Measurement and analysis of air quality in temporary shelters on three continents

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Abstract

Millions of displaced people are housed in shelters that generally consist of a single room, meaning that activities including cooking, sleeping and socialising all take place in the same space. Therefore, indoor air quality can be poor, resulting in estimated 20,000 displaced people dying prematurely every year. Very few studies considered the issue and all within one country. This paper describes the first comprehensive study investigating air quality in shelters by looking at Volatile Organic Compounds (VOCs), Particulate Matter (PM), and CO_2 in ten locations within Peru, Ethiopia, Djibouti, Jordan, Turkey and Bangladesh. It has the aim of: (i) discovering how widespread the issue is, (ii) identifying some of the causes, (iii) whether it is linked to cultural and behavioural factors, (iv) location and climate, or (v) shelters' materials or design. Results revealed very harmful levels of pollutants that are often linked to excess mortality - with total VOC concentrations as high as 102400µgm^{-3} and PM over 3000µgm^{-3}. The reasons for these concentrations were complex, multifaceted and setting-specific. However, it was an issue in both simple self-built shelters and mass-manufactured designs, and across all climates and cultures. In all cases, conditions could be greatly improved by improving airflow as windows were frequently blocked for various reasons. Therefore, airflow should be explicitly considered, whilst being cognisant of the local context; and when cooking is likely to occur indoors, chimneys must be fitted.

Key words: Indoor air quality, temporary shelters, refugee camps, Particulate Matter, Volatile Organic Compounds.

1. Introduction

Air quality is increasingly recognised as an important factor having a major effect on human health [1] [2] [3]. Numerous studies looked at the health impact as a result of exposure to certain pollutants. For example, exposure to CO_2 levels higher than 5000ppm is recognised to cause adverse health effects, but a growing body of research [4] suggests that exposure to CO_2 levels <5000ppm and as low as 1000ppm could cause health problems even if exposure only lasts for a few hours; these include inflammation, reduced higher-level cognitive abilities, bone demineralisation, kidney calcification, oxidative stress and endothelial dysfunction. Another study in 652 cities revealed that an increase of 10μgm^{-3} in PM_{10} levels was associated with a 0.44% increase in mortality (on average, the annual mean concentration of PM_{10} in 598 cities was 56.0μgm^{-3}) [5]. Whilst outdoor air quality mainly relates to pollution from transport and industry, sources of indoor pollution include tobacco smoking, dampness, cooking, indoor burning of solid fuels, dust, chemicals from building materials and coatings, furnishings, aerosol sprays, and cleaning products [6] [7] [8] [9] [10] [11] [12] [13]. Indoor pollutants are often present at higher concentrations than outdoors [14]. However, exposure time is also an important consideration [15]. Lim et al. (2012) reported that in 2010 the three leading health risk factors were high blood pressure, tobacco smoking, and household air pollution from solid fuels (wood, crop residues, animal dung, charcoal and coal) [16]. In much of the developing world and especially in refugee camps the use of solid fuels for cooking and heating is commonplace [17].

There are currently 70.8 million people displaced due to armed conflicts [18]. In addition, natural disasters were responsible for the displacement of a further 17 million people in 2018 [19]. Millions of displaced people are housed in temporary shelters for years or even decades. These shelters generally consist of a single unit, meaning that activities such as cooking, sleeping and socialising (which can involve smoking) all take place in the same space. Consequently, indoor air quality (IAQ) can be poor, and vulnerable people such as children and the elderly who spend most of their time indoors are often exposed to increased health risks. It is estimated that 20,000 refugees and internally displaced people die prematurely every year as a result of poor IAQ owing to the reliance on solid biomass for cooking and heating [20].

Very little work has been done to investigate IAQ in refugee camps or temporary shelters. A limited number of studies have examined the impact of cooking fuels specifically [17]. The Gaia project in Ethiopia by UNHCR and Shell Foundation found that in Shimelba Camp 69% of all cooking occurs inside the shelters, using charcoal (42%), fuelwood (31%) and kerosene (15%). Health issues such as cough, headaches, eye irritation, constant phlegm and shortness of breath were reported among primary cooks. As a result, ethanol combusting stoves known as CleanCook were distributed to households [21]. In another related study [22], the concentration of Carbon Monoxide (CO) and particulate matter ($PM_{2.5}$) were monitored before and after the installation of CleanCook in Kebribeyah and Bonga camps where three-stones fire were originally used. The study found that the average $PM_{2.5}$ concentrations over 24-hours for all monitored shelters decreased by 84% from 1250μgm^{-3} in the 'before' phase to 200μgm^{-3} in the 'after' phase. Similarly, the 24-hours CO mean decreased from 38.9ppm to 9.2ppm. Under the same Gaia project, measurement of CO in seven shelters in which fuelwood was used, revealed a high level of 100ppm before cooking which increased to nearly 300ppm during cooking, this then reduced to 150ppm following dinner [23].

None of these studies looked at the levels of volatile organic compounds (VOCs) or other sources of poor IAQ. This paper has the objectives of: (i) discovering how widespread the issue of poor air quality is in temporary shelters, (ii) identifying some of the causes, (iii) whether it is linked to cultural or behavioural factors, (iv) the location and climate, (v) or the shelters' materials or design The levels of airborne particulate matter (PM) and/or VOCs were measured in fifty-three occupied temporary shelters located in six different countries over three continents. In addition, CO_2 levels were measured where possible and other issues impacting IAQ such as mould growth or the intrusion of insects were reported. The shelters studied were in, Azraq and Zaatari Syrian refugee camps in Jordan; Hitsats Eritrean refugee camp in Ethiopia; Kutupalong Rohingya refugee camps in Bangladesh; Yemni refugee camp in Djibouti; informal refugee settlements near Adana in Turkey, and displaced people shelters located in Trujillo, Viru, Yanque and Chivay in Peru. In total, these camps host over one million displaced people (Figure 1).

Figure 1: Map source: Freepik.com, image adapted to highlight countries in which air quality measurements were taken (Peru, Turkey, Jordan, Djibouti, Ethiopia and Bangladesh).

2. Guidance and standards on IAQ

There are several environmental assessment schemes such as BREEAM and LEED, building regulations and guidance such as the UK Air Quality Strategy, which provide guidance on IAQ. The nature of pollutants, sources, construction materials, building designs and locations all play an important role in determining IAQ. Globally there is limited guidance on recommended concentration and enforceable standards specifically for IAQ [24]. The World Health Organization (WHO) provides guidance on pollutant levels below which no risk to health is present, as well as guidelines for PM exposure [15]. In the UK, the Committee on the Medical Effects of Air Pollution (COMEAP) recommends concentrations limits for formaldehyde, benzene, and polycyclic aromatic hydrocarbons, while in the US Environmental protection agency (EPA), provides reference concentrations for inhalation exposure for many chemicals [25]. No federally enforceable standards exist for VOCs in the US, which is similar around the world. However, Indoor Air Quality UK (IAQUK) provide several ratings from excellent (< 100µgm^{-3}) to inadequate (> 1000µgm^{-3}) for TVOC (Total VOC) and similarly for PM levels (excellent < 23µgm^{-3} and inadequate > 65µgm^{-3}) [26]. Table 1 presents a summary of the limits for common air pollutants according to different standards. While both BREEAM and LEED considers a variety of assessments and rewards testing and measurements of post-construction VOC and formaldehyde in accordance with either ISO 16000 [27] (for BREEAM and LEED) or the ASTM 5197 [28](LEED) suite of standards.

Table 1: Recommended maximum limits of exposure for different common indoor air pollutant according to leading organisations.

