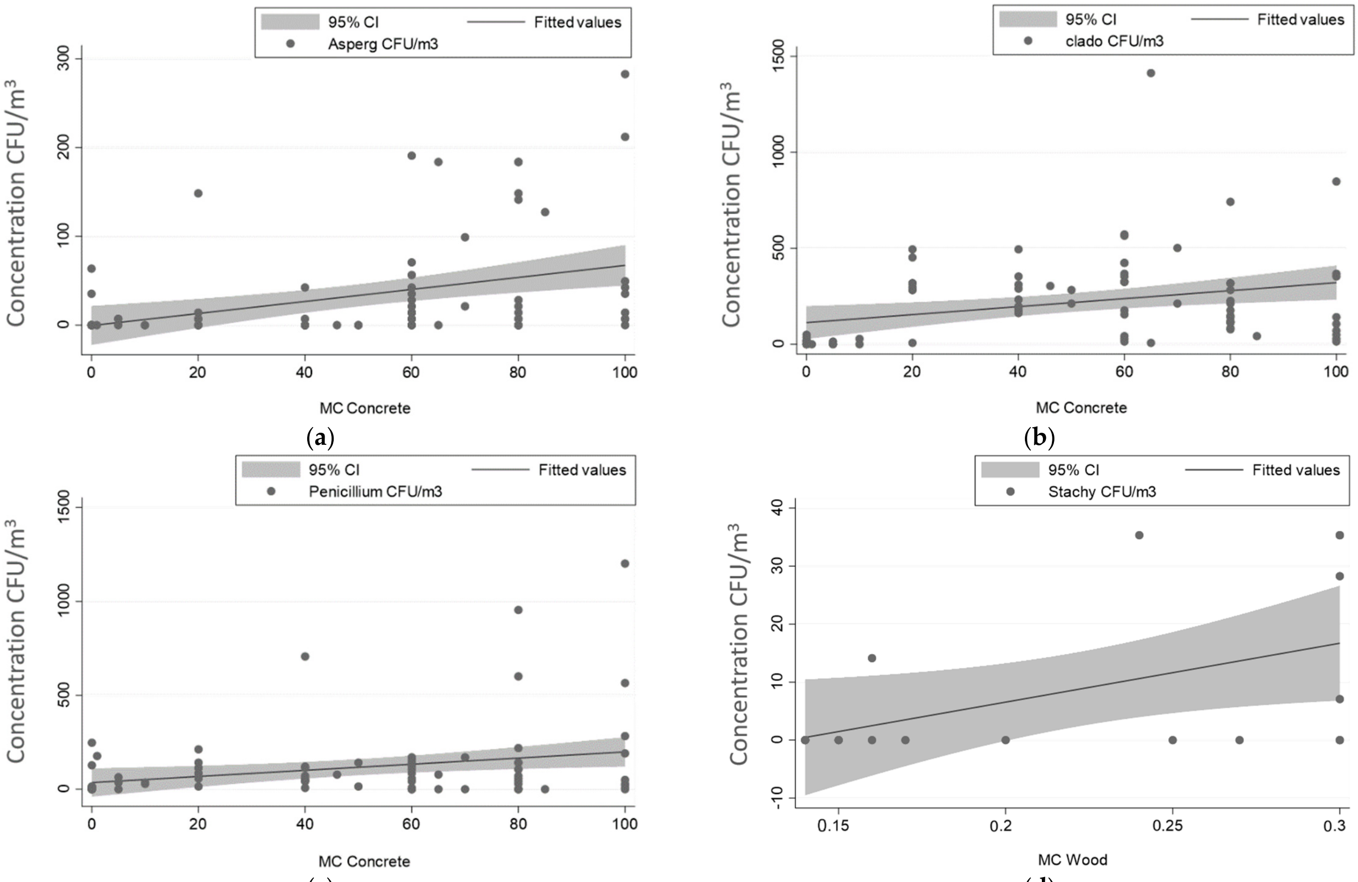
There were no significant correlations between concrete moisture content and mold concentrations, except for *Aspergillus* spp. ($R^2 = 14.2\%$, $p < 0.001$), *Penicillium* spp. ($R^2 = 7.6\%$, $p < 0.05$), and *Cladosporium* spp. ($R^2 = 9.3\%$, $p < 0.05$). However, a significant correlation was observed between moisture content in wood and *Stachybotrys* spp. ($R^2 = 24.3\%$, $p < 0.05$)

only (Figure 6). Although wood is used alongside concrete and other building materials in residential and non-residential structures, it is the predominant material in non-permanent shelters and unlike other shelter categories, it is exposed to moisture and environmental conditions. The abundance of *Stachybotrys* spp. in non-permanent shelters could hence be attributed to the bioreactivity of exposed wood and timber and would lead to material biodeterioration as well as health implications [37,74,75].

**Table 4.** Correlation between mold concentrations and occupancy.

| Genus | Occupancy | *p*-Value | $R^2$ |
|---|---|---|---|
| *Aspergillus* | 0.075 | 0.461 | 0.6% |
| *Cladosporium* | 0.215 | 0.032 * | 4.6% |
| *Penicillium* | −0.015 | 0.879 | 0.02% |
| *Alternaria* | 0.077 | 0.448 | 0.6% |
| *Stachybotrys* | 0.337 | <0.001 * | 11.3% |
| *Ulocladium* | 0.216 | 0.031 * | 4.7% |
| *Pithomyces* | −0.033 | 0.745 | 0.1% |
| *Candida* | −0.033 | 0.743 | 0.1% |
| *Rhizopus* | 0.014 | 0.893 | 0.02% |

* *p*-value less than 0.05 is considered to be significant.



(**a**) (**b**)

(**c**) (**d**)

**Figure 6.** Confidence interval (95%) for relationship model between moisture content in shelters and concentration of *Aspergillus* spp. (**a**), *Cladosporium* spp. (**b**), and *Penicillium* spp. (**c**). Graph (**d**) represents confidence interval (95%) for regression model between moisture content in wood and concentration of *Stachybotrys* spp.

### 3.2. Total Mold Indoor Count

Mean TIC was highest in non-residential (1112 CFU/m$^3$), followed by non-permanent (782 CFU/m$^3$) and residential (733 CFU/m$^3$) shelters (Figure 7). The Kruskal-Wallis test revealed a significant association between TIC and the type of shelter ($p < 0.05$).

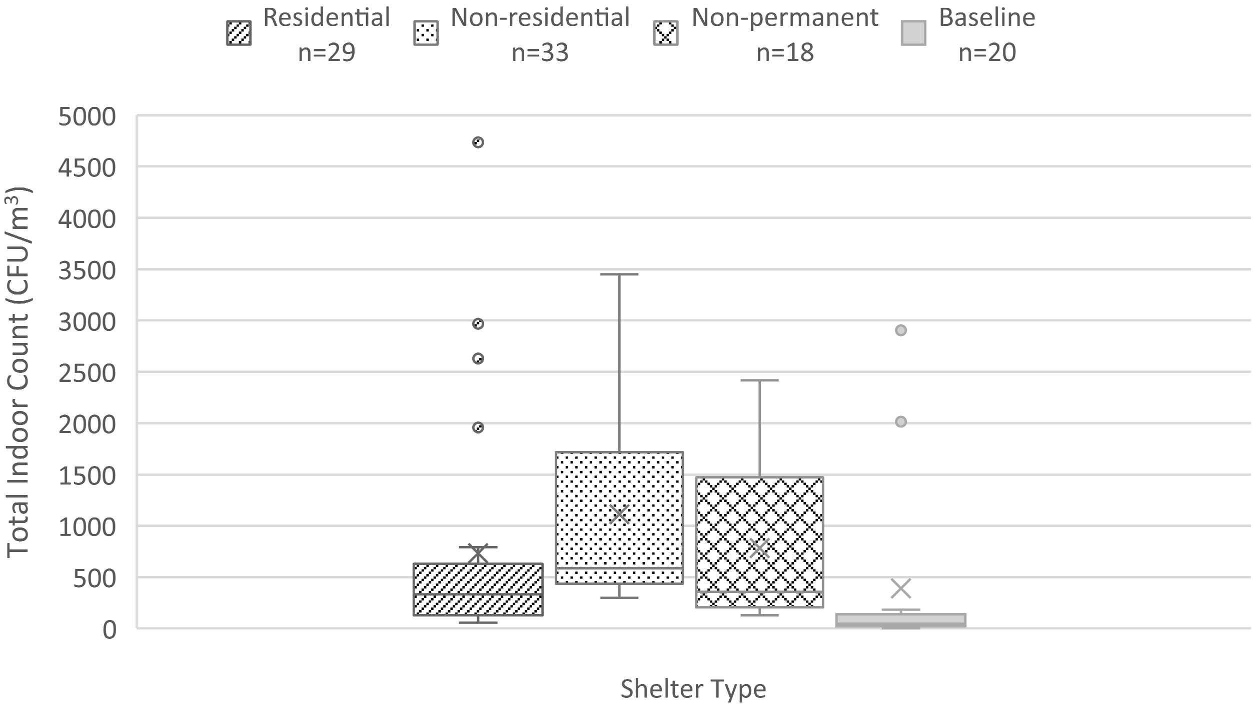


**Figure 7.** Mean total mold indoor count for each shelter type (Mean, depicted by the "×" mark; (range) CFU/m$^3$). Residential (733; (57–792)). Non-residential (1112; (297–3449)). Non-permanent (782; (127–2417)). Baseline households (389; (0–184)).

Mean TIC (Figure 8) was significantly highest (1243 CFU/m$^3$) in unfinished shelters and lowest (411 CFU/m$^3$) in standard shelters ($p < 0.05$). Furthermore, robust regression performed to account for outliers in the sample also revealed a significant association between TIC and occupancy ($p < 0.05$).

The outdoor air of the Bekaa region, where non-permanent settlements are established, had the second highest mold count compared to other regions which could be caused by outdoor concentrations of mold spores, reflecting higher infiltration and slow cross-flow ventilation guided by exhaust fans inside the tents. The winter storms of (2018–2019) caused flooding of shelters in most regions of Lebanon which damaged construction materials especially non-permanent shelters. Poor building design of some residential and non-residential shelters resulted in plumbing leaks and permeability of surfaces to moisture, further exacerbating absorbance and retention in shelters. Nevertheless, one of the sources of indoor mold growth, as determined from walkthrough observations of the settlements, could be attributed to excessive moisture and dampness from human activity. This was mainly observed in indoor line drying of laundry and wet floors from cleaning, dripping laundry, bathing, and accidental spillage, all of which contribute to ambient humidity following evaporation (Figure 9).

