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Critical Factors Contributing to Poor Natural Ventilation of Residential Buildings

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Abstract

The air tightness of buildings has the greatest potential for energy savings. Reduced fresh air intake raises concerns about natural ventilation systems and the need to provide users with a comfortable indoor climate. The pace at which heat is expelled from a building's interior surfaces increases with vent size, putting residents' health at risk and causing discomfort. The study aimed to evaluate critical factors that contribute to poor natural ventilation in residential buildings, and its associated effects. A quantitative research approach was adopted using purposive sampling for data collection due to undefined residential buildings. 215 questionnaires were distributed to occupants of residential buildings within six (6) selected communities within the Atwima Nwabiagya Municipality. 210 completed questionnaires were collected and analyzed using mean and relative importance index (RII) score ranking. From the findings, nineteen (19) identified variables categorized into three (3) main factors contribute to poor natural ventilation of residential buildings. The most critical factor is unplanned building design and usage with an average RII of (0.955). Most privately owned residential buildings were built with no professional consultation aiming to avoiding professional cost. Eleven (11) variables grouped under four (4) main effects were identified as effects associated with poor natural ventilation, the top-ranked ranked effects were Health risk with an average RII of 0.930. Good natural ventilation is a determinant factor for sustaining occupants' satisfaction and wellbeing. Therefore, it was recommended that purpose of room space should be well defined before its design and construction. Public education on the need to engage experienced professionals in design and construction should be intensified. The paper affirms to the relevance of natural ventilation for occupants in residential buildings; also, usefulness to engage construction professionals and clients.

Keywords: Health, Occupants, Poor natural ventilation, Residential buildings,

Vol. 8, No. 03; 2023

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1. Introduction

To promote energy saving of buildings, there is the need to adopt a modern methodology for ensuring air tightness of buildings. This can be achieved by reducing the size of openings for air inflow which intend affect the natural ventilation system. If implemented effectively, it becomes a key for ensuring comfortable indoor climate for occupants and preservation of building fabrics (Hollowell and Craig, 2011). Ventilation is the free flow of outward air into the inside of the building for the comfort of the occupants, and there are three types of ventilation which are: natural, mechanical and hybrid (mixed) forms (Wouters and Heijmans, 2001). When the air in room space is replaced with outside air without the aid of mechanical means in any form, it is said that Natural ventilation has occur. Natural ventilation systems depend on the pressure difference caused by the wind to move fresh dense air through buildings for temperature and humidity differences (Awukuand Wang, 2020). The size and location of the building's openings have a significant impact on how much air enters the structure. To complete the airflow circuit through a building, openings like as transom windows, louvers, grills, or open designs are used between rooms (Walker, 2016).

In Ghana's tropical climate, natural ventilation is a practical and affordable alternative to air conditioning, especially when the evenings are cool enough to pre-cool the building, reducing, or eliminating the need for mechanical cooling while simultaneously improving the indoor air quality of the building. Well-designed natural ventilation systems frequently create incredibly snug and enjoyable conditions for building occupants (Priolo and Allard, 2002). The recommended air change per hour (ACH) should be 0.5 l/h, which indicates that all room air should be totally and continuously replaced every two hours to maintain the acceptable indoor climate in residences (Hollowell and Craig, 2011). Building systems (original design or later improvements to the building and mechanical systems), building methods, pollutant causes (construction and furnishing materials, moisture, procedure, and activities inside the building, and outdoor sources), and building occupants interact to create the indoor climate in any given structure (EPA, 2018). The dry season, which runs from November through March, is characterized by a time of high temperatures and low relative humidity in Ghana's warm tropic climate zone. Between these months, most buildings' daily mean maximum interior temperatures range from 30 to 86 degrees Fahrenheit with little indoor air velocity. And between April and October, when it is the wet season, there are moderate temperatures and heavy humidity levels (Climate of Ghana, 2019). Most building occupants have persistent and increasing problems with the interior environment due to high indoor temperature (EPA 2018). Also, daily assigned activities are mainly spent within the building by occupants, together with, lots of installed or placed items i.e., furniture, television, sound system, fridge, cookers, lights, etc. which in one way or the other either generate heat or causes air pollution within the buildings.

