Designing Effective Ventilation Systems for Multi-Purpose Basement Shelters

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Abstract: In the Middle East, the basements were constructed to effectively use the underground space for storing food or extra stuff, for car parks, and other household uses. Also, since many countries of the Middle East suffered from wars for decades, basements also have been utilized as shelters. Since basement shelters may be occupied for days continuously during the war attacks, they should have proper ventilation systems to control both the moisture and the indoor air quality. This research introduces suggested ventilation systems designs for the multi-purpose basement shelters during three different scenarios which are: 1-in the regular days when no risk is found, 2-when the building is exposed to blast attacks, and 3-when the building is exposed to chemical attacks. Finally, this paper also shows the need of proper ventilation systems that can be installed in an effective way to prevent the health risks of the occupants and the structural damage of the building caused by poor ventilation.

Keywords: Ventilation, Basement, Shelters, Blast Attacks, Chemical Attacks, Moisture, Air Quality

1. Introduction

Historically, basements have become as a common part in old domestic buildings. In some parts of the world, basements are used as natural attack shelters, vehicles garage, places for furnaces, or to store food. In some of the Middle East countries (i.e. Iraq, Syria, and Turkey), the basement would be one of the two forms:

1. A Serdap: is a room having a fountain and oriented to the north and courtyard, it was used by residents in a hot climate (Sözen & Gedík, 2007).
2. A Pantry: is a cooling space used for storing food and keeping them fresh for a short and a long way (Baran & Yılmaz, 2011).

The best part of our houses that can be considered as a shelter is the basement, since it is under the ground (Summers, 1966). Monteyne (2011) in the study found that the natural protection factor on the first floor of a five-story house is 5 while it increases to be more than 10 in the basement.

The Middle East and especially Mesopotamia is known as the cradle of the civilization but at the same time the conflicts always happened between the different ethnic groups. In the last century conflicts in the Middle East started with the partitioning of Ottoman Empire and continued with the

World Wars, the wars between neighbor countries and the civil wars of countries took place in late 20th century. Iraq is one of the countries experienced many conflicts and wars with different blast and chemical attacks like the 1980s, in civil wars, Gulf war in the 1990s, the American - Iraqi war, in additionally to the terrorist attacks in the last decade.

The survival shelter is a place that can give cover and protection to people. It is a basic human need for surviving and being protected during emergencies, disasters and risks caused by warfare attacks (Poschl, 2017). The shelters are categorized into the following types: Shelter Buildings, host communities, tents, temporary bunk houses, temporary shelter, shelter kits, semi-permanent shelter and permanent shelter.

Each year, a lot of families around the world are in need of shelters for surviving in natural hazards such as earthquakes, floods and hurricanes (FEMA 453 Manual, 2006). Three main shelter types could be presented to help them, Reinforced Small Room as a part of a house which is useful only for earthquakes, and considered as a short term shelter. Site Constructed Underground Shelter which is suitable for different types of hazards such as earthquakes, floods, storms and hurricanes, and considered as a long term shelter (Blom et al, 2012.). The last type is Prefabricated Underground Shelter which is appropriate for almost all the types of natural hazards attacks and it is a type of long term shelter. During the warfare, blast attacks could be applied. The explosives used in these attacks are categorized as high-order explosives (HE) or low-order explosives (LE). HE produce a defining supersonic over-pressurization shock wave.

Additionally, chemical attacks could be applied to a big or small group of people. In this type of attacks, poisonous gases, vapors, aerosols liquids and solids are used. Being exposed to these materials may lead to severe health damage or even to death (Groseclose et al., 2000).

According to (FEMA 453 Manual, 2006), the types of shelters prepared for protection against chemical attacks are:

1. Shelters with low level of protection, they use minimum efficiency filters.
2. Shelters with medium level of protection, they are provided with gas absorbers for outside air and designed to minimize the entry of the toxic gases into the building through applying positive pressure in some points and through proper evacuation.
3. Shelters with high level of protection, those shelters are similar to the previous ones but the gas absorbers are applied on both outside and return air.