This was also evident as reflected by the significant association ($R^2$ = 23.63%, $p < 0.001$) between moisture content in concrete material and occupancy (Figure 10) suggesting that human activity and indoor practices could influence moisture content in residential, non-residential, and standard shelters where concrete is the predominant building material. Nevertheless, the low $R^2$ value indicates that occupancy reflected by human activity is just one of the factors affecting moisture content in structural material. The sampled shelters are architecturally different from each other and their susceptibility to moisture or water intrusion is determined by their design, age, and exposure to environmental factors [76,77].

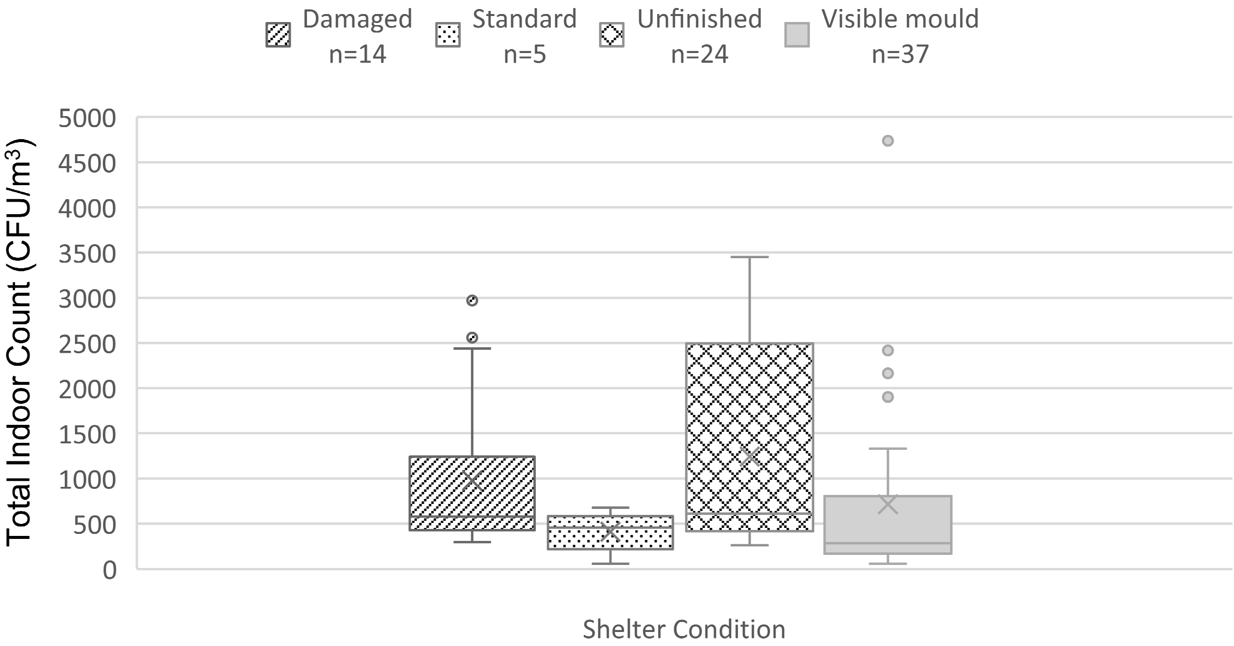


**Figure 8.** Mean total mold indoor count by the condition of shelter with lowest and highest concentrations (Mean, depicted by the "×" mark; (range) CFU/m$^3$). Damaged (977; (297–2438)). Standard (411; (0–678)). Unfinished (1243; (261–3449)). Visible mold (715; (57–1329)).

**Figure 9.** Line drying of laundry inside residential (**c**) and non-residential (**a**,**b**) shelters.

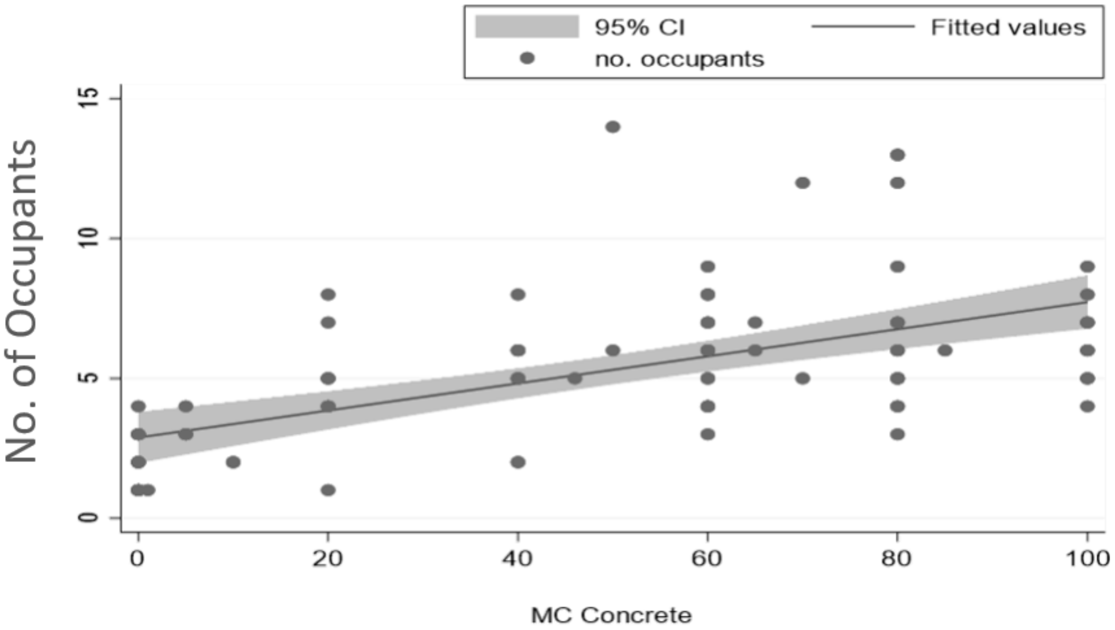


**Figure 10.** Confidence interval (95%) for regression model between moisture content in concrete and occupancy ($R^2$ = 23.63%).

The concern for inadequate ventilation and human activity in self-built shelters was also reported in a study conducted in 6 countries including Turkey and Jordan which host Syrian refugees. Results revealed high concentrations of total volatile organic compounds (TVOC = 102,400 $\mu g/m^3$) and particulate matter (PM = 3000 $\mu g/m^3$) mainly attributed to cooking, smoking and poor aeration of the indoor environment [78].

### 3.3. I/O Ratio

The mean I/O ratio was higher than 1 in all sampled environments including controls. The ratio was highest in residential shelters (10.1) followed by baseline households (10.9) and non-residential shelters (3.6), and lowest in non-permanent shelters (1.8), with no significant association with types of shelters. In relation to shelter condition, the I/O ratio was highest in structurally damaged shelters (13.8) followed by standard (9.6), visible mold (6.8), and unfinished shelters (4.4), with no significant associations, however. No association between moisture content and the I/O ratio was concluded. As for occupancy, there was a slightly negative correlation with the I/O ratio.

The outcomes can be attributed to the fact that outdoor concentrations vary depending on several factors and vastly influence the I/O ratio. Outdoor conditions due to weather or activity may suppress the release of spores from outdoor sources leading to higher indoor concentrations albeit indoor sources of potential fungal growth may be absent [79]. Additionally, the exceedances in I/O ratios could be due to single-sided ventilation prevalent in residential shelters compared to other categories [21].

Although mold is present in non-refugee households, sources of moisture are often remediated in residences with better socioeconomic status. Refugees, on the other hand, lack the privilege of improving living conditions, mainly due to prioritization of expenditure. Since remediation can be costly to refugee households and non-governmental agencies, household demographics and medical conditions should be taken into consideration during shelter assignment. Some remediation measures, however, are less costly than others such as in the case of non-permanent shelters where replacing water-damaged porous material such as wood could potentially reduce mold in indoor air. Finally, considering the large refugee population size vis-à-vis the availability of standard shelters, NGOs should focus on securing budgets to standardize the living conditions of refugee households and prioritize those with immunocompromised members. Accordingly, efforts must be made to develop a universal design for temporary shelters, accounting for ventilation and psychrometric requirements for human occupancy.

## 4. Conclusions

This study revealed several significant associations between categories of shelter and mold concentrations and has further established strong associations between certain mold types and shelter conditions. The aim of this study was to identify environmental risks associated with Syrian refugee shelters in Lebanon, focusing on indoor mold populations, and for NGOs to present local authorities and policymakers with scientific evidence of alarming nature and address a public health concern that may add to the existing burden on the national health system.

The shelter conditions in which Syrian refugees are residing are potential sources of diseases related to mold exposure. Several studies and international agencies including the World Health Organization have recommended remediating the sources of moisture and dampness to prevent microbial growth [21,80,81]. Cooperation, collaboration and international investment from humanitarian agencies and policymakers are imperative to establish adequate housing to protect the health and well-being of Syrian Refugees.

## 5. Limitations and Future Research

The study did have its limitations, more specifically, data was inherently impacted by outliers which require future studies to expand the sample size and account for indoor and outdoor influencing factors for mold. The study did not address seasonal variation in mold concentrations as it was performed only in the Spring season. Additionally, moisture content and dampness should ideally have been assessed more frequently to better reflect extreme weather events such as flooding over the winter period preceding sampling, as this increases background moisture levels. The I/O ratio should also be established for identified mold genera as the study only reported total outdoor counts without details on outdoor populations. Nevertheless, indoor microorganisms and dampness will persist in Syrian Refugee shelters in Lebanon and will worsen without proper intervention including improved ventilation and dilution. This investigation shows the vulnerability of shelters to climatic and environmental factors which worsen living conditions and indoor air quality. Further epidemiological studies, including in-depth investigation of fungal species and reported illnesses, are thus needed to determine the quantitative impact of these factors on the health of refugees, involving the cooperation of all stakeholders, particularly clinicians with access to health information for refugees, to determine whether indoor air quality is significantly influencing the health and wellbeing of this population.