According to Walker (2016), most residential buildings are described by poor design in considering climatic environmental condition, which necessitates a large amount of energy for cooling during extremes weather condition. On every daily activity occupant mostly spend more time at home or within their building more than staying out. Out of 24hrs, per day 13-15hrs are spent inside or within the building whiles 9-10hrs are spend outside on the daily activities which is from the working days (Monday to Friday), on weekend (Saturday and Sunday) most of the

Vol. 8, No. 03; 2023

ISSN: 2456-3676

hours are spent indoors. Several factors make the potential effect of indoor air quality on human health nationally noteworthy: Most Ghanaians, on average, spend around 85% of their time indoors, where several pollutants are frequently present in concentrations that are typically 2 to 5 times higher than those found outdoors. Babies, elderly individuals, those with cardiovascular or respiratory conditions, and those who are frequently most vulnerable to the negative effects of pollution, are likely to spend much more hours indoors (USEPA, 2017). This simply shows that a great deal of good "Indoor Air Quality" will be needed in the building (Walden, 2018). According to Rylance et al., (2015), Wellbeing affects linked with poor natural ventilation include: irritation of the eyes, running nose and dry throat, headaches, dizziness, fatigue, respiratory diseases, etc. The study therefore seeks to investigate the critical factors that contributes to poor natural ventilation and its associate effects using residential buildings in six (6) selected communities within the Atwima Nwabiagya Municipality of Ashanti region of Ghana.

2. Theoretical Background

2.1 *Ventilation*

By both dilution and internal removal of contaminants, ventilation is the flow and circulation of outside air within a structure or space to create breathable air for human habitation (Awbi, 2003). According to CDC (2005) and Dyer (2010)., building ventilation consists of these three fundamental components: 1) Ventilation Rate: The quantity and quality of outdoor air that is introduced into the area. 2) Airflow Direction: the general flow of air across a structure, from clean to unclean areas. 3) Air Circulation or Airflow Pattern: Each space area must have adequate access to outside air and should efficiently be capable of removing any airborne contaminants. The three types of ventilation: 1) Natural ventilation refers to purposefully planned passive ways, like as windows and doors, of providing sub aerial to an area without the need of mechanical devices. 2) Any method that introduces sub-aerial air to a location using power-driven devices, such a fan, is referred to as mechanical ventilation. This covers supply and exhaust airflow used in balanced systems and positive pressure and exhaust ventilation. 3) Mixed mode ventilation (also known as hybrid ventilation) systems combine mechanical and natural processes (Dyer, 2010).

2.2 *Natural Ventilation*

Natural pressure like wind and thermal resulting from differences in the densities of internal (used up) air and external (fresh) air, forcing the exterior air through properly engineered building envelope apertures. Examples of purpose-built apertures are doors, windows, solar chimneys, window towers, extractors, and trickling ventilators. A building's natural ventilation is significantly influenced by the environment, the architecture, and occupant behavior. There are numerous benefits of natural ventilation system, compared with mechanical ventilation systems when well installed and maintained (Atkinson et al., 2009; Awbi, 2003). Because of the use of natural forces and big openings, natural ventilation can typically provide a great ventilation amount more cheaply. It may be more energy-efficient to use natural ventilation, especially in cases where heating is not necessary. To obtain more light, natural ventilation that is well-designed could be utilised. By implementing natural ventilation, sustainable energy saving approach when the building is built and oriented in a appropriate way. Moreover, its short of extremely utilizing power, few discharges are distributed into the environment, assisting to avoid additional harm to the atmosphere (Dyer, 2010; Atkinson et al., 2009; Awbi, 2003).