Guidance	Pollutant						
	TVOCs μgm^{-3}	**Benzene μgm^{-3}**	**Formalde-hyde μgm^{-3}**	**Polycyclic aromatic hydrocarbons (PAH) μgm^{-3}**	**PM10 μgm^{-3}**	**PM2.5 μgm^{-3}**	**CO_2 PPM**
World Health Organization (WHO) [15]		No safe limit	100 (30-mins mean)	8.7×10^{-8}	50 (24-hrs mean)	25 (24-hrs mean)	
Committee on the Medical Effects of Air Pollutants, UK (COMEAP) [29]		5 (annual mean)	100 (30-mins mean)	0.25×10^{-3} (annual mean)			
Environmental Protection Agency EPA [25] [30]		30 (reference concentrati on RfC)			150 (24-hrs mean)	12 (annual mean)	
UK building regs [31]	300 (8-hrs mean)						
Finnish Society of IAQ and Climate [32] [33]	<200 (90% of occupants satisfied)		30		20		700
Chartered institution of Building Engineers, UK (CIBSE) guide A [34]							1000
UK HSE Workplace Exposure Limits [35] [36]		3250 (8-hrs weighted average)	2500 (8-hrs weighted average)				5000 (8-hrs weighted average)

3. Methodology

Due to the challenges of fieldwork in displacement settings, (e.g limited access times, and prevalent mistrust of monitoring equipment), it was not possible to conduct 24-hour monitoring of shelters. Instead, 'snapshots' of VOCs and PM levels were recorded over approximately 25-30 minutes, as this was deemed to be the best compromise between acceptability on site (to limit inconvenience to occupants), and smoothing out transient concentrations of VOCs and PM. Where possible, passive sampling for VOCs was conducted over a week; and CO_2 as spot measurements or over 24-hours. However, it was not possible to take all types of measurements in each location (see Table 2). The sampling across the studied countries was conducted during several trips over 3 years. Seasons and conditions varied, as well as the time of the day of sampling. However, all snapshot sampling was conducted during daytime hours (permitted camp access time). The shelters were mostly selected at random, mainly based on whether the occupants allowed us to conduct monitoring or not. The monitored shelters were not controlled and remained in use during sampling. For example, doors and windows were open or closed, and occupants on a few occasions were smoking or had guests visiting leading to an increased occupancy. In Ethiopia, Djibouti and Bangladesh where cooking with solid fuel was known to be an issue, additional sampling was agreed with the occupants during cooking as well as the random snapshots.

Table 2: Table summarising the format of testing carried out in the refugee shelters from camps from different countries included in this study.

Country (season)	PM (30 minutes sample)	VOCs (25 minutes active sampling)	VOCs (passive sampling over a week)	CO_2 (spot measurements)	CO_2 (24 hours)
Jordan (summer)	✓	✓	✓	✓	
Jordan (winter)				✓	
Turkey (spring)		✓			
Ethiopia (summer)	✓	✓	✓		
Ethiopia (winter)	✓	✓		✓	
Peru (summer)	✓	✓	✓		
Djibouti (autumn)	✓	✓	✓		✓
Bangladesh (summer)	✓	✓			

3.1 VOCs monitoring

VOCs are organic chemicals that can evaporate from liquid to gas phase at ambient temperature. Depending on the specific VOC, they can be harmful to human health in both low and high concentrations. VOCs are found in many everyday products, such as paints, cleaning and personal care products, fossil fuels, building materials, and furniture. The concentration of VOCs in shelters was determined by air sampling using conditioned Tenax TA Perkin Elmer style tubes in accordance with the International Organization for Standardization (ISO) standard EN-ISO-16000-6:2011 [27] supplied by Markes International Ltd. The sampling pump was a Casella Vortex, modified to use D size batteries in order to circumvent any possible issues with recharging in areas where availability of mains electricity could be intermittent.

Either active, passive or both VOC sampling was performed. Active sampling involved drawing air through the tube using a sampling pump calibrated at 12 litres/hour for 25 minutes (which will not allow the tube to become totally saturated). N.B. ISO 16000 part 6 does not specify sampling times, but it recommends flowrates between 50 and a maximum of 200 ml/min, and sampling volumes of between 1 and 5 litres of air. While it allows a flow rate lower than 50 ml/min to enable longer sampling times, the practical sampling period would be between 5 and 100 minutes.

Passive monitoring involved leaving an opened tube in the environment to be monitored for seven to 14 days to give an idea of mean VOC concentrations over longer periods of time. In the method used (based upon ISO 16017-2:2003 [37]) assumptions are made regarding the uptake rate of VOCs (in ml/min) over the period of diffusive sampling when converting the amount of compound on the tube to a time-weighted average concentration in air.

Analysis of the adsorbed VOCs on the tubes was conducted by the Building Research Establishment (BRE). In this context, VOCs are defined as chemical compounds with boiling points between 60-280°C trapped on the Tenax-TA tubes. Analysis of the tubes was carried out using a Perkin Elmer AutoSystem XL GC, equipped with a 350 Automatic Tube Desorber (ATD) and a Turbomass MS. Identification of VOCs was carried out using a combination of retention time and mass spectral "fingerprint"; quantification was carried out using a flame ionisation detector FID. TVOC concentration was calculated as the sum of compounds eluting between (and including) n-hexane and n-hexadecane, quantified as toluene. Therefore, the TVOC concentration can differ from the sum of the individual VOCs reported.

3.2 Particulate Matter (PM) monitoring

PM is dust and other particulates which originate from combustion (e.g cooking, smoking), the external environment or materials which can release particles. Inhalable particulates have different sizes up to 10µm in diameter. Inhalable coarse particles with a diameter less than or equal to 4 and 10µm (PM_4 and PM_{10}), and fine particles with a diameter of less than or equal to 2.5µm or 1µm ($PM_{2.5}$ and PM_1) were measured by air sampling using a TSI DustTrak DRX Desktop Aerosol Monitor. The PM_{10} fraction includes the PM_4 $PM_{2,5}$ and PM_1 fractions, etc. The device was placed in the middle of the shelter (approx. 0.5 to 0.8m above the floor) and air was sampled for 30 minutes at a constant total flow rate of 3 l/min. Results are reported as the total mass of particles from 0.1µm up to the particle size specified.

3.3 Carbon dioxide monitoring:

CO_2 is naturally present in the atmosphere at around 400ppm and doesn't constitute a health risk at low levels up to around 1000ppm. However, exposure to higher concentrations, which may occur in under-ventilated indoor environments can cause various health issues such as headaches and dizziness. At high concentrations above 40,000ppm exposure can lead to oxygen deprivation causing brain damage, or death. In Azraq and Zaatari camps, Jordan, 136 spot measurements of CO_2 were taken in summer and winter; and similarly, in Ethiopia spot measurements of CO_2 were taken in 286 shelters in Hitsats refugee camp using Extech CO_2 meter (model CO250) that can measure levels between 0 and 5000ppm. In Djibouti, CO_2 was monitored using TinyTag (model TGE-0011) CO_2 data logger. The TGE-0011 can monitor levels between 0 and 5000ppm using a 'self-calibrating' infrared sensor. 24-hours sampling from two different shelters at one-minute intervals was conducted.

3.4 Interviews and other observations:

Interviews and surveys with at least 40 families in each location were conducted as part of a larger study [38] [39] [40], information which are relevant to IAQ (ventilation adequacy, kitchen location, cooking fuels and other activities) are reported in section 4, thereby providing context to the measurements. Furthermore, during active sampling, the occupants were asked about their general health, due to the limited number of shelters monitored in each location (four to ten shelters), these conversations provide anecdotal evidence, which is drawn on in the results section were appropriate. The monitored shelters were also observed by the visiting researchers for other possible issues that may impact IAQ. For example, fungal (mould) growth is a known source of spores which are classed as PM, human activities that generate water vapour increases humidity inside the shelters, which supports mould growth.

4. The surveyed locations and shelters

Below is an overview of the studied locations' context, climate, shelters and human activities in these shelters as found during our visits and surveys. (See Table 3 for a summary).

Table 3: Summary of the climate, the shelter size (area), and mean number of inhabitants per shelter, mean temperature during active sampling, construction materials and fuel used for cooking in each location.