Basements in hot dry areas are one of the strategies used for internal thermal comfort and also used as shelters for protection. In old traditional buildings the basements were used for the purpose of thermal comfort. The semi basements which opened in two sides opposite to each other aimed to provide a cross ventilation or ventilation ducts known as wind catchers were used. The houses built in late 1980s were always provided with the basements specially constructed against the bomb attacks. These basements were deep and totally buried underground. Ventilation system is a process that aims to ensure keeping acceptable indoor air quality by providing outside fresh air or any recirculated air that has been treated (Standard, 1989). Basically, ventilation systems are divided into two major categories: (1) the Natural Ventilation Systems and (2) Mechanical Ventilation Systems. The air movement in the natural systems happens due to the disparity between the indoor and the outdoor temperature and also due to the wind (Awbi, 2004).

In the mechanical ventilation systems, some technologies are used to move the air. And the systems are categorized into the following types (Russell & Rudd, 2007): Continuous exhaust systems, Single-point exhaust systems, Multipoint exhaust systems, Intermittent exhaust systems, Exhaust with make-up air inlets systems, Local exhaust with make-up air integrated in HVAC system, Continuous supply systems, Intermittent supply with an inlet in return side of HVAC System, and Combined exhaust and supply systems.

Three major reasons affect the indoor air quality, inadequate and poor fresh air introduced, Air-conditioning (HVAC) systems (Hewett, 2010), and the dust exist in rugs and furniture, non-moisture-resistant materials, the high amount of toxicity of emissions from some types of equipment, furniture and furnishing materials, mold or other microorganisms that grow and multiply through heating are a significant source of IAQ problems (Binggeli, 2003).

The overall result of poor IAQ and other pollutants can be Asthma and Allergies that have reached an all-time high, especially in basements and closed areas (Leydecker, 2013). Also, it can extend to cause Sick Building Syndrome (SBS), the symptoms of which are headaches, upper respiratory irritation, or eye irritation, and sometimes include dizziness, nausea, throat irritation, and fatigue. The semi underground shelter designed against natural hazards should have an acceptable micro climate in the space by designing and preparing the basement to be well ventilated to get rid of polluted air, and by improving the indoor air quality. Also by using moisture-resistant materials and non-toxicity equipment basements could be ventilated.

2. Methodology

2.1 Designing Principles

The research is conducted on a Fully Underground Basement (which has no windows) of a one/two story-house.

The objective of this research is to design a ventilation system that can habilitate the fully ground basement:

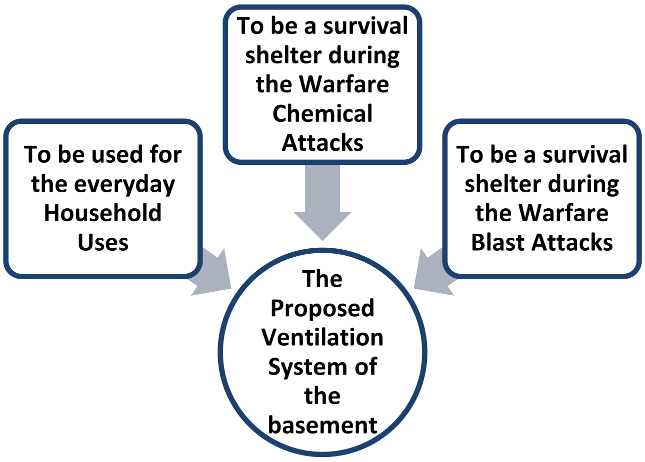

Figure 1: Diagram illustrates the criteria of the proposed ventilation system

For this, the following concerns were taken into account while designing the proposed ventilation system:

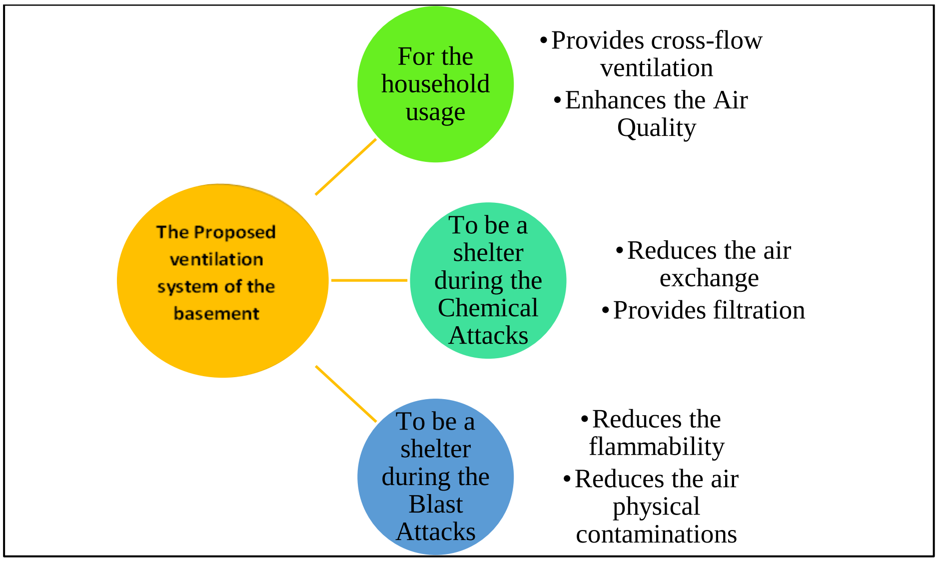

Figure 2: Diagram illustrates the concerns that the proposed ventilation system shall fulfill

Beside the previous concerns, the system is designed to be:

1. Economical
2. Easy to be maintained
3. Used as a shelter for more than 48 hours continously
4. Used to rehabilitate the existed basement

3. The Proposed Design

3.1 Regarding the Daily Usage

To provide good ventilation, the Upward Flow Ventilation System was chosen to be applied. In this system the chimneys are used to provide cross-flow ventilation and also an underground duct was used to provide internal fresh-air entry. This occurs when the wind pressure coefficient at the high-level (stack) outlet remains negative compared with the coefficients at the inlet openings.

Also, wind catchers (which is a combination of the scoop and the extract) is used. Typically the chimney duct is divided into four quadrants, each with an opening at the top. The aim is that for any wind direction, two quadrants will provide air entry and two will provide air exit.

Additionally, the underground ducts can provide cooling and heating of the inlet air, by virtue of heat transfer between the air and the surrounding ground material, which remains at a moderate temperature throughout the year. To ensure indoor quality air, moisture-resistant materials and nontoxicity components shall be used for the furniture and any other items inside the basement.

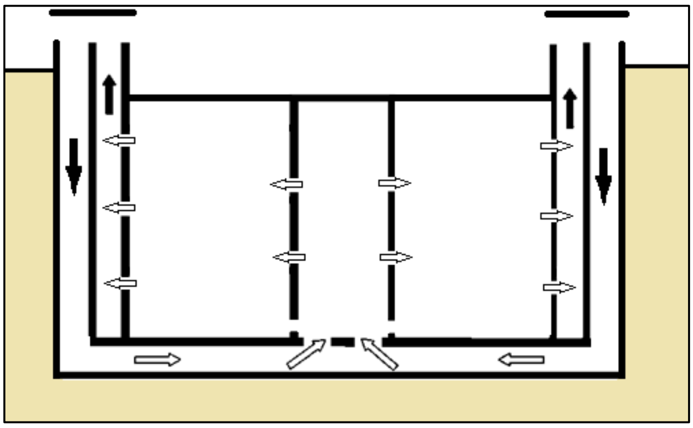

Figure 3: Sketch illustrates the upward flow ventilation system proposed for the daily usage

3.2 Regarding the Sheltering during Chemical Attacks

To reduce the air exchange rate with the external atmosphere, the ventilation system is based on drawing the air form outside the room, filtering and discharging to indoor in a way that create a positive pressure within the room. This positive pressure will eliminate the leakage of the air from outside to inside. Also, since the chemical attacks may be extended for days, the air will be drawn from the outdoors atmosphere to provide ventilation for the occupants and to overcome the limitation caused by the CO2 accumulation.

To filter the air, a filtration unit is used in the proposed system. The filtration unit should be designed to provide protection against poisoning chemicals and toxics. This unit must have both high-efficiency particulate air filters and an ultra-high efficiency gas absorber. The absorbers should include ASZM-TEDA carbon having a very fine mesh and with a very high percentage of adsorbing chemical elements capabilities.

As it can be realized, that the filtering unit should have a very high-quality performance which makes it to be expensive. Therefore, for a more economical strategy, it is suggested in this research to build a Safe Room within the basement which can compass the expected number of occupants. This room will exchange air with the outdoors via a special duct independent from the Upward Flow Ventilation System of the system.