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## References

1. UNHCR—Refugee Statistics. Available online: https://www.unhcr.org/refugee-statistics/download/?url=2bxU2f (accessed on 17 December 2022).
2. Lambert, H. Temporary refuge from war: Customary international law and the Syrian conflict. *Int. Comp. Law Q.* **2017**, *66*, 723. [CrossRef]
3. Regional Refugees and Resilience Plan Regional Strategic Overview. *Al-Ahram Weekly*. 6 April 2017. Available online: https://www.proquest.com/newspapers/refugee-resilience-plan/docview/1884990887/se-2 (accessed on 10 March 2018).
4. Syrian Regional Refugee Response. Available online: https://data2.unhcr.org/en/situations/syria/location/71 (accessed on 10 June 2018).
5. John Hopkins Bloomberg School of Public Health; Mèdecins Du Monde; International Medical Corps; American University of Beirut; UNHCR. *Syrian Refugee and Affected Host Population Health Access Survey in Lebanon*; UNHCR: Beirut, Lebanon, 2015.
6. El-Khatib, Z.; Scales, D.; Vearey, J.; Forsberg, B.C. Syrian refugees, between rocky crisis in Syria and hard inaccessibility to healthcare services in Lebanon and Jordan. *Confl. Health* **2013**, *7*, 6–8. [CrossRef] [PubMed]
7. Sanyal, R. A no-camp policy: Interrogating informal settlements in Lebanon. *Geoforum* **2017**, *84*, 117–125. [CrossRef]
8. *Choices: Syrian Refugees in Need of Health Care in Lebanon*; Amnesty International: London, UK, 2014. Available online: https://www.amnesty.org/en/documents/mde18/001/2014/en/ (accessed on 12 May 2017).
9. Allen, E.; Iano, J. *Fundamentals of Building Construction: Materials and Methods*; John Wiley & Sons: Hoboken, NJ, USA, 2019.
10. Govender, T.; Barnes, J.M.; Pieper, C.H. Housing conditions, sanitation status and associated health risks in selected subsidized low-cost housing settlements in Cape Town, South Africa. *Habitat. Int.* **2011**, *35*, 335–342. [CrossRef]
11. Bonner, P.C.; Schmidt, W.; Belmain, S.R.; Oshin, B.; Baglole, D.; Borchert, M. Poor Housing Quality Increases Risk of Rodent Infestation and Lassa Fever in Refugee Camps of Sierra Leone. *Am. J. Trop. Med. Hyg.* **2007**, *77*, 169–175. [CrossRef] [PubMed]
12. Kysia, R.F. Shelter. In *Handbook of Bioterrorism and Disaster Medicine*; Antosia, R.E., Cahill, J.D., Eds.; Springer: Boston, MA, USA, 2006; pp. 393–396.
13. Uhde, E.; Salthammer, T. Impact of reaction products from building materials and furnishings on indoor air quality—A review of recent advances in indoor chemistry. *Atmos. Environ.* **2007**, *41*, 3111–3128. [CrossRef]
14. Krieger, J.; Higgins, D.L. Housing and health: Time again for public health action. *Am. J. Public Health* **2002**, *92*, 758–768. [CrossRef] [PubMed]
15. El-Sharif, N.; Abdeen, Z.; Qasrawi, R.; Moens, G.; Nemery, B. Asthma prevalence in children living in villages, cities and refugee camps in Palestine. *Eur. Respir. J.* **2002**, *19*, 1026–1034. [CrossRef]
16. Abu Mourad, T.A. Palestinian refugee conditions associated with intestinal parasites and diarrhoea: Nuseirat refugee camp as a case study. *Public Health* **2004**, *118*, 131–142. [CrossRef] [PubMed]
17. Al-Khatib, I.A.; Arafat, R.N.; Musmar, M. Housing environment and women's health in a Palestinian refugee camp. *Int. J. Environ. Health Res.* **2005**, *15*, 181–191. [CrossRef] [PubMed]
18. Earl, C.S.; An, S.; Ryan, R.P. The changing face of asthma and its relation with microbes. *Trends Microbiol.* **2015**, *23*, 408–418. [CrossRef]
19. von Mutius, E. The microbial environment and its influence on asthma prevention in early life. *J. Allergy Clin. Immunol.* **2016**, *137*, 680–689. [CrossRef] [PubMed]
20. Huang, Y.J.; Marsland, B.J.; Bunyavanich, S.; O'Mahony, L.; Leung, D.Y.M.; Muraro, A.; Fleisher, T.A. The microbiome in allergic disease: Current understanding and future opportunities-2017 PRACTALL document of the American Academy of Allergy, Asthma & Immunology and the European Academy of Allergy and Clinical Immunology. *J. Allergy Clin. Immunol.* **2017**, *139*, 1099–1110. [PubMed]
21. World Health Organization. *WHO Guidelines for Indoor Air Quality: Dampness and Mold*; World Health Organization: Copenhagen, Denmark, 2009; Volume 33.
22. Rios, J.L.d.M.; Boechat, J.L.; Gioda, A.; Santos, C.Y.d.; Aquino Neto, F.R.d.; Lapa e Silva, J.R. Symptoms prevalence among office workers of a sealed versus a non-sealed building: Associations to indoor air quality. *Environ. Int.* **2009**, *35*, 1136–1141. [CrossRef] [PubMed]
23. Tong, Z.; Chen, Y.; Malkawi, A.; Adamkiewicz, G.; Spengler, J.D. Quantifying the impact of traffic-related air pollution on the indoor air quality of a naturally ventilated building. *Environ. Int.* **2016**, *89–90*, 138–146. [CrossRef] [PubMed]
24. Spengler, J.D.; Chen, Q. Indoor air quality factors in designing a healthy building. *Annu. Rev. Energy Environ.* **2000**, *25*, 567–600. [CrossRef]

25. *US Environmental Protection Agency Indoor Air Quality Tools for Schools: Reference Guide*; United States Environmental Protection Agency: Washington, DC, USA, 2009. Available online: https://www.epa.gov/iaq-schools (accessed on 8 April 2018).
26. Spaul, W.A. Building-related factors to consider in indoor air quality evaluations. *J. Allergy Clin. Immunol.* **1994**, *94*, 385–389. [CrossRef]
27. Nen, O.A.S.; Fisk, W.J.; Mendell, M.J. Association of Ventilation Rates and $CO_2$ Concentrations with Health and Other Responses in Commercial and Institutional Buildings. *Indoor Air* **1999**, *1*, 226–252.
28. Meklin, T.; Hyvärinen, A.; Toivola, M.; Reponen, T.; Koponen, V.; Husman, T.; Taskinen, T.; Korppi, M.; Nevalainen, A. Effect of Building Frame and Moisture Damage on Microbiological Indoor Air Quality in School Buildings. *AIHA J.* **2003**, *64*, 108–116. [CrossRef]
29. Moore, D.; Robson, G.D.; Trinci, A.P.J. *21st Century Guidebook to Fungi with CD*; Cambridge University Press: Cambridge, UK, 2011.
30. Burge, H.A. The fungi: How they grow and their effects on human health. *Heat. Pip. Air Cond.* **1997**, *69*. Available online: https://www.osti.gov/biblio/538129 (accessed on 8 April 2018).
31. Kazemian, N.; Pakpour, S.; Milani, A.S.; Klironomos, J. Environmental factors influencing fungal growth on gypsum boards and their structural biodeterioration: A university campus case study. *PLoS ONE* **2019**, *14*, e0220556. [CrossRef] [PubMed]
32. Storey, E.; Dangman, K.H.; Schenck, P.; Debernardo, R.L.; Chin, Y.S.; Bracker, A.; Hodgson, M.J. *Guidance for Clinicians on the Recognition and Management of Health Effects Related to Mold Exposure and Moisture Indoors*; University of Connecticut Health Center, Division of Occupational and Environmental Medicine, Center for Indoor Environments and Health: Farmington, CT, USA, 2004.
33. Verdier, T.; Coutand, M.; Bertron, A.; Roques, C. A review of indoor microbial growth across building materials and sampling and analysis methods. *Build. Environ.* **2014**, *80*, 136–149. [CrossRef]
34. Rea, W.J.; Didriksen, N.; Simon, T.R.; Pan, Y.; Fenyves, E.J.; Griffiths, B. Effects of toxic exposure to molds and mycotoxins in building-related illnesses. *Arch. Environ. Health* **2003**, *58*, 399–405. Available online: http://www.ncbi.nlm.nih.gov/pubmed/15143852 (accessed on 4 April 2018).
35. *ASHRAE Standard 62.1-2016*; Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers: Atlanta, GA, USA, 2016; p. 56.
36. Burge, H.A. Allergens and other air pollutants. *Monaldi Arch. Chest Dis. = Arch. Monaldi Per Le Mal. Del Torace* **1994**, *49*, 373–374.
37. Grant, C.; Hunter, C.A.; Flannigan, B.; Bravery, A.F. The Moisture Requirements of Molds Isolated from Domestic Dwellings. *Int. Biodeterior.* **1989**, *25*, 259–284. [CrossRef]
38. Mendell, M.J.; Mirer, A.G.; Cheung, K.; Tong, M.; Douwes, J. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: A review of the epidemiologic evidence. *Environ. Health Perspect.* **2011**, *119*, 748–756. [CrossRef]
39. Caillaud, D.; Leynaert, B.; Keirsbulck, M.; Nadif, R.; Roussel, S.; Ashan-Leygonie, C.; Bex, V.; Bretagne, S.; Caillaud, D.; Colleville, A.C.; et al. Indoor mold exposure, asthma and rhinitis: Findings from systematic reviews and recent longitudinal studies. *Eur. Respir. Rev.* **2018**, *27*, 170137. [CrossRef] [PubMed]
40. Quansah, R.; Jaakkola, M.S.; Hugg, T.T.; Heikkinen, S.A.M.; Jaakkola, J.J.K. Residential Dampness and Molds and the Risk of Developing Asthma: A Systematic Review and Meta-Analysis. *PLoS ONE* **2012**, *7*, e47526. [CrossRef] [PubMed]
41. Shultz, A.; Omollo, J.O.; Burke, H.; Qassim, M.; Ochieng, J.B.; Weinberg, M.; Feikin, D.R.; Breiman, R.F. Cholera Outbreak in Kenyan Refugee Camp: Risk Factors for Illness and Importance of Sanitation. *Am. J. Trop. Med. Hyg.* **2009**, *80*, 640–645. [CrossRef] [PubMed]
42. Biran, A.; Schmidt, W.; Zeleke, L.; Emukule, H.; Khay, H.; Parker, J.; Peprah, D. Hygiene and sanitation practices amongst residents of three long-term refugee camps in Thailand, Ethiopia and Kenya. *Trop. Med. Int. Health* **2012**, *17*, 1133–1141. [CrossRef] [PubMed]
43. Habib, R.R.; Basma, S.H.; Yeretzian, J.S. Harboring illnesses: On the association between disease and living conditions in a Palestinian refugee camp in Lebanon. *Int. J. Environ. Health Res.* **2006**, *16*, 99–111. [CrossRef] [PubMed]
44. Habib, R.R.; Mahfoud, Z.; Fawaz, M.; Basma, S.H.; Yeretzian, J.S. Housing quality and ill health in a disadvantaged urban community. *Public. Health* **2009**, *123*, 174–181. [CrossRef] [PubMed]
45. Cronin, A.A.; Shrestha, D.; Spiegel, P.; Gore, F.; Hering, H. Quantifying the burden of disease associated with inadequate provision of water and sanitation in selected sub-Saharan refugee camps. *J. Water Health* **2009**, *7*, 557–568. [CrossRef] [PubMed]
46. Cronin, A.A.; Shrestha, D.; Cornier, N.; Abdalla, F.; Ezard, N.; Aramburu, C. A review of water and sanitation provision in refugee camps in association with selected health and nutrition indicators—The need for integrated service provision. *J. Water Health* **2008**, *6*, 1–13. [CrossRef] [PubMed]
47. Benka-Coker, M.L.; Tadele, W.; Milano, A.; Getaneh, D.; Stokes, H. A case study of the ethanol CleanCook stove intervention and potential scale-up in Ethiopia. *Energy Sustain. Dev. J. Int. Energy Initiat.* **2018**, *46*, 53–64. [CrossRef] [PubMed]
48. Albadra, D.; Vellei, M.; Coley, D.; Hart, J. Thermal comfort in desert refugee camps: An interdisciplinary approach. *Build. Environ.* **2017**, *124*, 460–477. [CrossRef]
49. Everaerts, S.; Lagrou, K.; Vermeersch, K.; Dupont, L.J.; Vanaudenaerde, B.M. Wim Janssens Aspergillus fumigatus Detection and Risk Factors in Patients with COPD-Bronchiectasis Overlap. *Int. J. Mol. Sci.* **2018**, *19*, 523. [CrossRef] [PubMed]
50. Armstrong-James, D.; Meintjes, G.; Brown, G.D. A neglected epidemic: Fungal infections in HIV/AIDS. *Trends Microbiol.* **2014**, *22*, 120–127. [CrossRef] [PubMed]
51. Kirkpatrick, C.H. Fungal Infections in HIV Patients. *Ann. N. Y. Acad. Sci.* **2018**, *616*, 461–468. [CrossRef] [PubMed]