Country	Camp	Climate	Shelter Area (m^2)	Mean No of people/shelter	Mean Temp (˚C)	Shelter Materials	Cooking fuel
Jordan	Zaatari	Semi-arid	15	6	36.5	40mm insulated sandwich steel panels wall & roof, steel or MDF inner surface of the walls, suspended timber floor or concrete	Gas bottles (LPG)
	Azraq	Hot arid	24	6	35.6	Two layers of Corrugated Galvanised Iron (CGI) & 15mm aluminium foam insulation, concrete floor	LPG
Turkey	Adana	Mediterranean	12-24	6	23.7	Fabric and plastic sheets on earth ground	LPG/wood
Ethiopia	Hitsats	Semi-arid	15-20	6.5	33.7 (S) 30 (W)	Block walls, CGI roof, earth ground	Charcoal
Djibouti	Markazi	Hot arid	18	4	28	Prefabricated insulated steel panels	Kerosene
	Markazi	Hot arid	9			Prefabricated insulated steel panels	Kerosene
Bangladesh	Cox's Bazar	Tropical monsoon	19.5	5.5	33.5	Self-built bamboo shelters with tarpaulin sheeting	Wood
Peru	Trujillo	Hot arid	19	4.2	29.5	6mm cement panels, suspended timber floor, fibre cement roof	LPG/wood
			12.5			Timber walls, concrete floor, CGI roof	LPG/wood
	Viru	Hot arid	20	3.7	28	Plaster, bamboo panels, concrete floor, CGI roof	LPG/wood
			18			OSB (orientated strand board) panels, suspended timber floor, CGI roof	LPG/wood
	Yanque	Cold semi-arid	18	3	20.8	52mm insulated sandwich panel wall & roof, concrete floor	LPG/wood
	Chivay	Cold semi-arid	18	3.2	16.5	52mm insulated sandwich panels wall & roof, suspended timber floor	LPG/wood

4.1 Azraq and Zaatari refugee camps in Jordan

Due to the ongoing war in neighbouring Syria, Jordan currently hosts over 100,000 refugees in Azraq and Zaatari refugee camps alone (Figure 2). Jordan is characterised by an arid climate and suffers from dust storms in autumn and spring.

4.1.1 Zaatari Refugee Camp

a. Location and environment: Zaatari refugee camp (32.29°N, 36.33°E) located in northern Jordan, opened in 2012 and is home to nearly 80,000 Syrian refugees. The mean maximum outdoor temperature is 32.7°C, and the mean minimum is 1.9°C [41].

b. The shelters: The shelters used are generally caravan-like structures made of 40mm polyurethane insulated sandwich panel with inner and outer surfaces of 0.35mm steel sheet; however, they sometimes have medium-density-fibreboard (MDF) inner surfaces. The floors are either a concrete slab or a suspended timber floor. The caravans have one door and one or two windows. Each caravan (15m^2) is designed to house a family of six; however, the refugees have significantly adapted these shelters, creating extensions and relocating windows.
c. Activities: our surveys have found that cooking takes place outside the caravan in a makeshift enclosure built by the refugees themselves in 57% of the cases, and inside the caravan in 43%. Gas bottles (LPG) are the main cooking and heating fuel. In winter a gas heater is used for an average of 10 hours a day. Cleaning products are generally used frequently in the morning. Dust and sandstorm were the occupants main concern with regards to air quality in shelters.

4.1.2 Azraq Refugee Camp

a. Location and environment: Azraq camp (31.91°N, 36.59°E) is in the Jordanian desert. It first opened in 2014, and currently houses 40,000 refugees. In Azraq, the mean maximum outdoor temperature is 36°C and the mean minimum is 2.8°C [41].
b. The shelters: 13,500 shelters were built of corrugated galvanised iron sheeting (CGI) separated by 10mm of foam-based insulation. The shelters have only one window and high-level openings consisting of short lengths of 152mm waste pipes on the gables, three in total, thereby restricting the ability to cross ventilate.
c. Activities: Gas bottles are the primary source of heating and cooking fuel (Figure 3). Cooking was reported to take place in the main unit by 75% of interviewed families. Cleaning products are generally used frequently in the morning. Similarly to Zaatari, sand ingress was a major concern.

Figure 2: (a): Mobile shelters in Zaatari refugee camp, Jordan; (b): T shelters in Azraq refugee camp, Jordan. Photos credits: S.T. Coley

Figure 3: Azraq & Zaatari refugee camps. (a): plastic bags used to fill in gaps in the structure to prevent sand ingress; (b): gas heater used in winter; (c): examples of gas cookers used inside shelters; (d): example of makeshift external kitchen; (e): example of an internal kitchen seperated from the living and sleeping space with a curtain. Photos credits: authors.

4.2 Informal refugee settlements near Adana, Turkey

a. Location and environment: Turkey, currently hosts over 3.5 million Syrian refugees. Thousands of these have settled in informal makeshift camps near agricultural land on which they also work. In Adana, the mean maximum outdoor temperature is 25.3°C and the mean minimum is 14°C [41].
b. The shelters: The shelters were tent-like structures, mostly made from repurposed greenhouse's frames, plastic sheeting and fabric and situated directly onto earth that is covered with cardboard and carpets.
c. Activities: solid fuel (coal, wood, cardboard and other household waste) burning stoves were used for heating in winter and for warming food. Gas hobs were used for cooking (Figure 4).

Figure 4: (a): inside of self-built shelter in Adana, Turkey; (b): outside view of the shelters; (c): stoves used for heating; (d): gas hob for cooking. Photos credits: authors.

4.3 Hitsats refugee camp in Ethiopia

a. Location and environment: Hitsats camp opened in May 2013 and is home to 15,000 Eritreans refugees. The location is generally characterised as semi-arid. The mean maximum outdoor temperature is 37.5°C, and the mean minimum is 20°C [41].
b. The shelters: Around 1,333 permanent shelters are mainly built of hollow concrete blocks (HCB) on a stone masonry foundation directly on earth and CGI roofs supported by wooden pole trusses. The shelters' area is 15 to 20m^2, with one or two a 60x80cm openings covered with CGI. The shelters are sometimes overcrowded with up 25 people. A limited number of shelters are entirely built with CGI.
c. Activities: The households visited were all using charcoal stoves (Figure 5). Cooking took place either inside the shelter or in a makeshift extension adjacent to the shelter, in addition traditional bread stoves were used outdoors. Coffee is also prepared on the coal stoves inside the shelters several times a day. No heating devices were used; the cooking stoves were used for heat in winter.

Figure 5: (a): shelters made of blocks in Hitsats refugee camp; (b): coal-stove used for cooking and making coffee inside shelters; (c): traditional bread cooking outdoor stove. Photos credits: authors.

4.4 Disaster stricken areas in Peru

IAQ in temporary shelters was investigated in two main regions in Peru; the first included La-Esperanza camp and Viru town which affected by severe flooding and displacement of 79,623 people in 2017. The second location in the Andes Mountains included the towns of Yanque and Chivay which were affected by 2016 earthquake of 5.8 magnitudes.

4.4.1 La-Esperanza Camp, Trujillo

a. Location and Environment: La-Esperanza Camp (-8.04°N, -79.05°E) located in the north of Peru, on the outskirts of Trujillo city. It was established in 2017 for 251 displaced people. The mean maximum outdoor temperature is 22.3°C, and the mean minimum is 15.5°C [41].
b. The Shelters: Two types of shelters were visited. The first type consists of three spaces and have three 0.8m^2 windows on the front facade and two small raised windows on the rear facade. These shelters are elevated off the ground by wooden pillars. They are made of a timber structure and 6mm panels (composed of cement, cellulose fibre, silica, water and aggregates [42]), a corrugated 'fibre-cement' sheet for the roof and a phenolic plywood board for the floor. The second type of shelters consists of two rooms, each has one window. It is built from a timber structure and timber panels, installed on a concrete floor, with a CGI roof. The spaces between the shelters are mostly covered with plastic sheeting to create extensions, blocking the windows and preventing adequate ventilation.
c. Activities: Our surveys have found that 95% of the households have built extensions with temporary materials like plastic-sheeting or timber. In over half of the cases, cooking happens in these external spaces. Whilst all the shelters have an interior kitchen with a gas hob, 26% of

households still use wood for cooking in external kitchens. This is because gas is more expensive than wood which can be collected for free (Figure 6).