3.3 Regarding the Sheltering during Blast Attacks

For reducing the flammability, two components shall be added. Firstly inflammable materials shall be used in the area surrounding the building. This will mitigate the risk of fire when a blast projectile impacts the building. Also, fire alarms and smoke detectors are being used to stop the flow of the air through the wind catchers.

Also simple physical filtering units can be applied in the air entrance canals to eliminate the tiny particles produced by the blast projectiles from entering the indoor atmosphere.

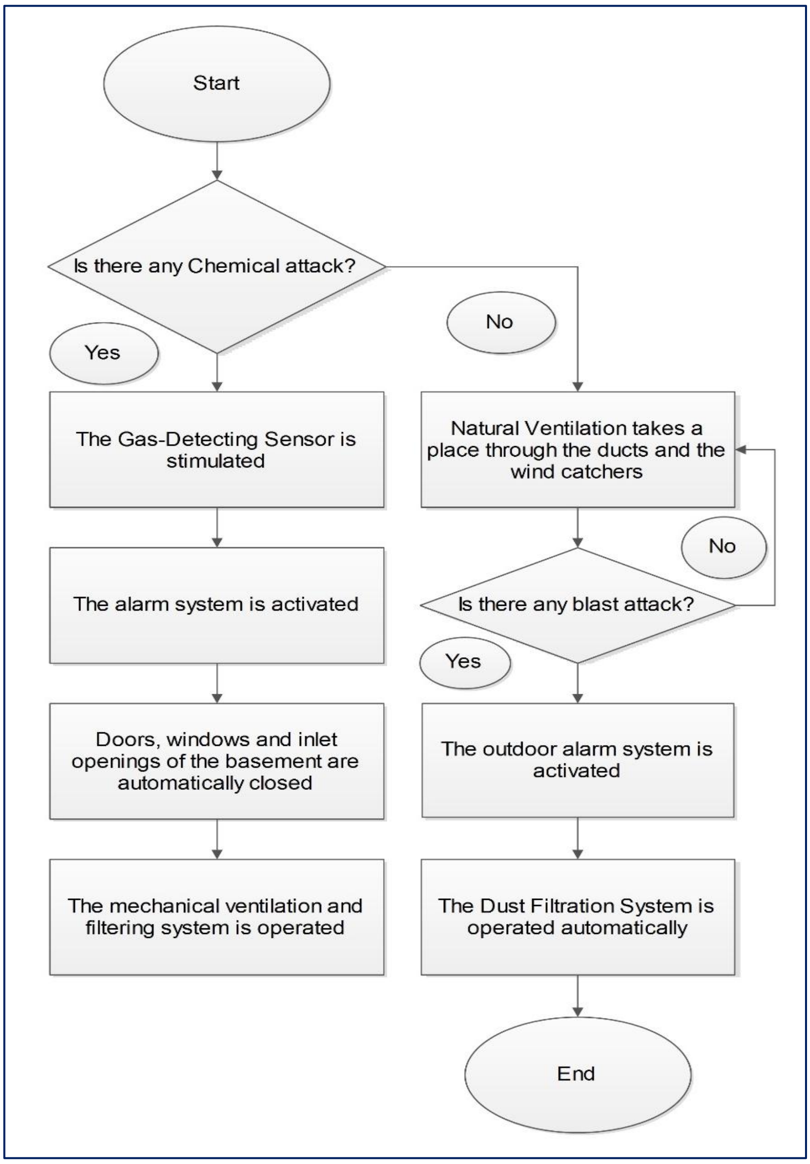

Figure 4: Flowchart of the proposed ventilation system mechanism

4. Checking the Validity of the System

4.1 Validating the Ventilation System Designed for Daily Usage

The proposed design is validated by applying the physical, mathematical and mechanical formulas on a model basement with the following dimensions:

Length = 7 (m), Width = 9 (m), Height = 3 (m)

In this research, the natural ventilation caused by wind was adopted. The difference in the air pressure value causes the natural ventilation.

The followings describe the stages that the Natural Ventilation takes place along the day:

- During the night, the walls of the wind tower get cooled which causes the outdoor air to be vacuumed into the tower.

- In the beginning of the daylight, the outdoor air is vacuumed into the inner space because it is cooler than the indoor air.
- During the daylight, the tower walls get heated by the solar radiation, the wind calms down inside.
- At the sunset, the pressure and the density of the air close to the towers walls decrease, and this leads to pulling out the indoor air to the outside by the effect of the coolness in the outdoor air.