52. Durden, F.M.; Elewski, B. Fungal infections in HIV-infected patients. *Semin. Cutan. Med. Surg.* **1997**, *16*, 200–212. [CrossRef]
53. Downs, S.; Mitakakis, T.; Marks, G.; Car, N.; Belousova, E.; Leüppi, J.; Xuan, W.E.I.; Downie, S.; Tobias, A.; Peat, J. Clinical Importance of Alternaria Exposure in Children. *Am. J. Respir. Crit. Care Med.* **2001**, *164*, 455–459. [CrossRef] [PubMed]
54. *BS EN ISO 16000-19*; Indoor Air Part 19: Sampling Strategy for Molds. British Standards Institution: London, UK, 2014.
55. *BS ISO 16000-18*; Indoor Air Part 18: Detection and Enumeration of Molds-Sampling by Impaction. British Standards Institution: London, UK, 2011; 29p.
56. Thermo Fisher Scientific. *Series 10-Instruction Manual*; Single Stage Viable Sampler; Thermo Fisher Scientific: Waltham, MA, USA, 2009.
57. *BS ISO 16000-17*; Indoor Air Part 17: Detection and Enumeration of Molds—Culture-Based Method. British Standards Institution: London, UK, 2009.
58. Yamamoto, N.; Hospodsky, D.; Dannemiller, K.C.; Nazaroff, W.W.; Peccia, J. Indoor Emissions as a Primary Source of Airborne Allergenic Fungal Particles in Classrooms. *Environ. Sci. Technol.* **1900**, *49*, 5098–5106. [CrossRef] [PubMed]
59. Watanabe, T. *Pictorial Atlas of Soil and Seed Fungi: Morphologies of Cultured Fungi and Key to Species*, 3rd ed.; CRC Press/Taylor & Francis: Boca Raton, FL, USA, 2010.
60. Sciortino, C.V. *Atlas of Clinically Important Fungi*; John Wiley & Sons, Incorporated: Hoboken, NJ, USA, 2017.
61. *ASTM F2659-10*; Standard Guide for Preliminary Evaluation of Comparative Moisture Condition of Concrete, Gypsum Cement and Other Floor Slabs and Screeds Using a Non-Destructive Electronic Moisture Meter. ASTM International: West Conshohocken, PA, USA, 2016; Volume 10, pp. 1–6.
62. Lennartsson, P.R.; Taherzadeh, M.J.; Edebo, L. Rhizopus. In *Encyclopedia of Food Microbiology*, 2nd ed.; Batt, C.A., Tortorello, M.L., Eds.; Academic Press: Oxford, UK, 2014; pp. 284–290.
63. Sircar, G.; Bhattacharya, S.G. 221 Allergenic Significance of Airborne Rhizopus Stolonifer (ehrenb.) Vuill, a Common Bread Mold. *World Allergy Organ. J.* **2012**, *5*, S73–S90. [CrossRef]
64. Hurraß, J.; Heinzow, B.; Aurbach, U.; Bergmann, K.; Bufe, A.; Buzina, W.; Cornely, O.A.; Engelhart, S.; Fischer, G.; Gabrio, T.; et al. Medical diagnostics for indoor mold exposure. *Int. J. Hyg. Environ. Health* **2017**, *220*, 305–328. [CrossRef]
65. Kuhn, D.M.; Ghannoum, M.A. Indoor Mold, Toxigenic Fungi, and *Stachybotrys chartarum*: Infectious Disease Perspective. *Clin. Microbiol. Rev.* **2003**, *16*, 144–172. [CrossRef]
66. Jones, R.; Recer, G.M.; Hwang, S.A.; Lin, S. Association between indoor mold and asthma among children in Buffalo, New York. *Indoor Air* **2011**, *21*, 156–164. [CrossRef]
67. Rea, W.J.; Didriksen, N.; Simon, T.R.; Pan, Y.; Fenyves, E.J.; Griffiths, B. Effects of Toxic Exposure to Molds and Mycotoxins in Building-Related Illnesses. *Arch. Environ. Health* **2003**, *58*, 399–405. [CrossRef]
68. Escriva, L.; Font, G.; Manyes, L.; Berrada, H. Studies on the Presence of Mycotoxins in Biological Samples: An Overview. *Toxins* **2017**, *9*, 251. [CrossRef]
69. Bloom, E.; Bal, K.; Nyman, E.; Must, A.; Larsson, L. Mass spectrometry-based strategy for direct detection and quantification of some mycotoxins produced by Stachybotrys and Aspergillus spp. in indoor environments. *Appl. Environ. Microbiol.* **2007**, *73*, 4211–4217. [CrossRef] [PubMed]
70. Simoni, M.; Lombardi, E.; Berti, G.; Rusconi, F.; La Grutta, S.; Piffer, S.; Petronio, M.G.; Galassi, C.; Forastiere, F.; Viegi, G. Mold/dampness exposure at home is associated with respiratory disorders in Italian children and adolescents: The SIDRIA-2 Study. *Occup. Environ. Med.* **2005**, *62*, 616–622. [CrossRef] [PubMed]
71. Müller, A.; Lehmann, I.; Seiffart, A.; Diez, U.; Wetzig, H.; Borte, M.; Herbarth, O. Increased incidence of allergic sensitisation and respiratory diseases due to mold exposure: Results of the Leipzig Allergy Risk children Study (LARS). *Int. J. Hyg. Environ. Health* **2002**, *204*, 363–365. [CrossRef] [PubMed]
72. Bellanger, A.; Reboux, G.; Roussel, S.; Grenouillet, F.; Didier-Scherer, E.; Dalphin, J.; Millon, L. Indoor fungal contamination of moisture-damaged and allergic patient housing analysed using real-time PCR. *Lett. Appl. Microbiol.* **2009**, *49*, 260–266. [CrossRef]
73. Andersen, B.; Frisvad, J.C.; Søndergaard, I.; Rasmussen, I.S.; Larsen, L.S. Associations between Fungal Species and Water-Damaged Building Materials. *Appl. Environ. Microbiol.* **2011**, *77*, 4180–4188. [CrossRef] [PubMed]
74. Alfieri, P.V.; Correa, M.V. Analysis of biodeterioration wood estate: Use different techniques to obtain images. *Matéria* **2018**, *23*. [CrossRef]
75. Hyvarinen, A.; Meklin, T.; Vepsalainen, A.; Nevalainen, A. Fungi and actinobacteria in moisture-damaged building materials—Concentrations and diversity. *Int. Biodeterior. Biodegrad.* **2002**, *49*, 27–37. [CrossRef]
76. U.S. Department of Housing and Urban Development Assessing Housing Durability: A Pilot Study. 2001. Available online: https://www.huduser.gov/publications/pdf/housing_durability_0602.pdf (accessed on 10 December 2018).
77. Daquisto, D.; Crandell, J.; Lyons, J. *Building Moisture and Durability Past, Present and Future Work*; Prepared by Newport Partners for Office of Policy Development and Research, Department of Housing and Urban Development; Newport Partners: Irvine, CA, USA, 2004.
78. Albadra, D.; Kuchai, N.; Acevedo-De-los-Ríos, A.; Rondinel-Oviedo, D.; Coley, D.; da Silva, C.F.; Rana, C.; Mower, K.; Dengel, A.; Maskell, D.; et al. Measurement and analysis of air quality in temporary shelters on three continents. *Build. Environ.* **2020**, *185*, 107259. [CrossRef]
79. American Conference of Governmental Industrial Hygienists. *Bioaerosols: Assessment and Control*; ACGIH: Washington, DC, USA, 1999.