Figure 6: La-Esperanza camp, makeshift extensions between shelters restrict ventilation, (a): shelter type 1; (b): shelter type 2. Photo credits: authors

4.4.2 Viru

a. Location and Environment: Viru town (-8.40°N, -78.80°E) is near the city Trujillo. Shelters were installed on the plots of destroyed houses rather than moving the affected population to a camp. The mean maximum outdoor temperature is 22.3°C, and the mean minimum is 15.5°C [41].
b. The Shelters: There were two types of temporary housing. Both shelters consist of one large room. The first type has an area of 20m^2, erected on a concrete slab, the structure is made of timber, the walls are made from bamboo cane panels and the roof is made of CGI. The walls were reinforced on the inside with plaster. The shelter design is well ventilated; however, in most cases, all openings were blocked by panelling or plastic sheets due to the shelter being cold at night and in winter. The second shelter is made of a timber structure, suspended timber floor, orientated strand board (OSB) wall panels and CGI roof. It has only two windows on the front facade and an area of approximately 18m^2.
c. Activities: The shelters are mainly used as bedrooms; make-shift external kitchens are made using tarpaulin or CGI (Figure 7). Similarly to La-Esperanza, gas hobs or wood stoves are used for cooking.

Figure 7: Viru, (a): shelter type 1: high level openings covered with tarpaulin to protect from the cold. (b) external cooking using wood fire; (c): internal cooking using a gas hob. Photos credits: authors

4.4.3 Yanque and Chivay

a. Location and environment: Yanque and Chivay towns (-15.65°N, -71.65°E) are located at an altitude of 3420m and 3635m above sea level respectively and were affected by 2016 earthquake. The mean maximum outdoor temperature is 17.6°C, and the mean minimum is -1.3°C [41]. Ash and volcanic activity affect the air quality in Yanque and Chivay.
b. The Shelters: The Housing Ministry installed 109 shelters on the plots of the affected people in Yanque and 162 Shelters in Chivay. The shelters are made of 52mm insulated sandwich panels with inner and outer surfaces of 0.35mm steel sheet to form the walls and the ceiling. The shelters either sit on a concrete slab that was constructed by the occupants or have a suspended floor made of metal and timber structure with a vinyl floor covering. Two single-glazed windows are provided. The shelter has a total area of 18m^2 and is divided into two rooms.
c. Activities: Gas hobs are available for cooking within the shelters; however, it is more common for cooking to take place outside the shelter using wood (Figure 8). In some of the cases, the windows were covered with plastic sheets to prevent draughts, and the walls were covered with cardboard or blankets to avoid cold surfaces. No heating stoves were reported to be used in winter despite the low temperatures. The concrete floors were generally damp.

Figure 8: Typical cooking facilities at Yanque and Chivay camps. (a): Gas hob inside the shelter; (b) external makeshift wood stove. Photos credits: authors

4.5 Refugee camps around Cox’s Bazar in Bangladesh

a. Location and environment: Bangladesh host almost a million Rohingya refugees. The majority are hosted in camps in Cox’s Bazar region, Kutupalong refugee camp is the largest of these. The climate is classified as tropical with the average annual temperature of 25.6°C.

b. Shelters: refugees have settled in makeshift settlements and spontaneous camps in self-built shelters with bamboo and tarpaulin bought or supplied upon arrival. Most shelters lack any windows for security and privacy concerns, or perceived difficulty in creating these without compromising the structural integrity of the shelters.

c. Activities: The great majority of the displaced families use wood or rice husks as a cooking fuel, collected locally or distributed to them. A few families had access to bottled gas. Cooking mostly happens indoors due to camps overcrowding and lack of external space for such activity (Figure 9).

Figure 9: Kutupalong refugee camp, Bangladesh; (a): overcrowding in the camp limits ability to ventilate; (b): Cooking inside shelters using wood fire, Dust-Trak particulate monitor and VOC sampling pump are visible on the red chair. Photo credits: authors.

4.6 Markazi refugee camp, Obock, Djibouti

a. Location and Environment: Markazi camp is near Obock in northeast Djibouti and has a population of 1,233 refugees, mostly from Yemen. The climate is extremely hot and very dry in summer. No weather data is available for Obock, the mean maximum outdoor temperature of Djibouti city is 34°C, and the mean minimum is 25.8°C [41].

b. The shelters: Prefabricated shelters are comprised of either two rooms for families or a single room for singles, a kitchenette and a toilet. All the shelters are equipped with air conditioners (AC). There are two windows in the two-room shelters and one window in the single-room shelters.

c. Activities: Almost all households cook on kerosene stoves inside the shelters during electricity hours (Figure 10). During cooking, the AC are on and the door and windows are closed to maintain cool temperatures. Kerosene is also used to repel insects. Most of the visited families complained of eye irritation and respiratory issues (e.g. difficulty breathing and coughing).

Figure 10: (a): Prefabricated shelters in Markazi refugee camp, Djibouti; (b): Kerosene stove. Photos credits: authors

5. Results

5.1 VOCs

VOCs identified in the air sampled within temporary shelters are presented in Table 4. In this study, the compounds detected have been classified as nuisance, irritant, harmful and toxic depending on the relative impact they may have on the wellbeing of shelter occupants. These classifications are subjective and may vary for different occupants depending on their personal tolerances. Compounds that are likely to have originated from personal care products such as fragrances have been classified as nuisance/irritant [43]. Compounds from sources such as paints/solvents which are not acutely toxic, but where exposure may lead to effects such as sensitisation and a lowering of wellbeing, have been classed as harmful. The concentrations of all compounds which are known to cause serious health effects such as cancer, irrespective of the concentration detected, are classed as toxic.

In both Azraq and Zaatari camps in Jordan, the TVOC levels detected were low (ranged from 6 to 80µgm^{-3}) - well below the 300µgm^{-3} guideline concentration for TVOCs suggested by UK building regulations [31]. Common compounds found were mostly those that originate from personal care and cleaning products and all fall under the nuisance/irritant category. This was also the case in the shelters in Adana, Turkey where TVOC was between 27 to 65µgm^{-3}.

Similarly, in shelters in all regions studied in Peru, TVOC levels ranged from 1 to 176µgm^{-3} and mostly fell under the nuisance/irritant category. However, in one case in La-Esperanza, low concentrations of undecane (2µgm^{-3}) and dodecane (2µgm^{-3}) which can be harmful were detected. Both undecane and dodecane are solvents found in paints, adhesives and fuels.

In Bangladesh, Ethiopia and Djibouti where solid fuels are used for cooking inside the shelters, VOCs were higher during cooking and sometimes significantly exceeding recommended limits. In Bangladesh, TVOC levels from 436 to 4830µgm^{-3} were observed during cooking with wood fuel. A significant proportion of the VOCs consisted of benzene, up to 845 µgm^{-3} in one case, and styrene up to 179µgm^{-3}. These high levels are particularly concerning as these compounds are toxic and the WHO recommends no safe level for benzene and 70µgm^{-3} for styrene [15]. In Ethiopia, TVOC levels ranged from 10 to 297µgm^{-3}, and benzene levels of up to 10µgm^{-3} were detected.