The rate of the air flow through the inlet can be found by utilizing the following formula (in case of diagonal winds).

$$Q = 0.36 * A * V$$

Q = air flow rate (m^3/s)

A = the cross section area of the inlet (m^2)

V = Velocity of the wind (m/s)

- The average wind velocity in Erbil/Iraq is 3.14 (m/s).
- For a square window with a side of 0.7 m, the cross section area is ($0.49m^2$).

Accordingly, the air flow-rate can be calculated as the following:

$Q = 0.36 * 0.49 * 3.14 = 0.553 \ (m^3/s)$

The maximum allowable concentration of Co_2 in a room C_i (ppm) is calculated by using the following formula:

$$C_i = C_o + F/Q$$

C_o = containment density (ppm).

F = average of producing containments within the room (cfm).

Q = air flow rate (cfm).

- C_o = 300 (ppm).
- The amount of Co_2 produced by a human is: f = 0.012 ($pound/min$).
- From (1), $Q = \frac{0.553*2.85}{\frac{1}{60}} = 94.563$ ($pound/min$).

Accordingly, and in the case of 10 inhabitants:

$C_i = 300 + \frac{0.012*10}{94.563} = 300.00127$ (ppm).

4.2 Validating the Ventilation System Designed for the Safe Room (to be used during the chemical attacks)

Since the safe-room is designed to be a shelter during the chemical attacks, the outdoor leakage shall be extremely minimized. Therefore, mechanical ventilation is applied for both supplying and exhausting the air into and from the safe-room. Therefore, the system that suits this case the best is the Exhaust – Supply Ventilation System. For this, a centralized centrifugal ventilation system is used. This system is composed of the following components: DEFUSAR, grills, horizontal and vertical ducts, filter for supplying the air into the room, fans.

The average of air exchange CFM (cubic feet/m) is calculated as the following (by considering that one air-change process takes 2 minutes to be completed):

$$CFM = \frac{Building\ Voulum\ (feet)}{minutes\ per\ an\ air - change\ (\text{min})} = \frac{7 * 9 * 3 * 35.31}{2} = 3337\ \text{cubic feet/m}$$

The design specifications of the filter used:

1. Type: High Efficiency Particulate Air (HEPA) filters.
2. Efficiency: able to remove 99.999% of the air borne particles with 0.15 radius.
3. Absorber: Ultra High Efficacy Gas Absorber which should include (ASZM-TEDA) carbon.

Note: ASZM-TEDA is impregnated carbon used for the military purposes. The letters refer to the component materials: (Copper – Silver – Zinc – Molybdenum – Triethylenediamine).

Despite the high efficiency of this filter, it has some limitations as the activated carbon eliminates oxygen from air. Therefore, necessary procedures for low oxygen spaces should be applied.

5. Findings

It has been found that by applying the Upward Ventilation System, the amount of the Co_2 contamination (300.00127 ppm) is less than the acceptable level (600 ppm) which refers to the suitability of the proposed system as ventilation system.
The distance between the inlet opening and the ceiling is $\frac{1}{3}$ of the height of the room ($\frac{1}{3}$ * 3 = 1 m for the proposed model). Also, the vertical dimension of the wind catcher opening is $\frac{2}{3}$ of the vertical dimension of the window ($\frac{1}{3}$ * 0.7 = 0.23 m for the proposed model).
During the chemical attacks, and when applying positive pressure, the fan capacity shall be greater than 3337 CFM and the filters shall be provided with ASZM-TEDA carbon to provide a safe atmosphere.

6. Conclusion

1. The Upward Ventilation System is found to be effective to provide a good ventilation for the underground spaces during the daily usage.
2. The Crossflow Ventilation is found to be useful for keeping the air quality of the underground spaces within the acceptable limits.
3. To ensure a safe atmosphere during the chemical attacks, a positive pressure shall be provided in the inner space.
4. The outdoor leakage can be extremely minimized through applying mechanical ventilation for both supplying and exhausting the air into the room.

5. To filter the air during the chemical attacks, HEPA filters provided with ASZM-TEDA carbon shall be utilized.
6. To mitigate the risks during the blast attacks, inflammable materials shall be used in the area surrounding the building, in addition to a fire alarm system and a simple dust filter.

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