80. Jaakkola, M.S.; Quansah, R.; Hugg, T.T.; Heikkinen, S.A.; Jaakkola, J.J. Association of indoor dampness and molds with rhinitis risk: A systematic review and meta-analysis. *J. Allergy Clin. Immunol.* **2013**, *132*, 1099–1110.e18. [CrossRef] [PubMed]
81. Institute of Medicine (U.S.) Committee on Damp Indoor Spaces and Health. *Damp Indoor Spaces and Health*; The National Academy Press: Washington, DC, USA, 2004.

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# Biomonitoring Environmental Exposure in Syrian Refugees in Lebanon

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**Abstract:** Over one million Syrian refugees have been residing in substandard living conditions in Lebanon for the past decade. Non-invasive biomonitoring of fractional exhaled nitric oxide (FeNO) as a pulmonary inflammation biomarker was conducted following and preceding indoor environmental assessments (which revealed elevated mould counts in informal tented settlements and non-residential shelters) to further evaluate effects of environmental exposure to indoor contaminants. Results of biomonitoring ($n = 57$) provided some insight regarding existing respiratory conditions and the possible implementation of minimally invasive methods to establish susceptibility profiles in Syrian refugees amid limited access to healthcare. The clinical interpretation of FeNO results suggested possible persistent exposure to allergens in addition to significant type 2 inflammation in some subjects. These findings warrant the need to expand this study, investigate other biomarkers, and attempt to correlate findings with environmental conditions to evaluate if a dose–response relationship exists.

**Keywords:** biomonitoring; environmental epidemiology; refugees; respiratory health

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## 1. Introduction

Lebanon has witnessed a massive influx of Syrian refugees since 2010, which was met with various challenges mainly due to the lack of preparedness of the hosting country, which had been suffering from an ongoing economic and political crisis for several years. Lebanon became the second largest Syrian refugee hosting country, after Turkey, in 2017, with over one million refugees registered with the United Nations High Commissioner for Refugees (UNHCR) [1–3]. Compared to the Lebanese host population, Syrian refugees required more medical care, whereby around 60% of medical care needs of children were attributed to respiratory problems and the majority of medical care needs of adults were reported as infections and communicable diseases [4]. Access to healthcare and secondary care has been challenging for Syrian refugees mainly due to socio-economic factors and a competing host community, of which 50% are uninsured and sponsored by the Ministry of Public Health [4–7]. In 2015, the most prevalent reported chronic condition among refugees under 17 was chronic respiratory diseases, including asthma, emphysema, chronic bronchitis, and chronic obstructive pulmonary disease, accounting for 12.9% of reasons for hospitalization. Asthma and pulmonary disease, which were among the five most prevalent chronic conditions reported by surveyed Syrian refugees in 2015, grew to 19% in 2021, becoming the highest reported chronic conditions among the total refugee population [4,8]. Counting as more than 50% of the Syrian refugee population in Lebanon, children with asthma and respiratory diseases are at even higher risk in terms of susceptibility to indoor pollutants [9,10].

A preceding study conducted in the four major governorates of Lebanon revealed several significant associations between categories of shelter and mould concentrations, and further established strong associations between certain mould types and shelter conditions [11]. The reported medical conditions of Syrian refugees have not been correlated with housing, shelter type, nor environmental factors. Moreover, as access to medical information was challenging due to confidentiality and lack of formal diagnosis, this research was designed to obtain cross-sectional epidemiological data that are both minimally invasive and prompt by collecting fractional exhaled nitric oxide (FeNO) samples with the aim to create a respiratory health and susceptibility profile for refugees based on shelter type without attributing health conditions to housing or shelter type, as many refugees arrived in Lebanon with pre-existing medical conditions. Thus, it is of utmost importance to investigate emerging health effects in refugee settlements in Lebanon, especially for younger age groups, due to the fact that newborn children and children up to the age of about 14 years of refugee families who fled the war in 2010 were born in refugee camps.

In epidemiological studies, biomonitoring is used in combination with health data to address the biological or toxic effects of pollutants, also known as the body burden. This tool can be an indicator of temporal exposure trends in relation to geographic characteristics and identifying vulnerable subpopulations [12]. Although biomonitoring cannot indicate the source of exposure, it can document routes of exposure such as inhalation, dermal absorption, and ingestion. Most importantly, biomonitoring helps establish or rule out correlations between environmental exposure and associated health effects [13].

Biomonitoring includes sub-organismal measurements known as biomarkers, which are defined as biochemical responses and chemically induced histopathological alterations [14]. There are three types of biomarkers: markers of exposure, markers of effect, and markers of susceptibility [15]. Biomarkers of exposure characterize tissue and body fluids chemical residues, in addition to metabolites of xenobiotic compounds and exposure-related physiological changes. Biomarkers of effects are quantifiable biochemical and physiologic changes resulting from exposure ranging from biomolecular changes at the sub-cellular level to organ and tissue level changes. Biomarkers of susceptibility, such as polymorphisms of xenobiotic compounds, reflect fundamental characteristics of organisms that render them prone to adverse effects of exposure to specific substances [12,15].

Lam and Gray (2003) summarized the benefits of adopting biomarkers in environmental assessments. The authors argued that biomarkers are effective tools as early warning signals of adverse biological effects when they are optimally sensitive. Furthermore, the advantage of biomarkers over chemistry-based surveillance is in the ability of biomarkers to indicate biological effects. Biomarkers are also effective in reflecting the overall toxicities of complex mixtures. In this regard, specific biomarkers indicate that toxicity occurs when chemicals bind to specific receptors to trigger a toxic action. These responses are developed into bioassays, such as an enzyme-linked immunosorbent assay (ELISA), which are considered economical compared to the chemical analysis of toxins [16]. The specificity and sensitivity of biomarkers are extremely important in justifying their use and receiving accurate exposure or effect information.

Moreover, blood, serum, and plasma are the biological matrices generally used, as they have well established standard operating procedures for sampling. Urine and other matrices are also used based on the type of toxin or pollutant. The choice of matrix also depends on whether it is invasive or non-invasive [12].

Infection, trauma, or exposure to exogenous toxins and irritants stimulates reactions such as inflammation and oxidative stress. In order to detect and monitor cytokine-mediated inflammation and oxidant stress, exhaled gases provide an effective tool of measurement [17]. Human breath contains endogenous compounds, such as inorganic gases (NO and CO), VOCs, and non-volatile substances such as isoprostanes, peroxynitrite, and cytokines [18]. These endogenous compounds have been vastly investigated in the literature for their diagnostic potential [19,20].

NO is produced by different types of pulmonary cells, including inflammatory, endothelial, and airway epithelial cells, and has been implicated in the pathophysiology of lung disease, playing key roles in vasodilation and bronchodilation, and as an inflammatory mediator [17,21]. Measurement of exhaled NO has been suggested for non-invasive diagnosis and monitoring of diseases in which airway excretion of NO is altered [22]. Additionally, the fraction of NO in exhaled air, also known as FeNO, is highly correlated with eosinophilic airway inflammation, and its measurement has been adopted in the diagnosis of respiratory illnesses such as asthma, COPD, cystic fibrosis, and primary ciliary dyskinesia [22,23]. The presence of NO in the airways is due to the activation of the transcription factor NK-kB by cytokines in epithelial cells, which triggers the production of the enzyme inducible nitric oxide synthetase (iNOS), which is responsible for the production of NO [24].

Tang et al. (2017) collected exhaled breath condensate (EBC) and serum from 102 acute respiratory distress syndrome (ARDS) ICU patients aged between 42 and 73, before treatment. EBC and serum NO from ARDS patients were significantly higher than those from controls (47.81 µmol/L EBC and 48.45 µmol/L serum NO compared to 15.65 µmol/L and 18.76 µmol/L, respectively, from controls). Although levels were significantly lower 5 days after treatment was administered, EBC and serum NO were still higher in treated ARDS patients than controls' levels were. These findings suggest that quantifying EBC NO levels can help in the evaluation of treatment efficacy and determining prognosis of ARDS [25].

A study conducted by Nguyen-Thi-Bich et al. in 2016 attempted to evaluate correlations between FeNO and atopic status, blood eosinophil levels, FCER2 mutation, and asthma control in 42 Vietnamese children with uncontrolled asthma. FeNO levels were significantly higher in patients with a positive skin prick test for respiratory allergens ($p < 0.05$) and significantly correlated with blood eosinophil levels ($r = 0.5217$; $p = 0.0004$), inferring that FeNO level is a feasible biomarker for the prediction of the clinical and biological status of asthmatic children [26]. Another study of asthmatic children, performed by Brzozowska et al. (2015), aimed to show correlations between FeNO levels and cytokine concentrations. Their results revealed a significant positive correlation between the FeNO level and IL-2, monocyte hemoattractant protein-1 (MCP-1), platelet-derived growth factor BB (PDGFBB), and tissue inhibitory of metalloproteinase 2 (TIMP2), and suggested that EBC may be a useful non-invasive tool to phenotype asthma [27].

Further interpretation of FeNO results could also suggest the likelihood of type 2 (T2) inflammation, which is used in the aetiology and pathogenesis of asthma and is driven by the production of pro-inflammatory type 2 cytokines [28–31]. Intermediate levels suggest the likelihood of T2 inflammation, while high levels suggest significant T2 inflammation [32]. No body of evidence exists to conclude correlations between FeNO and severe asthma; nevertheless, results from clinical studies and research do correlate with the management of asthma and the maintenance of inhaled corticosteroids [32–35].

## 2. Materials and Methods

A NIOX VERO® (Circassia AB, Uppsala, Sweden) airway inflammation monitor was used to measure FeNO from Syrian refugees who were registered in the Save the Children beneficiary database, following ethical approval obtained from the Brunel Research Ethics Committee. The portable device includes a breathing handle connected to a display instrument that includes an NO sensor. Monitoring occurred inside refugee shelters, and subjects were instructed to exhale forcefully and steadily into the breathing handle through a disposable patient filter and mouthpiece attached to the handle. The device displayed animation especially to guide children on how to maintain a steady flow. The device allowed measurement of exhaled breath via a 10 or 6 s option, depending on the age of the subject [36].