The highest TVOCs inside shelters were found in Markazi camp, Djibouti, where cooking on kerosene stoves caused levels ranging from 140 to 17200µgm^{-3}. However, even in shelters in which no kerosene stoves were used for cooking during sampling; high levels of VOCs were still detected for different reasons. Kerosene is not only used for cooking, but it is also sprayed on the floors to repel insects and flies. For example, in one shelter, in which the occupants usually cook inside using kerosene but were not doing so during sampling, the TVOC level was 3920µgm^{-3}. While in another shelter, in which occupants were deep-frying fish on an *electric* hob during sampling, TVOCs were 2920µgm^{-3}. The highest TVOC was found in a shelter where the occupants never cook inside but were burning Arabic incense during sampling to ward off insects (TVOC=102400µgm^{-3}). The VOC levels recorded in Djibouti are alarming, with harmful aliphatic hydrocarbons ranging from 240 to 81600µgm^{-3}, and benzene levels between to 5 to 6400µgm^{-3}.

It is noteworthy that during sampling inside some of the shelters, research team members were often only able to tolerate the kerosene-polluted atmosphere for up to five minutes before having to leave for fresh air outside the shelter. In almost every shelter at least one of the occupants complained of headaches, respiratory problems and itchy eyes which was almost inevitably due to kerosene inhalation. These issues are potentially further exacerbated due to lack of ventilation during cooking. To maintain tolerable temperatures inside the shelters, families in Markazi camp, Djibouti, usually cook when electricity is available allowing the AC to be switched on with doors and windows closed.

*Table 4: Total Volatile organic compound (TVOC) and toxic VOC levels found in all shelters (Shelter ID: The first letter stands for the country, camp name, shelter number, NC: no cooking, C: cooking, * indicates passive sampling). (#A) Nuisance VOCs: α-pinene, β-pinene, terpenes, limonene, decamethylcyclopentasiloxane, Octamethylcyclotetrasiloxane (OMCTS) D4, octanal, nonanal, decanal, naphthalene, ethylbenzene, benzoic acid, 2-ethylhaxan1-ol, 2-ethylhexylacetate, 2-ethylhexylacrylate, p-cymene. (#B) Harmful VOCs: octane, nonane, decane, undecane, dodecane, di-isobutylphthalate*

Country	Shelter ID	Known polluting activity during active sampling	µgm^{-3}								
			TVOC	Toluene	Hexamethylcyclotri siloxane (HMCTS)	Aliphatic hydrocarbons	Styrene	Benzene	Methylcyclohexane	#A	#B
Ethiopia (June 2019-summer)	E-Hitsats-1-NC		25					10			
	E-Hitsats-2-C	Cooking (coal)	10								
	E-Hitsats-3-NC		15		7						
	E-Hitsats-4-NC		12								
	E-Hitsats-1*		279							241	
	E-Hitsats-2*		63					4		29	
	E-Hitsats-3*		44							34	
	E-Hitsats-4*		41					2		24	2
Ethiopia (Jan 2020 - winter)	E-Hitsats-5-C	Cooking (coal)	10					4			
	E-Hitsats-5-NC		1		4						
	E-Hitsats-6-C	Cooking (coal)	46		6			24		7	
	E-Hitsats-6-NC		3		6						
	E-Hitsats-7-C	Cooking (coal)	17		3			13			
	E-Hitsats-7-NC		2		4			2			
	E-Hitsats-8-C	Cooking (coal)	76		20			21	8	3	
	E-Hitsats-8-NC		75	6	79				43	18	
	E-Hitsats-9-NC		4					2		3	
Dji	D-Markazi-1-C	Cooking (Kerosene)	3560	152	80	3360		31			

	D-Markazi-2-C	Cooking (Kerosene)	17200	208	140	15600		680			
	D-Markazi-3-C	Cooking (electric hob) – deep frying fish	2920			3600					
	D-Markazi-4-C	Cooking (Kerosene)	7200	132		5800		720			
	D-Markazi-5-NC		3920	12	38	2600		8			
	D-Markazi-6-C	Cooking (Kerosene)	1800	21		1800		29			
	D-Markazi-7-C	Cooking (Kerosene)	4800	64	40	4400		26			
	D-Markazi-8-C	Cooking (Kerosene)	5600	116	34	4400		440			
	D-Markazi-9-C	Cooking (Kerosene)	140	24		440		3		37	76
	D-Markazi-10-NC	Burning Arabic incense	102400	1880	600	81600		6400			
Peru (Feb 2019 – Summer)	P-LaEsp-2-NC*		42	11						14	
	P-LaEsp-3-NC		21	7						4	
	P-LaEsp-3-NC*		55	15						5	
	P-LaEsp-4-NC		45	35						2	
	P-LaEsp-5-NC		88	15						14	10
	P-LaEsp-6-NC		30							14	
	P-Yanque-1-C	Cooking (LPG)	3								
	P-Yanque-2-NC		1								
	P-Chivay-1-NC		4								
	P-Chivay-2-NC		176		21					136	
Jordan (Aug 2017 – Summer)	J-Zaatari-1b-NC*		9	1						4	
	J-Zaatari-1b-NC		16		4					17	
	J-Zaatari-2-NC		14		3					14	
	J-Zaatari-2-NC*		9		6					1	
	J-Azraq-1-NC		6		6					5	
	J-Azraq-2-NC		24		6					21	
	J-Azraq-3-NC		21		27					13	
	J-Azraq-3-NC*		18							25	
	J-Azraq-4-NC		80		87					71	
Turkey Mar 18	T-Adana-1-NC		65							54	
	T-Adana-2-NC		27							4	
	T-Adana-3-NC		31							12	
	T-Adana-4-NC		34							10	
Bangladesh (Oct 2018 – Summer)	B-CXB-1-NC										
	B-CXB-2-NC		184								
	B-CXB-4-C	Cooking (wood)	436	28				53		73	
	B-CXB-5-C	Cooking (LPG)	8								
	B-CXB-7-NC		4830	278			179	845			
	B-CXB-10-C	Cooking (wood)	504	48				220			

5.2 Particulates

The highest levels of particulates were recorded in Bangladesh, Ethiopia and Djibouti during cooking, followed by Jordan as a result of the dusty desert location. However, even without cooking, PM levels were clearly greater than those recommended as acceptable. Figure 11 shows mean particulate levels in all shelters where no cooking took place during sampling. Mean PM_1, $PM_{2.5}$, PM_4 and PM_{10} were higher than 50µgm^{-3} in all locations without cooking. As a way of comparison, the average level on indoor exposure to $PM_{2.5}$ in the UK is 3µgm^{-3} [44]. The high exposure is mainly due to the locations of these camps. In Zaatari and Azraq camps, mean $PM_{2.5}$ levels were 2.6 and 1.8 times higher than IAQUK 'inadequate' rating (> 65µgm^{-3}), while mean PM_{10} levels were 5 and 4 times higher, respectively. In Ethiopia's Hitsats camp mean $PM_{2.5}$ (without cooking) was two times higher than IAQUK inadequate rating in summer but falls under the 'poor' rating (54-64µgm^{-3}) in winter. This is likely due to the higher levels of ventilation during the summer period which means allowing dust and other external pollutants inside the shelters.