2.2.1 Types of Natural Ventilation

According to Ohba and Lun, (2010), natural ventilation often comes in four different forms: top-down ventilation, cross flow ventilation, stack ventilation, and single-side ventilation. The same room louvers are used for the supply and extraction of single-sided ventilation. The holes for single-sided ventilation ought to cover 4% of the floor area. Although this technique is less effective, it is practically universal, and the internal doors can stay closed. In a building using the cross flow ventilation technology, the ventilation supply and extraction are located on the same level. Louvers are used to supply and remove air. Interior doors must be left open or have transfer vent grilles installed. *In Stack Ventilation method*, two ventilation holes, a low-level grille and a high-level grille, are normally located above the door when using the stack ventilation system. Through the louvers, outside air is drawn in, and it is expelled through a chimney. Even when there is no wind, this device will provide ventilation. The regions that require cooling must be near the chimney or protected by effective transit grilles. *Top-down ventilation system*, a system which makes use of roof turrets that can catch wind coming from any angle. Due to its utilization of the wind's natural ability to suck relatively clean, fresh air from above roof level into the building below using a wind-catcher device, it has been demonstrated as dependable and well-liked natural ventilation techniques (Chudley and Greeno, 2014).

2.2.2 Drawbacks to Natural Ventilation System

According to Atkinson (2009), there are a variety of disadvantages to a natural ventilation system, including the following: regarding interior condition, natural ventilation varies and is impacted by the external climate. Wind and temperature difference are the two components that generate airflow rates and fluctuate stochastically. Natural ventilation can be difficult to control because the airflow might be uncomfortable in certain areas while remaining stagnant in others. Under some unfavorable environmental conditions, a low air-change rate is feasible. Additionally, it's challenging to control the flow of air without using a well-maintained negative pressure, which raises the danger of contamination in corridors and other spaces. Furthermore, natural ventilation forbids the use of particulate filters. For reasons of temperature, safety, and culture, windows and vents may need to be kept closed; under these situations, ventilation rates may be considerably reduced. Natural ventilation requires the presence of natural forces; hence a great amount of ventilation calls for availability of a higher natural force. Additionally, natural ventilation systems frequently don't work as intended, and routine procedure may be interfered with for several reasons, including faulty design, inadequate maintenance, and improper management. The efficiency of a natural ventilation system can be affected if it cannot be installed correctly or retained due to financial constraints, increasing the danger of the transfer of airborne diseases even if basic natural ventilation systems can have extremely minimal maintenance costs.

Vol. 8, No. 03; 2023

ISSN: 2456-3676

Cross-flow

2.3 Major Design Elements of Natural Ventilation

Estimating vent and window widths is only one aspect of designing natural ventilation; it also calls for creative thinking and meticulous attention to detail. There are three (3) layers to the design procedure for natural ventilation, according to Priolo and Allard (2002): Site design includes things like building placement, layout, orientation, and landscaping. Building design includes things like building type, function, from, envelop fabrics, natural vent strategy, inside allocation of space, and functions, heat system, venting, and air conditioning, if applicable. Vent opening design includes things like where openings are located, what kinds of openings are used, what sizes are used, and control methods.

2.3.1 Site Design

Buildings must be integrated with the topography and other structures on the site. Minor site modifications may be permitted in certain circumstances if wildlife and the environment are protected. Utilizing the site's natural airflow patterns for natural ventilation is the greatest way to maximize its potential (Atkinson, et al., 2009). Make sure each building is exposed to South-West breezes when multiple is being constructed on the same site, but not to North-East winds during hot weather. The shape and position of the building should maximize the negative pressures that follow airflows. Priolo and Allard's (2002) discussion of the various building shapes' effects on downwind wakes is helpful. Air movement around the buildings is additionally impacted by vegetation due to wind shielding, wind deflection, air acceleration, and funneling. When traveling through areas with dense forest canopy, the air quality and circumstances are also altered (Ohba and Lun, 2010).

2.3.2 Building design

Following the recommendations for aspect ratios, overhangs, wind barriers, and recessed spaces is crucial for simple buildings. Utilizing computational fluid dynamics to examine several design choices for enhancing the potential of natural ventilation and preventing cold draughts in large and complicated buildings (Priolo and Allard, 2002). At the outside ground level internal space distribution, caution should be made to ensure pedestrian comfort. For instance, to prevent the backflow of contaminated air and odors into adjacent places, relatively dirty areas should be placed on the leeward side. On the windward side, there should be large windows for additional rooms or living areas to create a funnel effect and draw in more air. Buildings' interior barriers and furnishings shouldn't obstruct airflow (Atkinson et al., 2009; Ohba and Lun, 2010).