The original study design aimed to monitor refugees in the same Lebanese provinces and shelter types covered in the preceding study [11]. A sample size representing the refugee population registered with UNHCR was calculated to be 385, with a 95% confidence interval and a 5% error margin. Other nationalities that did not share the same humanitarian and socio-political profile of Syrian refugees were excluded from this study. Additionally, individuals with recently diagnosed infections or exhibiting infectious symptoms were also excluded from this study. This study was limited to 2 days due to national security concerns following the aggravation of the civil uprising in Lebanon, which began in October 2019, and hindered transportation to refugee settlements, with restricted mobilization of NGOs, limiting the sample size to 57. This study was then discontinued following the COVID-19 pandemic due to shelter-in-place orders and the nature of the study, which was considered an aerosol-generating procedure (AGP) in a non-controlled environment.

Subjects were asked whether they were diagnosed with respiratory illnesses and whether they were smokers, then further labelled by age group (child "C", adult "A", or elderly "E") and gender (male "M" or female "F") (Table 1). The 57 selected subjects, of whom 60% were children, delivered a single exhaled breath measurement each. FeNO measurements were taken between December 2019 and January 2020 in non-residential and non-permanent shelters only, in the South governorate and Bekaa regions of Lebanon, respectively, with the following demographic distribution.

**Table 1.** FeNO population data ($n$ = 57).

| Type of Shelter | Gender | Children (<18) | Reported Conditions | Adults (18 < 60) | Reported Conditions | Elderly (>60) | Reported Conditions |
|---|---|---|---|---|---|---|---|
| Non-residential | F | 8 | Asthma (1) | 6 | Asthma (1) | 1 | Allergies (1) |
| | M | 6 | Smoker (1)<br>Asthma (1)<br>Allergies (1) | 3 | Smoker (2) | 2 | Asthma (2) |
| Non-permanent | F | 10 | Asthma (1) | 6 | Asthma (1)<br>Allergies (1) | 0 | None |
| | M | 10 | Asthma (2) | 4 | Smoker (2) | 1 | None |

## 3. Results and Discussion

FeNO results were interpreted as low, intermediate, or high, based on the official clinical practice guidelines of the American Thoracic Society (ATS) and the National Institute for Health and Care Excellence (NICE). The ATS cut off level for high levels of FeNO is 50 parts per billion (ppb) compared the 40 ppb set by the NICE guidelines, which were adopted for this study's clinical interpretation. Accordingly, the NICE intermediate levels were 25–40 ppb and 20–35 ppb for adults and children, respectively [35,37].

### *3.1. Non-Residential Shelters*

Of the 26 monitored refugees in non-residential shelters, six children (four M and two F) reported high levels of FeNO (>40 ppb), two of whom reported asthma and one of whom reported an allergy. Only one adult (F) had high levels of FeNO, and one child (17 years, M), who was a smoker, had intermediate levels (Figure 1).

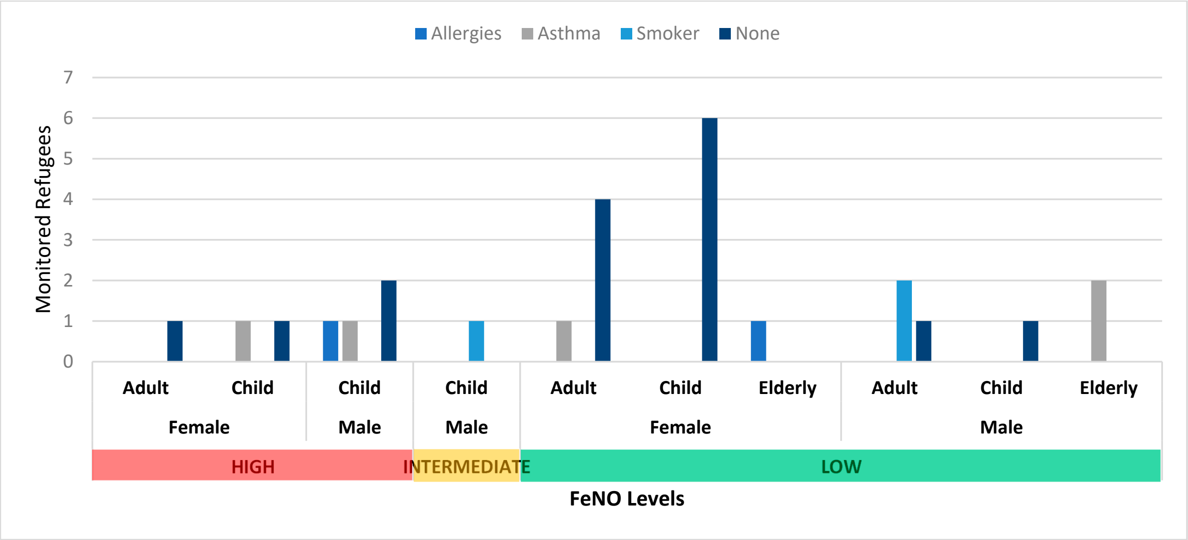

**Figure 1.** Non-residential FeNO results.

### *3.2. Non-Permanent Shelters*

Monitoring results from non-permanent shelters reported high FeNO levels in four children (two M and two F), two of whom had asthma. Furthermore, three adults (two F and one M) reported high levels of FeNO, whereas intermediate levels were reported in one child (F) and one elderly person (M) (Figure 2).

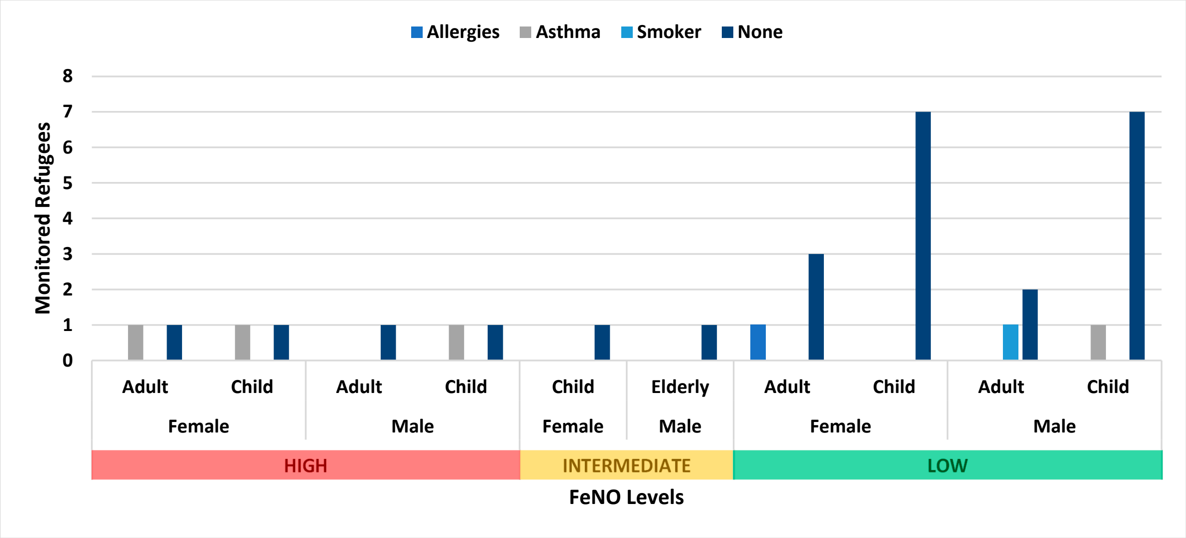

**Figure 2.** Non-permanent FeNO results.

The mean FeNO level for children residing in non-residential shelters was 23.4 ± 4.7 ppb compared to 16.4 ± 2.3 ppb for those in non-permanent shelters. As for adults, the mean FeNO level was 18.8 ± 3.1 ppb in non-residential shelters compared to 29.3 ± 5.8 ppb in non-permanent shelters (Figure 3).

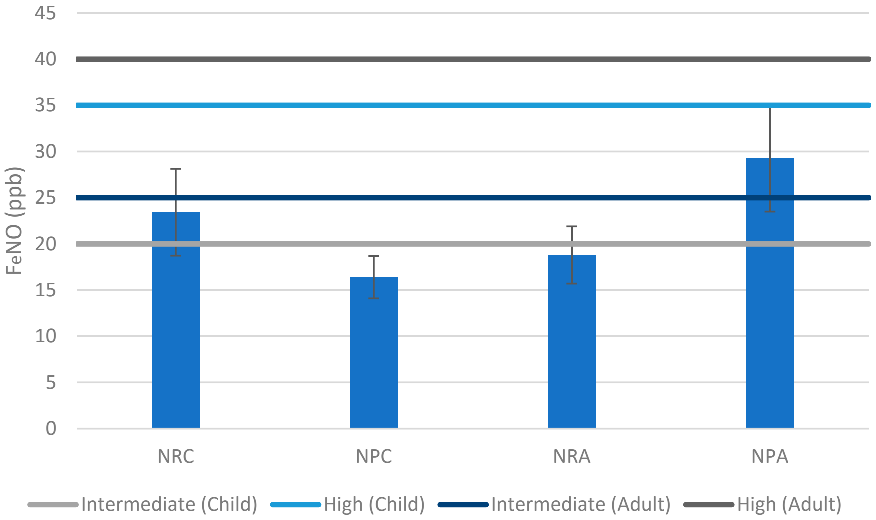

**Figure 3.** FeNO levels, means, and standard errors. NRC (non-residential children); NPC (non-permanent children); NRA (non-residential adults); NPA (non-permanent adults).

The mean FeNO level exceeded the intermediate category for children in non-residential shelters and for adults in non-permanent shelters. The difference in the children's age group results could be due to the fact that children residing in non-residential shelters were observed to be spending more time indoors due to the limitation of outdoor activities in such shelters, which included repurposed classrooms. On the other hand, children of non-permanent shelters, which are informal tented settlements established on or near agriculture fields, were observed to be spending more time outdoors. Furthermore, the preceding study revealed that non-residential shelters had the highest mean mould concentration, followed by non-permanent shelters [11]. As for the adult age group, the number of monitored adult females in non-residential shelters was twice that of adult males. Some studies suggested that older males had higher median FeNO levels than females, and others found a negative correlation with female age [38–41]. Nevertheless, although mean levels may indicate a higher susceptibility of children in non-residential shelters and adults in non-permanent shelters, the small sample size and unaccounted-for environmental factors and baseline conditions could not substantiate this conclusion. Further research is required that takes confounding factors into consideration. Although no significant correlation was observed between the age of subjects and FeNO levels ($R^2$ = 0.7%) in both types of shelters, this may have been due to the small sample size.