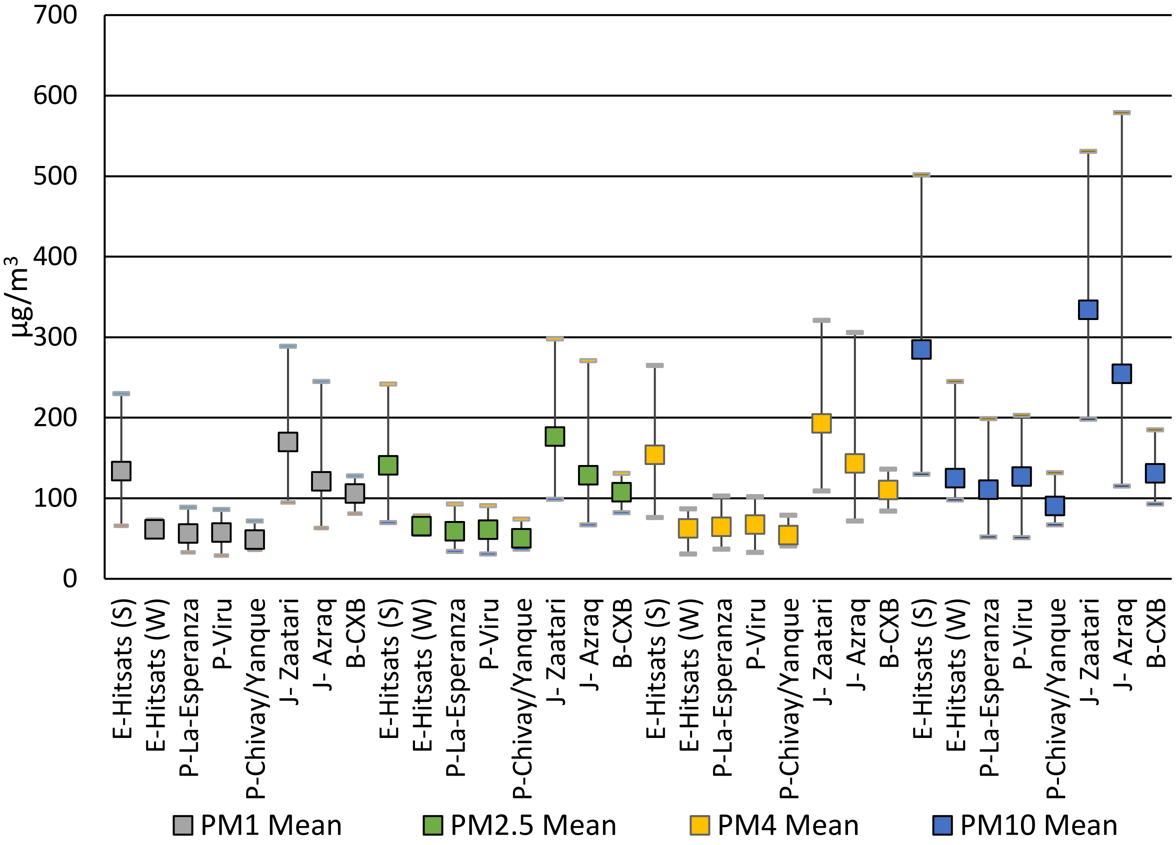

Figure 11: Mean, maximum and minimum particulate levels without cooking in Ethiopia (Hitsats) for summer (S) and Winter (W), Peru (La esperranza, Viru, Yanque and Chivay), Jordan (Azraq and zaatari) and Bangladesh Cox's Bazar (CXB).

Figure 12 shows the average concentration of PM_1, $PM_{2.5}$, PM_4, and PM_{10} in all shelters studied. Where cooking took place in the shelter the label is marked with (C) and where no cooking took place it is marked with (NC).

In Bangladesh, under ambient conditions in the shelters when no cooking was taking place mean $PM_{2.5}$ was 107µgm^{-3} and PM_{10} was 131µgm^{-3}. When wood was used as a cooking fuel, particulates reached levels greater than 3200µgm^{-3}. Opening the windows in the shelter helped reduce this to levels below 1770µgm^{-3}, however these concentrations are still above recommended values. The results show that an effective method of reducing particulates is the use of liquid petroleum gas (LPG) as an alternative fuel which reduced levels to that when no cooking took place.

In Ethiopia, cooking using coal resulted in PM_{10} levels reaching 861µgm^{-3}. In Djibouti, $PM_{2.5}$ reached 2730µgm^{-3} and PM_{10} 2770µgm^{-3} when cooking using kerosene. However, even when using an electric cooker PM levels of 1870µgm^{-3} were recorded, due to the type of cooking (deep-fried fish in oil and spices), which led to the generation of aerosols. These levels were exacerbated due to the lack of ventilation as windows were closed and AC was on.

Interestingly in shelter D-Markazi-5-NC where no cooking was taking place, high particulate levels of 1420µgm^{-3} were recorded. This was attributed to low air exchange rates which were indicated by a CO_2 concentration of over 2000ppm and an extremely strong odour of kerosene. Kerosene in the atmosphere was also supported by a high concentration of aliphatic hydrocarbons, 2600µgm^{-3} identified in the VOC studies. In addition, the shelter inhabitants often smoked shisha. These observations indicate that high particulate levels may be attributed to other activities rather than just those generated as a direct result of the fuel and stove type used for cooking.

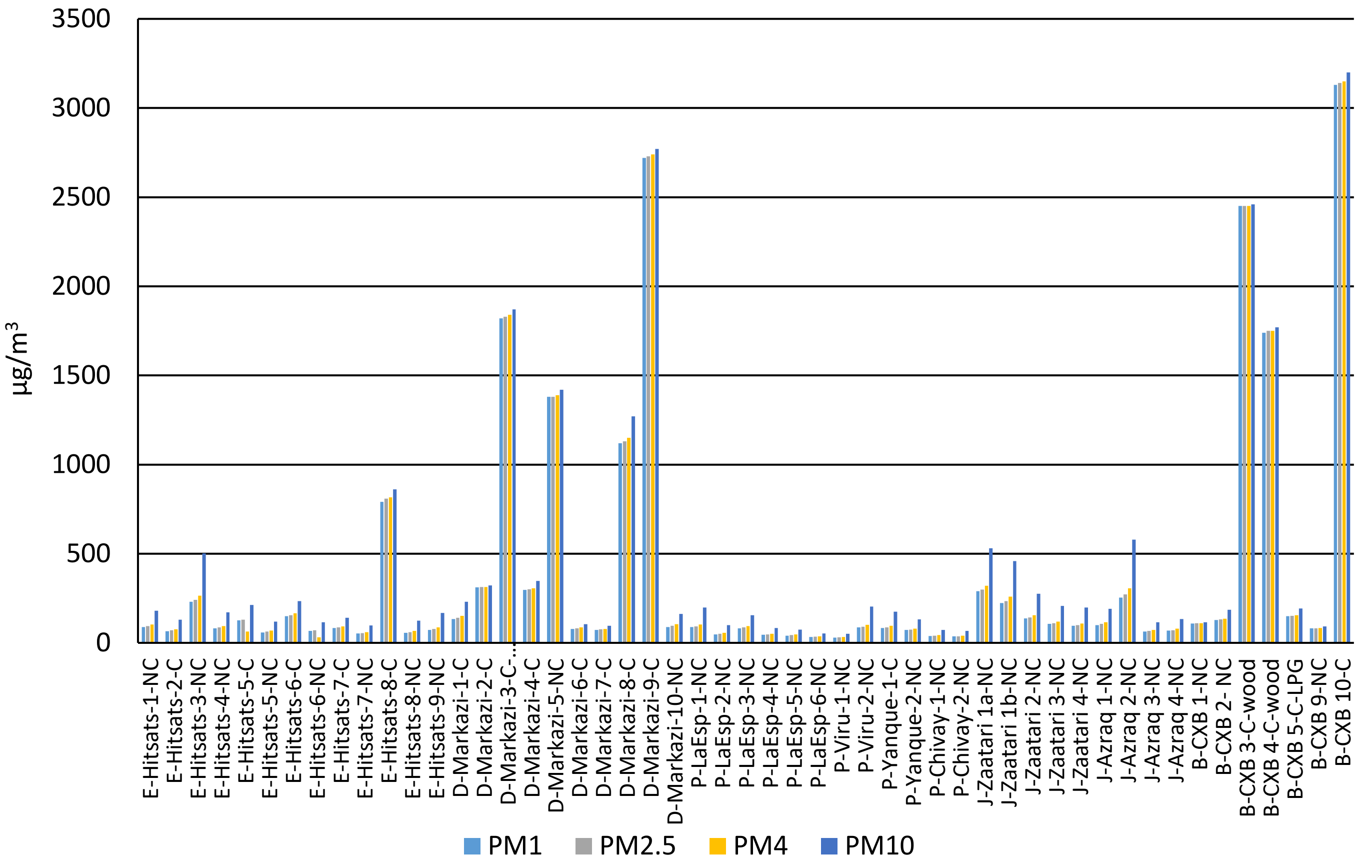

Figure 12: Concentration of PM_1, $PM_{2.5}$, PM_4, and PM_{10} in all studied shelters, cooking (C) and no cooking (NC)

5.3 Carbon dioxide:

The CO_2 level was monitored in two shelters in Markazi camp in Djibouti over 24-hours. In shelter 1, the family consisted of three members; they were heavy shisha (waterpipe) smokers, their kitchen was located inside the shelter. CO_2 levels in shelter 1 over the 6 days recording period were: mean= 1514ppm, Standard Deviation SD=645, maximum= 3,587ppm, minimum = 604ppm (see Figure 13 13). In shelter 2, the family consisted of six members, their kitchen was located outside the shelter unit, there are several gaps in the recording due to the battery running out and no electricity being available at times. However, overall CO_2 levels were lower than shelter 1, with mean CO_2= 987ppm, SD=181.5, maximum= 1495ppm, minimum= 690ppm.