2.3.3 Vent opening design

In accordance with Priolo and Allard, (2002), Natural ventilation flow rate is determined by the smallest opening area (the bottleneck) in any design. To enhance airflow, outlet and inlet ports should be as similar in size as possible. Given the potential conflict between cross and stack ventilation (or buoyant) ventilation, human cooling, thermal mass cooling, etc., the position of openings must be carefully addressed. It's crucial to choose the right openings and design them properly, including windows, screens, louvers, solar chimneys, and passive stacks. The vent sizing techniques mentioned before might be used to perform proper sizing. The following factors were listed by CIBSE (2005) as important to consider: furniture and internal portioning, ward depth, shading, daylight and glare control, heating and cooling, noise and acoustics, fire safety, and security — opening windows can pose a security risk, especially on ground floors.

2.4. Natural Ventilation and the Comfort of Human

Creating a suitable microclimate in the space being ventilated is the key aim of a ventilation system. Microclimate here refers to both the warm air environment and the air quality. These two elements are crucial to the comfort and wellbeing of occupants, so they must be considered when scheming a ventilation system for a space or a building. The best strategy to prevent the issue of sick building syndrome, which is related to artificial ventilation, is still to ventilate buildings naturally (Liddament, 2012). Therefore, the comfort standards and air quality needed to provide a comfortable indoor climate should be known to the ventilation system's designers and operators. These necessitate an understanding of the heat up balance in the human physique and the inside atmosphere, the variables influencing thermal comfort and discomfort, and the levels of indoor contamination that the inhabitants can bear (Awbi, 2003; Ohba and Lun, 2010).

2.4.1. Interior Contaminants

It is required to determine indoor pollutants, their sources within the structure, and allowable concentrations of indoor air before a ventilation rate can be detailed to diluted or extract them. as the interior environment contains more than 8,000 chemical species.

2.4.2 Radon

A radioactive gas called radon is present in the air indoors. Lung cancer risk is increased. The World Health Organization's "Air Quality Guidelines for Europe" provides risk estimates for radon (WHO). Soil gas from beneath the building is typically the main source of radon indoors. High levels of radon are present in soil gas, with wide variability (Abdou and Budaiwi, 2009).

2.5. Indoor Air Quality (Iaq)

According to Batiment and Luxembourg, (2000), There are two things that the air in a location must provide for its people. First, there shouldn't be much of a health risk from breathing the air. Second, rather than being stale, stuffy, and unpleasant, the air should be viewed as being fresh and pleasant. Human needs vary significantly from person to person. While some people do, others do not spend a significant portion of their time in the same indoor setting. Some people are extremely sensitive and have high standards for the air they breathe. People in other groups tend to be less sensitive and need less air. The degree to which human needs are addressed can be used to describe the indoor air's quality. If there aren't many complaints about the air and the risk to health is minimal, the air quality is high. The quality of the air inside a building change over time. It is affected by modifications in building operation, tenant activity, and exterior climate, claim Abdou and Budaiwi (2009). Ventilation combined with source control may be used to regulate indoor air quality. The ventilation needed to control the health risk posed by air pollutants will be covered separately in these recommendations from the ventilation needed to achieve the target perceived air quality. For design, it is advised to use the highest of these values. A building with windows of a specified size should be built to provide the room or space with excellent natural ventilation (Balta et al., 2010; Ohba and Lun, 2010).

2.6. Factors Contributing to Poor Natural Ventilation

According to Rezaiyan and Cheremisinoff (2005)**,** the interior atmosphere of any given structure is determined by the collaboration of the site, climate, building system (original design and later modifications to the structure and mechanical systems), building methods, pollutant sources (construction materials and furnishings, moisture, processes, and activities within the building, and outside sources), and building inhabitants(Marius, and Panayotis, 2011). Identify the primary sources of pollution and haphazard building design and usage as the main causes of poor natural ventilation.