Table 2 below highlights interpretations of FeNO levels reported by symptomatic and asymptomatic monitored refugees in both types of shelters.

**Table 2.** Clinical interpretation of FeNO levels in symptomatic and asymptomatic refugees.

| FeNO Levels | T2 Inflammation | Symptomatic | Asymptomatic | Reference |
|---|---|---|---|---|
| Low | Unlikely | 6 | 34 | [32] |
| Intermediate | Likely | 0 | 3 | |
| High | Significant | 6 | 8 | |

The majority of monitored refugees were asymptomatic, as highlighted in Table 2. One of the clinical management guidelines for asymptomatic patients with high and intermediate levels of FeNO is to consider high baseline NO production and/or persistent allergen exposure potentially due to subclinical inflammation of lower airways with the absence of symptoms [32,42,43]. Additional confounding factors, such as gender, age, smoking, nutrition, cirrhosis, viruses, and bacterial infections, should also be taken into account when interpreting FeNO results [44–46]. Although other shelter types, such as residential shelters, were not assessed, as mentioned, the previous study revealed that non-residential shelters had the highest concentrations of mould, followed by non-permanent shelters [11]. Repetitive long-term exposure to mould and other aeroallergens in these shelter categories could explain the high FeNO levels observed in asymptomatic subjects [47]. Figure 4 depicts the underlying and environmental conditions that lead to the production of FeNO.

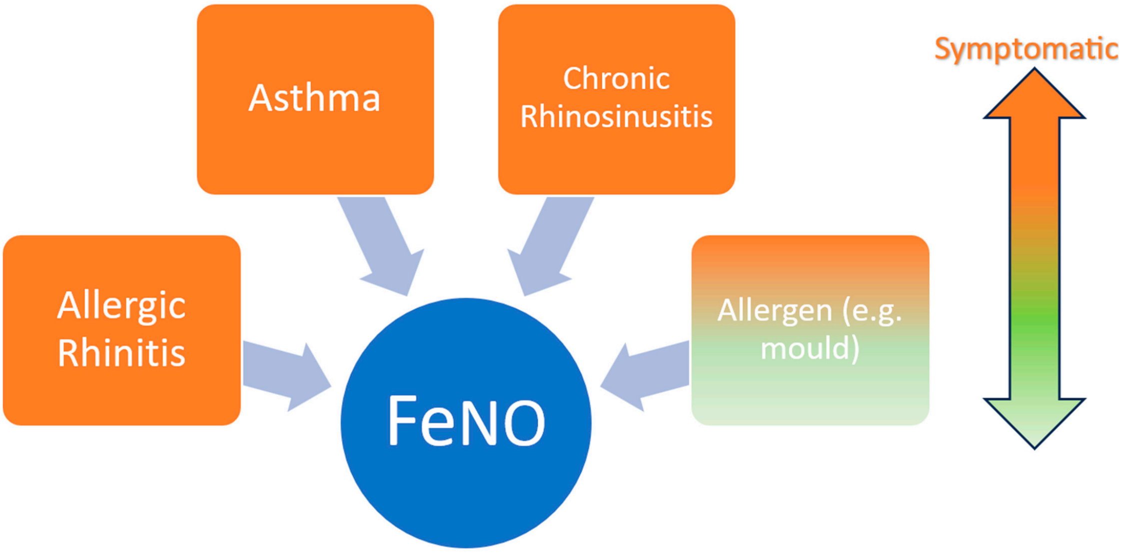

**Figure 4.** Environmental and underlying medical conditions leading to the production of FeNO in symptomatic and asymptomatic subjects.

## 4. Conclusions, Limitations, and Future Research

The findings of this study, although limited, clearly suggest an urgent need to repeat and broaden this study to include residential shelters and an increased sample size to investigate the presence of any significant correlation between FeNO levels and environmental conditions in shelters. Furthermore, a more inclusive study would benefit refugee health management by establishing a health susceptibility profile of refugees in circumstances where continuous clinical management cannot be maintained. As previous surveys reported an increasing rate of hospitalization due to asthma and pulmonary diseases, this type of data will assist NGOs in the proper deployment of resources and households, and can also be used to communicate concerns to policy makers and reduce the rate of hospitalization and additional burden on the host country's health system by acting as an early warning system.

Although several environmental factors are impacting refugee wellbeing, further epidemiological studies are needed to determine the quantitative impact (dose–response relationship) of these factors on the health of refugees. Stakeholder meetings, including clinicians, indoor air quality specialists, public specialists, and humanitarian aid and government agencies, should be urgently convened to determine whether indoor air quality is significantly influencing the health and wellbeing of this population. Although FeNO detection holds potential benefits as a non-invasive biomonitoring method, it does have limitations due to previously mentioned confounding factors. Of particular value would be exploring other biomarkers and expanding the biomonitoring capability and application of portable electrochemical sensors and non-invasive methods to facilitate the greater sample size required for statistical robustness in a cost-effective and time efficient manner, while minimising adverse impact on study subjects, particularly the elderly and children.

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## References

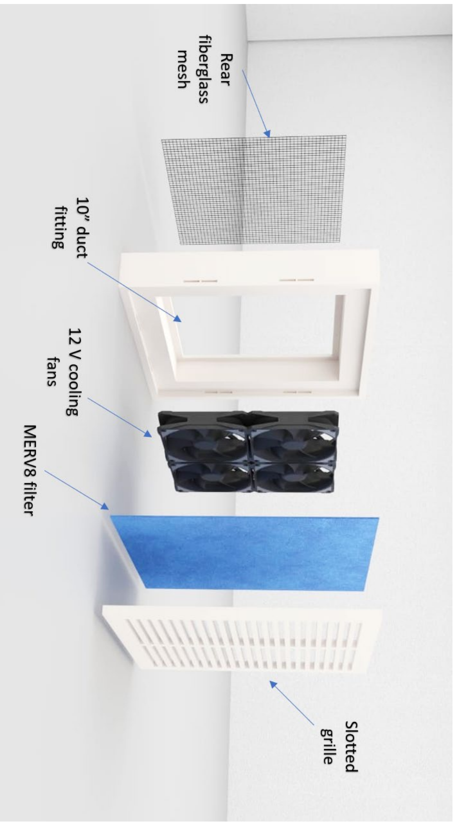
1. Lambert, H. Temporary refuge from war: Customary international law and the Syrian conflict. *Int. Comp. Law Q.* **2017**, *66*, 723. [CrossRef]
2. UNHCR. *3RP Regional Refugee & Resilience Plan 2017–2018*; UNHCR: Geneva, Switzerland, 2017.
3. UNHCR. Refugee Statistics. Available online: https://www.unhcr.org/refugee-statistics/download/?url=2bxU2f (accessed on 17 December 2022).
4. John Hopkins Bloomberg School of Public Health; Mèdecins Du Monde; International Medical Corps; American University of Beirut; UNHCR. Humanitarian Aid and Civil Protection Syrian refugee and Affected Host Population Health Access Survey in Lebanon. 2015. Available online: https://data.unhcr.org/en/documents/details/44869 (accessed on 24 April 2022).
5. Blanchet, K.; Fouad, F.M.; Pherali, T. Syrian refugees in Lebanon: The search for universal health coverage. *Confl. Health* **2016**, *10*, 12. [CrossRef]
6. El-Khatib, Z.; Scales, D.; Vearey, J.; Forsberg, B.C. Syrian refugees, between rocky crisis in Syria and hard inaccessibility to healthcare services in Lebanon and Jordan. *Confl. Health* **2013**, *7*, 6–8. [CrossRef]
7. Amnesty International. *Agonizing Choices: Syrian Refugees in Need of Health Care in Lebanon*; Amnesty International: London, UK, 2014.
8. UNHCR. *Health Access and Utilization Survey among Syrian Refugees in Lebanon*; UNHCR: Geneva, Switzerland, 2022.