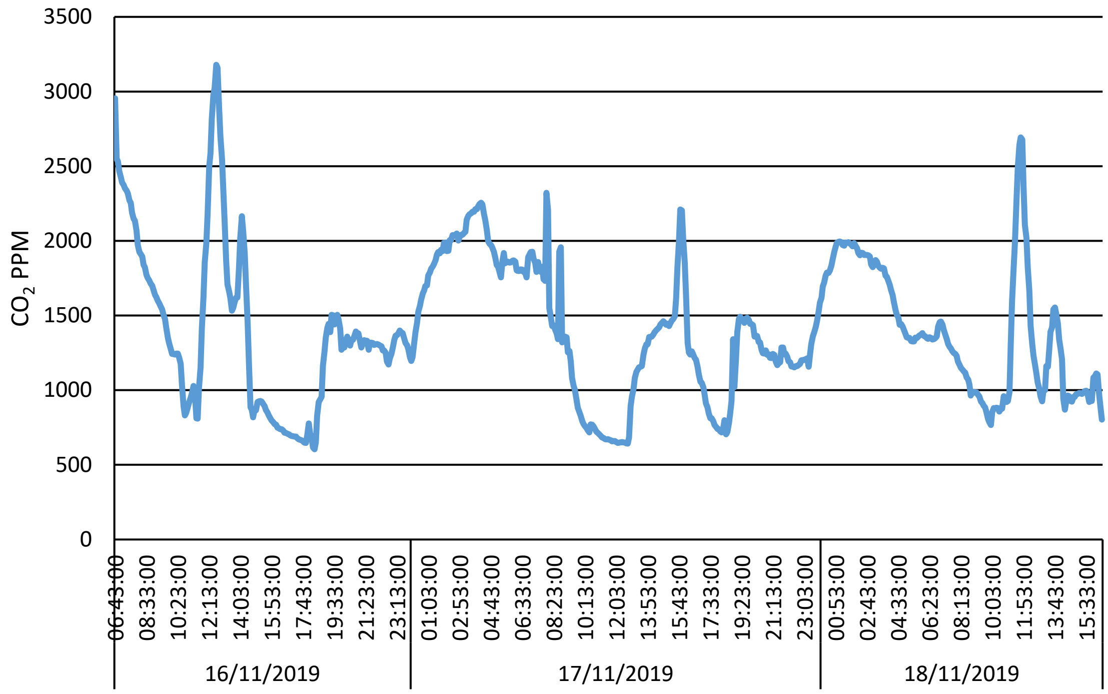

Figure 13: CO_2 levels in shelter 1 over 46 hours (Kitchen located inside the shelter). The shelter has three occupants, and two are heavy shisha smokers. The occupants cook their main meal (lunch) between 1pm to 2 pm during electricity hours. Electricity is available in the camp from 9am to 2pm and then again from 6pm till midnight. When electricity is available air conditioning is on and windows are closed.

In Hitsats camp in Ethiopia, spot measurements of CO_2 levels were recorded in 286 shelters in winter. CO_2 levels were high up to 5000ppm (which is the upper limit recordable on the measuring device), and a minimum of 1359ppm. The great majority of shelters (32%) had CO_2 levels in ranges of 4001 to 5000ppm (Figure 14). This is mainly the result of poor ventilation, overcrowding inside shelters (up to 25 inhabitants in several cases), and cooking inside the shelters using coal stove.

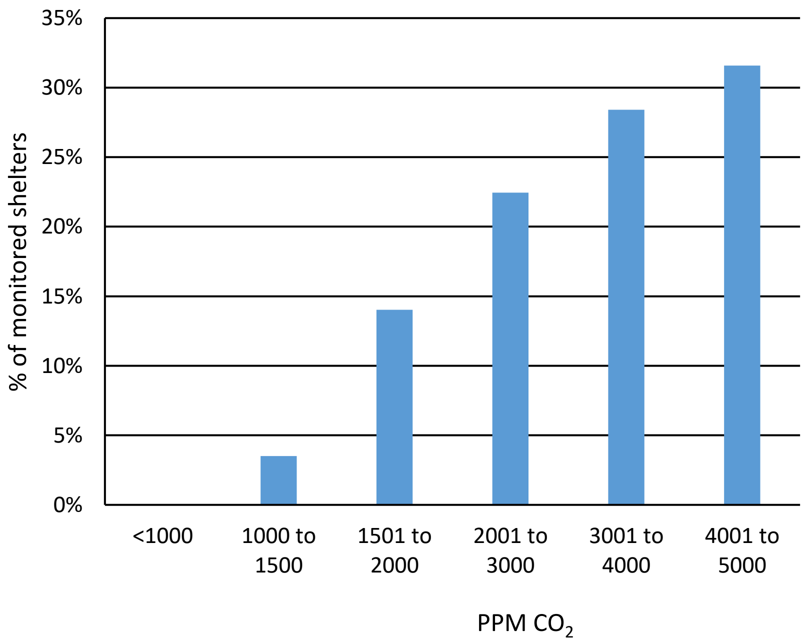

Figure 14: Relative frequency distribution of CO_2 spot measurements in 286 shelters in Hitsats refugee camp, Ethiopia.

In Azraq and Zaatari camps, Jordan, 136 CO_2 spot measurements were taken in summer and winter (see Table 5). Whilst the CO_2 levels in summer are not of a concern, in winter up to 2444ppm were measured in Zaatari camp. This was mainly due to reduced ventilation in winter and tobacco smoking.

Table 5: The mean CO_2 levels and standard deviation (SD), maximum and minimum found in Zaatari and Azraq camps in summer and winter.

		CO_2 PPM			
Season	**Camp**	**Mean**	**SD**	**min**	**max**
Summer	Zaatari	797	106	638	1150
	Azraq	827	141	678	1260
Winter	Zaatari	992	372	708	2444
	Azraq	1153	312	739	2078

5.4 Additional observations:

Mould growth was observed in shelters with inner MDF surfaces in Zaatari camp, Jordan. The occupants reported condensation issues when cooking and whilst asleep. This was particularly issue in winter when ventilation is limited, and surfaces are cold. In summer, commonly used evaporative-cooling strategies such as spraying the walls and floor with water can raise humidity above natural levels [38].

In Ethiopia and Bangladesh, termite infestation was a major issue (Figure 15), which can affect PM levels inside the shelters. In Bangladesh, the bamboo shelters were not treated with an insecticide, and 'sawdust' (termite excrement) was reported by the refugees as an issue. In Ethiopia, large termite mounds were found inside the shelters. The occupants reported destroying these mounds, only for them to appear again a few days later.