2.6.1 Pollutant Sources

According to Marius and Panayotis (2011); Ohba and Lun, (2010), It is possible for a wide range of different contaminants to contribute to poor indoor air quality. However, they can be separated into two (2) main categories: internal and external contamination. External pollution is that which originates from outside the structure. Several of these come from:

- **Emissions** - These sources are anthropogenic, or they were created because of human activity. One of the primary kinds is industrial emission, which comes from places like chemical manufacturing plants or chemical storage facilities and can have an impact on the indoor air quality of nearby buildings. Vehicle exhaust emissions from surrounding streets or garages may potentially be a contributing factor to poor indoor air quality in nearby buildings. Inadequate waste or debris storage or collection can also lead to emissions that affect the indoor air quality of the building they originate from or of surrounding structures. The emission might occasionally be created inside the building, ejected using an extraction system and due to the design of the air conditioning system, and then reinvaded back into the building. This might occur in locations where food is being processed, such as labs, printers, or kitchens.
- **Microbial** - Pollen, dust, and fungal spores are examples of microbial sources. Buildings near stagnant water sources may have poor indoor air quality as a result.
- **General Air Pollution** - Anthropogenic (human-based) activity as well as natural processes both contaminate or pollute the atmosphere. Natural sources of pollution include dust, smoke from forest fires, smoke, and ash from volcanic eruptions, as well as the decay of plants and animals. Anthropogenic pollution includes smog, smoke from the burning of coal, fossil fuels, and other materials, as well as pollution from the many forms of transportation.

Internal Pollution: Within the building, internal pollution and indoor air pollution are both produced (Reshetniak, 2014; Marius and Panayotis, 2011). According to EPA (2018), these can occur in a variety of locations inside the facility, including offices, restrooms, people using the building, or even air handler units.

Housekeeping activities - During usage or storage, chemicals and/or cleaning supplies may introduce substances like volatile organic compounds into interior spaces. The contamination of indoor air may also be caused by improper waste storage or disposal. When people are present, dusting, sweeping, and vacuuming introduce additional indoor air contaminants that lower the quality of the air indoors.

Building Materials and Furnishings - Paints and carpets are the two main indoor producers of organic chemicals. Both emit volatile organic compounds (VOCs), particularly when new paint or carpet is present. Many other building components, such as glues and adhesives (used for carpets and tiles), window sealants, floor varnish, and wall and floor coverings, produce VOCs. Additionally, VOCs are released during the "off-gassing" phase of newly purchased furniture. The health of the occupants could be more at risk from other insulation-related building components. Fiberglass is one among them, and it can be discovered in ceiling tiles or in the ductwork for your air conditioner. Asbestos is the other insulation-related building material that has been linked to health problems in people. The term "asbestos" is used to refer to a variety of inorganic minerals that contain fibers that share characteristics including high tensile strength, heat resistance, and fire resistance. This characteristic has brought asbestos to the public's attention and led to its regulation as a dangerous air pollutant by the USEPA since 1973. Asbestos exposure has been linked to three different types of illnesses:

•Lung scarring from asbestosis

•Lung Cancer, mesothelioma, thus cancer of the lining of lungd and abdomen.

Personal Activities - Inadequate indoor air quality is made worse by occupant behaviors like smoking and cooking. Known as cantoins, the smoke from cigarettes, cigars, and pipes contains a mixture of unsavory gases and cancer-causing particles. Due to the lack of regulations regarding indoor smoking in Trinidad and Tobago, this is more crucial there. Smoking is prohibited in several establishments, such as the Piarco International Airport. Smoking is only occasionally permitted in specific situations and designated spaces in the majority of public facilities (malls, movie theaters, and offices). Poor indoor air quality can also be attributed to colognes, perfumes, and body odor.

Microbiological Sources -In Port of Spain, rodents and pigeons are a widespread issue that run the danger of introducing harmful microbiological contaminants to the indoor air. These pests can also damage air conditioning ducting and air handler units. Examples of microbiological sources of indoor air contamination include stagnant water in drain pans of air handler units, microbiological development on water-damaged carpets, furniture, or ceiling tiles.