9. Li, Y.; Feng, L.; Chen, B.; Kim, H.; Yi, S.; Guo, Y.L.; Wu, C. Association of urban particle numbers and sources with lung function among children with asthma or allergies. *Sci. Total Environ.* **2016**, *542*, 841–844. [CrossRef]
10. Lin, L.; Tsai, M.; Chen, M.; Ng, S.; Hsieh, C.; Lin, C.; Lu, F.L.; Hsieh, W.; Chen, P. Childhood exposure to phthalates and pulmonary function. *Sci. Total Environ.* **2018**, *615*, 1282–1289. [CrossRef]
11. Alaouie, M.; Troisi, G.M.; Saliba, N.; Shaib, H.; Hajj, R.; El Hajj, R.; Malak, S.; Jakarian, C.; Jaafar, W. Fungal Exposure and Shelter Assessment in Syrian Refugee Settlements in Lebanon. *Aerobiology* **2023**, *1*, 19–36. [CrossRef]
12. WHO. *Regional Office for Europe Human Biomonitoring: Facts and Figures*; WHO: Geneva, Switzerland, 2015; p. 88.
13. Sexton, K.; Needham, L.L.; Pirkle, J.L. *Human Biomonitoring of Environmental Chemicals*; National Academies Press: Washington, DC, USA, 2004; Volume 92, p. 38.
14. Hanson, N.; Halling, M.; Norin, H. *Biomarkers for Environmental Monitoring Suggestions for Norwegian Monitoring Programs*; Norwegian Environment Agency: Trondheim, Norway, 2013.
15. National Research Council. *Biological Markers in Environmental Health Research*; Committee on Biological Markers of the National Research Council; National Research Council: Washington, DC, USA, 1987; Volume 74, pp. 3–9.
16. Lam, P.K.S.; Gray, J.S. The use of biomarkers in environmental monitoring programmes. *Mar. Pollut. Bull.* **2003**, *46*, 182–186. [CrossRef]
17. Paredi, P.; Kharitonov, S.A.; Barnes, P.J. Analysis of Expired Air for Oxidation Products. *Am. J. Respir. Crit. Care Med.* **2002**, *166*, S31–S37. [CrossRef]
18. US Consumer Product Safety Commission. *Indoor Air Pollution: An Introduction for Health Professionals*; DIANE Publishing: Darby, PA, USA, 1996.
19. Horvath, I.; Loukides, S.; Wodehouse, T.; Kharitonov, S.A.; Cole, P.J.; Barnes, P.J. Increased levels of exhaled carbon monoxide in bronchiectasis: A new marker of oxidative stress. *Thorax* **1998**, *53*, 867–870. [CrossRef]
20. Uasuf, C.G.; Jatakanon, A.; James, A.; Kharitonov, S.A.; Wilson, N.M.; Barnes, P.J. Exhaled carbon monoxide in childhood asthma. *J. Pediatr.* **1999**, *135*, 569–574. [CrossRef]
21. Nathan, C.; Xie, Q. Nitric oxide synthases: Roles, tolls, and controls. *Cell* **1994**, *78*, 915–918. [CrossRef]
22. Taylor, D.R.; Pijnenburg, M.W.; Smith, A.D.; Jongste, J.C.D. Exhaled nitric oxide measurements: Clinical application and interpretation. *Thorax* **2006**, *61*, 817. [CrossRef]
23. Kelekci, S.; Sen, V.; Yolbas, I.; Uluca, Ü.; Tan, I.; Gürkan, M.F. FeNO levels in children with asthma and other diseases of the lung. *Eur. Rev. Med. Pharmacol. Sci.* **2013**, *17*, 3078–3082.
24. Pignatti, P.; Visca, D.; Loukides, S.; Märtson, A.; Alffenaar, J.C.; Migliori, G.B.; Spanevello, A. A snapshot of exhaled nitric oxide and asthma characteristics: Experience from high to low income countries. *Pulmonology* **2022**, *28*, 44–58. [CrossRef]
25. Tang, K.; Shao, X.; Liu, F.; Zhu, B.; Dong, Z.; Xu, W.; Yang, Q. Correlation between nitric oxide content in exhaled breath condensate and the severity of acute respiratory distress syndrome. *Int. J. Clin. Exp. Pathol.* **2017**, *10*, 7350.
26. Nguyen-Thi-Bich, H.; Duong-Thi-Ly, H.; Thom, V.T.; Pham-Thi-Hong, N.; Dinh, L.D.; Le-Thi-Minh, H.; Craig, T.J.; Duong-Quy, S. Study of the correlations between fractional exhaled nitric oxide in exhaled breath and atopic status, blood eosinophils, FCER2 mutation, and asthma control in Vietnamese children. *J. Asthma Allergy* **2016**, *9*, 163–170.
27. Brzozowska, A.; Majak, P.; Jerzyńska, J.; Smejda, K.; Bobrowska-Korzeniowska, M.; Stelmach, W.; Koczkowska, M.; Stelmach, I. Exhaled nitric oxide correlates with IL-2, MCP-1, PDGF-BB and TIMP-2 in exhaled breath condensate of children with refractory asthma. *Adv. Dermatol. Allergol./Postępy Dermatol. Alergol.* **2015**, *32*, 107–113. [CrossRef]
28. Fahy, J.V. Type 2 inflammation in asthma—Present in most, absent in many. *Nat. Rev. Immunol.* **2015**, *15*, 57–65. [CrossRef]
29. Dunican, E.M.; Fahy, J.V. The role of type 2 inflammation in the pathogenesis of asthma exacerbations. *Ann. Am. Thorac. Soc.* **2015**, *12*, S144–S149. [CrossRef]
30. Busse, W.W.; Kraft, M.; Rabe, K.F.; Deniz, Y.; Rowe, P.J.; Ruddy, M.; Castro, M. Understanding the key issues in the treatment of uncontrolled persistent asthma with type 2 inflammation. *Eur. Respir. J.* **2021**, *58*, 2003393. [CrossRef]
31. Kosoy, I.; Lew, E.; Ledanois, O.; Derrickson, W. Characterization of uncontrolled, severe asthma patients with type 2 inflammation (T2): Results from a physician survey across countries from Latin American, Eurasian Middle East regions and China. *J. Asthma* **2022**, *59*, 1021–1029. [CrossRef]
32. CIRCASSIA. Clinical Guidelines for The Interpretation of FeNO Levels. 2020. Available online: https://www.niox.com/en-us/feno-asthma/interpreting-feno/ (accessed on 24 April 2022).
33. Centre of Excellence in Severe Asthma. Inflammation Biomarkers in the Assessment and Management of Severe Asthma—Tools and Interpretation. 2019. Available online: https://www.severeasthma.org.au/biomarkers-recommendation/ (accessed on 24 April 2022).
34. Chiappori, A.; De Ferrari, L.; Folli, C.; Mauri, P.; Riccio, A.M.; Canonica, G.W. Biomarkers and severe asthma: A critical appraisal. *Clin. Mol. Allergy* **2015**, *13*, 20. [CrossRef]
35. Dweik, R.A.; Boggs, P.B.; Erzurum, S.C.; Irvin, C.G.; Leigh, M.W.; Lundberg, J.O.; Olin, A.; Plummer, A.L.; Taylor, D.R. An Official ATS Clinical Practice Guideline: Interpretation of Exhaled Nitric Oxide Levels (FeNO) for Clinical Applications. *Am. J. Respir. Crit. Care Med.* **2011**, *184*, 602–615. [CrossRef]
36. CIRCASSIA. *NIOX VERO Airway Inflammation Monitor*; User Manual; Circassia AB: Uppsala, Sweden, 2016.
37. National Institute for Health and Care Excellence. *Asthma: Diagnosis, Monitoring and Chronic Asthma Management*; National Institute for Health and Care Excellence: London, UK, March 2017.
38. Kumar, R.; Gupta, N.; Goel, N. Correlation of atopy and FeNO in allergic rhinitis: An Indian study. *Indian J. Chest Dis. Allied Sci.* **2013**, *55*, 79–83.

39. Czubaj-Kowal, M.; Nowicki, G.J.; Kurzawa, R.; Polak, M.; Ślusarska, B. Factors Influencing the Concentration of Exhaled Nitric Oxide (FeNO) in School Children Aged 8–9-Years-Old in Krakow, with High FeNO Values $\geq$ 20 ppb. *Medicina* **2022**, *58*, 146. [CrossRef]
40. Murugesan, N.; Saxena, D.; Dileep, A.; Adrish, M.; Hanania, N.A. Update on the role of FeNO in asthma management. *Diagnostics* **2023**, *13*, 1428. [CrossRef]
41. Serbina, N.V.; Salazar-Mather, T.P.; Biron, C.A.; Kuziel, W.A.; Pamer, E.G. TNF/iNOS-producing dendritic cells mediate innate immune defense against bacterial infection. *Immunity* **2003**, *19*, 59–70. [CrossRef]
42. Such, J.; Francés, R.; Pérez-Mateo, M. Nitric oxide in patients with cirrhosis and bacterial infections. *Metab. Brain Dis.* **2002**, *17*, 303–309. [CrossRef]
43. Zhang, X.; Xu, Z.; Lin, J.; Xie, G.; Lv, C.; Zhang, M. Sex differences of small airway function and fractional exhaled nitric oxide in patients with mild asthma. *Ann. Allergy Asthma Immunol.* **2023**, *130*, 187–198.e3. [CrossRef]
44. Olivieri, M.; Corradi, M.; Malerba, M. Gender and exhaled nitric oxide. *CHEST J.* **2007**, *132*, 1410. [CrossRef]
45. Janahi, I.; Saadoon, A.; Tuffaha, A.; Panneerselvam, B. Effects of age, gender, and environmental exposures on exhaled nitric oxide level in healthy 12 to 18 years Qatari children. *Ann. Thorac. Med.* **2012**, *7*, 98–103. [CrossRef]
46. Zhang, H.; Shu, L.; Cai, X.; Wang, Z.; Jiao, X.; Liu, F.; Hou, P.; Wang, L.; Shan, L.; Chen, N. Gender and age affect the levels of exhaled nitric oxide in healthy children. *Exp. Ther. Med.* **2013**, *5*, 1174–1178. [CrossRef]
47. Escamilla-Gil, J.M.; Fernandez-Nieto, M.; Acevedo, N. Understanding the cellular sources of the fractional exhaled nitric oxide (FeNO) and its role as a biomarker of type 2 inflammation in asthma. *BioMed Res. Int.* **2022**, *2022*, 5753524. [CrossRef]

# SWAC and SWAV Design Specification

| Parameters/Item | Unit | Range | Type | SWAC Unit |
|---|---|---|---|---|
| Application | N/A | N/A | Forced air - recirculation | <br> |
| Air flow | $m^3/hr$ | 282 – 798.5 | Volumetric | |
| Acoustics | dB | 56.0±0.07 - 79.5±0.12 | N/A | |
| Installation | N/A | N/A | Wall mount | |
| Manufacturing Cost | USD | 185 | Material | |
| Power consumption | Watt | 80 | N/A | |
| Voltage requirement | Volt | 12 | N/A | |
| Power source | N/A | N/A | Solar (photovoltaic) | |
| Weight of device | Kg | 5.9 | N/A | |
| Frame material | N/A | N/A | Zinc-plated steel | |
| Frame dimensions | cm | L:52 – H:40 – W:40 | N/A | |
| Fan and motor | N/A | N/A | PVC - Axial – DC brushed motor | |
| Fan dimensions | Inch | 12 | N/A | |
| Gross dimensions | cm | L:53 – H:42 – W:42 | N/A | |

| **Parameters/Item** | **Unit** | **Range** | **Type** | **SWAV Unit** |
|---|---|---|---|---|
| Application | N/A | N/A | Forced air |  |
| Air flow | $m^3/hr$ | 124 - 194 | Volumetric | |
| Acoustics | dB | 46±0.03 - 63.3±0.03 | N/A | |
| Installation | N/A | N/A | Wall mount | |
| Manufacturing Cost | USD | 56 | Material | |
| Power consumption | Watt | 20 | N/A | |
| Voltage requirement | Volt | 12 | N/A | |
| Power source | N/A | N/A | Solar (photovoltaic) | |
| Weight of device | Kg | 1.5 | N/A | |
| Frame material | N/A | N/A | Stainless steel | |
| Frame dimensions | cm | L:25.4<br>H:25.4<br>W:3.5 | N/A | |
| Fan and motor | N/A | N/A | PVC – DC brushed motor | |
| Fan dimensions | cm | 12 | N/A | |
| Gross dimensions | cm | L:32<br>H:32<br>W:4 | N/A | |