Figure 15: (a): Termite mounds inside a shelter, Ethiopia (b): termite-infested bamboo shelter, Bangladesh; (c): Mould growth on MDF inner surfaces in Zaatari camp, Jordan. *Photos credits: authors.*

6. Discussion and recommendations

This study highlighted several key challenges associated with working in displacement camps. Gaining access was limited to specific hours of the day and the occupants were frequently suspicious of the monitoring equipment through fears that it may contain eavesdropping capabilities. Hence monitoring over a 24-hour period to obtain daily means was often not possible. However, despite these limitations, this study has clearly demonstrated that air quality is consistently poor with high levels of CO_2, PM and VOCs such as benzene, styrene and aliphatic hydrocarbons (data set available at [45]). The levels found were high enough to cause immediate respiratory issues as was the case with the research team conducting this study, and are strongly linked to excess mortality [5].

The reasons for high levels of VOCs were directly related to occupants' activities such as cooking with polluting fuels, using insect repellent and deep-frying food. Most of VOC levels measured where no cooking took place inside the shelters or cleaner cooking fuels were used were low, indicating that emissions from the materials used in shelter construction are generally not a cause for concern. VOCs resulting from personal care products were also measured at acceptably low levels.

PM levels were related to external conditions and the location of these shelters as well as cooking activities. Frequently, political pressures, the scale, nature, timing, or direction of movement of the refugee flow across countries, will dictate the location of displacement camps. In many cases, camps may end up being situated in locations where the local geography and climate may bring additional challenges in providing a healthy living environment. For instance, sandstorms were frequent in Jordan and the locations of the refugee camps in remote desert locations exacerbated the issue of dust. Dust or sandstorms are the results of strong atmospheric turbulence near the surface that lifts large amounts of dust into the atmosphere. In recent years, Jordan and neighbouring countries have experienced an increased intensity and frequency of dust-storms [46]. With mineral dust being a major component, as well as high microbial content, the potential for adverse health effects is high [47]. During our visits, refugees frequently complained about dust and sand ingress, even without major sandstorms happening, stating that they have no option but to close windows to prevent sand ingress, despite the very high temperatures.

This highlights a clear conflict between mitigating high particulate levels inside shelters (by keeping dust and sand out) and providing adequate ventilation for cooling and/or purging VOCs and cooking fumes (particulates and VOCs). Overcrowding and other harmful activities such as smoking inside shelters contributed to the high CO_2 ppm levels observed, particularly in winter, when windows are likely to be closed to maintain warmth inside the shelter. A similar conflict between maintaining thermal comfort and adequate air quality was observed in Markazi camp in Djibouti, where temperatures are extremely high. Due to the high temperatures all year round, and lack of shaded areas outside, cooking mostly took place inside the shelters when air conditioning is on, and windows are closed. This has resulted in some of the highest levels of indoor air pollution being recorded.

In Bangladesh, the camps suffered from significant overcrowding, with shelters too close to each other's. This meant that airflow rates were inadequate, and no external space was available for cooking. In many cases, the self-built shelters didn't have any windows due to structural safety or privacy concerns by the refugees. With such limitations on the ability to ventilate, identifying affordable alternatives to polluting cooking fuels and nontoxic methods of deterring infestation by insects is necessary to reduce harm to health. Humanitarian agencies are already addressing this with biogas stoves being piloted by UNHCR in Hitsats camp [48] and LPG cooking stoves being rolled out in Cox's Bazar following our investigation (T. Klansek, private communication). However, even when cleaner cooking stoves are provided, inhabitants may still resort to collecting wood which is freely available as opposed to buying clean fuels. This was observed in Peru, where despite being provided with gas stoves, 26% of interviewees used wood for cooking as they could not afford gas.

Indoor air quality in shelters could be improved through a better shelter design. The shelters mostly consisted of a small single open space that did not allow any separation of different activities. This resulted in all occupants being exposed to indoor pollutants and potentially suffering the resulting health implications, for instance, passive smoking. Furthermore, ensuring adequate ventilation is key. In all locations studied, windows were blocked or closed for various reasons ranging from thermal comfort, privacy or security concerns to lack of space resulting in extensions blocking the windows of the main shelter unit. These climatic and sociocultural factors that significantly impact ventilation regimes and how shelters are used, are not considered during shelter design and implementation. A context-specific, culturally, and climatically sensitive design can ensure that these factors are well-thought-out, and airflow rates could be calculated accordingly. For example:

- In locations where cooking is only likely to take place indoors (for instance because the climate is too cold), cooking areas should be separated from the main living space by solid partitions (as opposed to curtains that are commonly used in temporary shelters e.g. Figure 3e) and ventilation of these kitchens should be independent to minimise interzonal infiltration. In warmer climates, kitchens could be provided outside the main shelter unit, either as an independent unit or as a shaded external space. Care should be taken to ensure that external cooking areas are not adjacent to the shelter windows to prevent smoke infiltration. Generally, where possible shelters should be designed to provide separation of functions so that polluting activities (cooking, social smoking) can take place in an isolated space to vulnerable people's (children, elderly) sleeping and living space.

- Chimneys should be incorporated into the shelter design above cooking stoves as they can help extract cooking fumes in cases where windows need to be closed due to thermal comfort, privacy or sand ingress concerns. Chimneys can also vent out fumes in cases of overcrowded camps with limited air movement (e.g Figure 9a). Installing chimneys is an inexpensive and effective solution, yet none of the shelters visited in all six countries had a chimney over cooking stoves. Unlike windows, chimneys do not rely on occupants opening them, do not allow passers-by to see into female areas and are less of a security concern.

- Site layout and shelter orientation: carefully considering wind direction and orientation of windows ensures optimum ventilation. Although this may not be desirable in dusty locations, and hence the need for a location-considerate design. Site Layout is important to ensure there is sufficiently large gap between shelters for effective ventilation, and where burning of solid fuels is likely to occur, additional care should be taken in the positioning of windows to prevent smoke infiltration between neighbouring shelters. Providing means of background ventilation such as trickle-vents should be considered in order to help maintain adequate ventilation to control concentrations when windows are closed for warmth or other reasons. However, ensuring these are not blocked up by occupants will need consideration.

- High-level windows could be considered, particularly in kitchens, to address concerns about privacy.

- Mitigating intrusion by insects using appropriate building materials, for example, concrete slabs instead of building shelters directly onto earth, treated bamboo to prevent termite infestation, and the provision of mosquito nets over windows.

7. Conclusions

This paper is the first in-depth study of the indoor air quality of shelters in refugee and displacement camps. Ten locations in six countries across three continents were visited, namely: Azraq and Zaatari camps in Jordan; Hitsats camp in Ethiopia; Kutupalong camps in Bangladesh; Markazi camp in Djibouti; informal refugee settlements near Adana in Turkey; and displaced people shelters located in Trujillo, Viru, Yanque and Chivay in Peru. In total samples of VOCs and PM were collected from fifty-three individual shelters and CO_2 measurements in 424 shelters.

The study aimed to assess indoor air quality in different temporary shelters across the world and investigate the various factors impacting it, including cultural or behavioural factors, the location, climate, the shelters' design and materials and the way in which the shelter is used by its inhabitants'. This investigation revealed not only how widespread the issue is, but also how bad the levels of indoor air pollution are in shelters. These included harmful levels of toxic and irritant volatile organic compounds (VOCs) up to 102400μgm^{-3} in one case, airborne particulate matter (PM) in excess of 3000μgm^{-3} and CO_2 levels in excess of 5000ppm (the highest recordable level on the measuring device used). The reasons for these concentrations proved to be complex, multifaceted and setting-specific. For example, overcrowding of camps restricting the ability to ventilate, privacy concerns leading to lack of windows and thermal comfort requirements resulting in sealed shelters. However, the prevalent use of coal, wood and kerosene as cooking fuels is partially to blame. Other sources of pollutants found were dust due to the arid location of the camps, indoor smoking and the use of Arabian incense and spraying kerosene to repel insects. These issues are exacerbated by poor shelter designs (that mostly consist of a single open space in which all activities including cooking take place) and could be mitigated. Therefore, six design recommendations are made, particularly the inclusion of chimneys over cooking stoves and explicitly considering airflow levels in a culturally and climatically sensitive manner.

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