Special Use Areas - While operating, spaces like labs, printers, kitchens, exercise rooms, smoking lounges, or woodworking shops may produce contaminants that, if drawn into a building's air supply, could be sources of poor indoor air quality. (Marius and Panayotis, 2011.; Reshetniak, 2014).

2.6.2 Unplanned Building Design and Usage

This is a typical reason why indoor air quality is poor. In commercial and residential structures, garages or adjacent rooms are converted into special purpose facilities like labs, printing rooms, or mechanical shops. This kind of impromptu use leads to insufficient ventilation and air conditioning systems, which may create sources of pollution and lead to poor indoor air quality. Similar to this, converting structures like structures into industrial unit where the occupant's number is improved may lead to the structure not being able to adequately service the area and remove contaminant produced by occupants (Mariusand Panayotis, 2011; Reshetniak, 2014).

Vol. 8, No. 03; 2023

ISSN: 2456-3676

The relaxation of the building's inhabitants and the efficiency of the structure and its systems will both be significantly impacted by the location of the building or buildings. In fact, proper orientation may determine how feasible it is to use natural airflow for cooling. In the initial stages of planning and design for any building project, considering the air and heat consequences of site preparation and allocation need be given the utmost emphasis (Guyer et al., 2017).

2.7. Factors Affecting Natural Ventilation

According to Guyer et al., (2017) and Reshetniak, (2014), the main key factors that affects natural ventilation are:

- **Topographic Features** - Avoid enclosed valleys and extremely protected areas for best ventilation. Sites close to hills or ridge tops may have more exposure to the wind for ventilation. Wind speeds on ridge crests can be higher than those on flat ground; a typical guideline is a 20% rise. Buildings on or near the top of a site slope (for enhanced wind exposure) and fronting south (to southeast for decreased afternoon solar contact) are advised if continuous ventilation is needed.
- **Obstructions** - Obstacles include things like structures, fences, trees, and other landscaping. They have an impact on how the building is affected by the wind and sun. To maximize ventilation, buildings should not be situated next to any obstructions and should be far enough apart from one another to operate independently. Five times the height of the windward structure, or at least 5H, of unobstructed space is needed to accomplish this.
- **Pollution Sources** -Naturally ventilated buildings should be located upwind of pollution sources due to difficulty to filter pollutants out the air that enters them. When this isn't possible, it's preferable to place far away from upwind contamination sources, like major roads or kitchen exhaust, so that the effluence has time to disperse in the environment before it enters the structure.
- **Constructing a new building in a developed area** -One of the most crucial factors when placing multiple buildings or a new structure in an area that has previously been built must be the provision for air flow. Of addition to having an impact on the nearby older structures, new construction changes the aeration in an older structure and the flow of air in nearby open areas. You can arrange your buildings and open areas so that each one still has access to the prevailing winds.
- **Orientation of Streets regarding Prevailing Winds**-The wind will be directed into the streets if they are constructed parallel to the direction of the predominant winds. If there are no significant gaps between the buildings along the roadways, this funneling will be more noticeable. The flow will be determined by the street width as previously said if streets are constructed perpendicular to the prevailing winds and structures are unceasing. Due to the forms of the building wakes, bigger building-to-building spacings require a pure separation (street width) of at least five building heights to sustain ventilation.

2.8. Effects of Poor Ventilation

The impacts of poor indoor air quality have been reviewed and discussed including direct and indirect consequences. The direct impact on health, productivity, income, and brand perception, according to the EPA (2018).

2.8.1. Health Effects

According to Al-Homoud, et al., (2009) & Awuku and Wang (2020), Poor indoor air quality would have a direct impact on occupants' health (s). There are a variety of outcomes, including some of the following:

Sick Building Syndrome (SBS) – A building structure is considered as experiencing a sick syndrome when 20% of more occupant's frequently experiences sickness symptoms like nausea, headaches, dizziness, sore throat, dry or itchy skin, sinus congestion, nose irritation, and excessive fatigue. SBS is not limited to local buildings and has been a challenge and a global concern. The SBS is used to define a situation where building occupants suffer sudden changes in their comfort and health that relate to time spent in the building. The SBS symptons can be non-specific and mirror the common cold or other respiratory infections. They can also appear alone or in combination with one another, cycle or occur episodically. The symptoms typically include skin irritation (dryness, rashes), mucous membrane (irritation of eyes, nose, throat, and sinuses). General symptoms like (headache, weariness, and lassitude), and to a large extent respiratory symptoms (cough, shortness of breath).

Building Related Illness (BRI)). A term that refers to well-known illness brought by exposure to the building air, which has signs of a sickly condition BRI is distinguished by what are frequently a distinct collection of symptions, clinical indicators, laboratory test findings, and specific contaminants. BRI is brought on by bacteria, fungus, and virus. Fiberglass, dermatitis, nosocomial infections, and illnesses associated with hypersensitivity are all included in BRI (e.g., common allergy, asthma and humidifier fever) (KLEPEIS, et al., 2001).

- **Legionnaires Disease** – This is the BRI infectious illness that is most well-known. It has symptoms similar to pneumonia, including headaches, chest discomfort, vomiting, diarrhoea, loss of appetite, fever, dry cough, frequent chills, and myalgia. It is brought on by the bacterium Legionella pneumophila. The fatality rate is 15%. Pontiac fever, a very mild clinical manifestation of Legionnaire's disease but a non-pneumatic illness, has been linked to Legionella pneumophilia (EPA, 2018).

2.8.2 Low Productivity

The illnesses and symptoms we earlier described in a professional situation may result in employee or worker absenteeism. Companies can experience a decline in productivity as a result. Lower productivity occurs when one room space can no longer occupied for an extended length of time. Inhabitants may be less productive as well as an individual if they continue to report to work despite having the symptoms or illnesses stated in the previous sections. Continued poor indoor air quality can lead to low employee morale, which can again reduce staff productivity (Gerald, 2008; KLEPEIS, et al., 2001).

2.8.3 Loss in Revenue

In a commercial situation, absenteeism that lowers productivity instantly results in a reduction in income. Instead of routine maintenance, money is lost on air conditioning system repairs and/or replacements. This occurs when microbial contamination enters the system by pigeons or rodents, causing the system to be condemned. Legal repercussions from poor indoor air quality are also conceivable. If affected inhabitants need not be compensated, revenue may be lost in the payment of legal fees. If compensation is not necessary. Employees in Trinidad and Tobago currently have legal grounds to establish complaints of ailments related to time spent at work thanks to the arrival of the Occupational Safety and Health Act, which was once declared.

The Act also implies that employers and employees have a responsibility to protect the health and safety of workers at workplace. The Act lists general obligations of employers to employees (Part II - General Duties 6), general obligations of occupiers (Part II - 6) and general obligations of occupiers to protect public safety and health (Part VI - Health, 36), as well as the removal of dust and fumes (Part IV - Safety, 24). (Part IV - 9). Litigation may be a time-consuming and expensive process that depletes a company's resources and profits (Marius and Panayotis, 2011).

2.8.4 Negative Corporate Image

In Trinidad and Tobago, a single landlord typically owns several properties in the nation's capital, Port of Spain. Accounts of poor indoor air quality in certain owners' properties could lead to a decline in tenancy and a bad reputation for that landlord. Like how news of ailments connected to time duration at work can harm a company's reputation, A company's reputation can't be directly assessed, but it has an impact on how customers perceive it, which may theoretically have an impact on revenue. Reversing a bad reputation and altering the public's opinion of a corporation can also come at a hefty price (Occupational Safety and Health Act, 2003).

3. Research Methodology

The research approach used for the current study was quantitative research method. The data was collected through field observations, and structured questionnaire. Due to unknown population of residential buildings within the Atwima Municipality, the study adopted random sampling for the selection of the communities and purposive sampling for the collection of data. The communities within Atwima Nwabiagya Municipality were grouped into three categories which are Developed Communities, Fast Developing Communities, and Under Development Communities.

Table 1 below shows Classification of Communities.

DEVELOPEDCOMMUNITIES	*FAST DEVELOPING COMMUNITIES*	*UNDERDEVELOPED COMMUNITIES*
Nkawie	*Manhyia*	*D. K. C.*
Abuakwa	*Maakro*	*Abuakwa-Housing*
Toase	*Koforidua*	*Wioso*
Mpasatia	*Abakomadi*	*Afari*
Besease	*Sepaase*	*Nsonyameya*
Hiawu-Besease		*Asenemaso*
Atwima-Agogo		

***(Source:** Atwima Nwabiagya Municipal Assembly, 2021)*

Two (2) communities were randomly selected from the three (3) categories each; making six (6) communities which are: Nkawie, Abuakwa, Manhyia, Koforidua, Wioso, Asenemaso. Data collections were carried out using structured questionnaires, and observation. Rerspondence were asked to indicate their opinion using 5-point Likert scale where 5=most critical, 4=very critical, 3= neutral, 2 = critical and 1= not critical. Data collected was edited, coded, and analyzed using descriptive statistics. Data obtained from the survey was analyzed using Relative importance index (RII) and Mean score with the aid of the International Business Management Statistical Package for Social Sciences, version 21(IBM SPSS, v21). Analysed data was presented in tabular, bar and pie chart form to give meaning to the discussions and relevance of the study.

4. Discussion, Data Analysis and Results

A total number of 210 responded to the questionnaires that was distributed at each selected communities within the Atwima Nwabiagya Municipality. It was self-administered to occupants that were in the house during the time of the survey. Table 2 shows the breakdown.

Table 2 Number of Respondents

Class of Communities	*Communities*	*No. of Respondents*	*Total*
Developed Communities	*Nkawie*	*40*	*83*
	Abuakwa	*43*	
Fast Developing Communities	*Manhyia*	*38*	*72*
	Koforidua	*34*	
Under Developing Communities	*Wioso*	*29*	*55*
	Asenemaso	*26*	
	Total	***210***	***210***

***(Source:** Field survey, 2021)*

4.1 Duration of Occupancy

Table 3 below clearly shows that 9.5% of occupants has been occupying the building/room less than 1 year while 49.5% between 1 – 5 years and 41% more than 5 years. This helps in achieving

ISSN: 2456-3676

a be-fitting results on the poor natural ventilation, based on long stay they could well define the problems (effects) and factors that influence the poor natural ventilation.

Table 3 Duration of Occupancy

Duration of Occupancy	***Frequency***	***Percent***
LESS THAN 1 YEAR	20	9.5
BETWEEN 1 - 5 YEARS	104	49.5
5 YEARS AND ABOVE	86	41.0
Total	**210**	**100.0**

(Source: *Field survey, 2021)*

4.2 Factors That Contributes to Poor Natural Ventilation

4.2.1 External Pollution

The table 4 below shows the data surveyed on the External Pollution on the factors that contributes to poor natural ventilation. Evidence from the survey shows that, Improper storage or collection of garbage with RII 0.977 has larger influence to the poor natural ventilation follows by generation of stinks from neighbourhood having O.935, Emission from vehicle exhaust from garages or roadways with 0.928, Emission from human activities with 0.920 and emission from chemical storage been last accordingly having 0.749. From the literature review, external pollution is the major factor for poor natural ventilation since, air generated outside of the building, one way or the other affects the healthy unused air coming into the buildings (Mariusand Panayotis, 2011).

Table 4: External Pollution

Factors	Mean	RII	Ranks
Improper storage or collection of garbage	4.89	0.977	1st
Generation of stinks from neighbourhood	4.68	0.935	2nd
Emission from vehicle exhaust from garages or roadways	4.64	0.928	3rd
Emission from human activities, like cooking	4.60	0.920	4th
Emission from chemical storage	3.75	0.749	5th
Average Mean	**4.51**		

(Source: *Field survey, 2021)*

4.4.2 Internal Pollution

Internal pollutions are the indoor air contamination, those generated within the building. These may happen changing building location within such as washroom, kitchen, etc. Per the findings in table 5, Special use area with 0.955 ranked first, follows by housekeeping activities having 0.949. Personal activities with 0.934 as ranked third, Microbiological sources with 0.895 emerged as fourth on the ranking. Building materials with 0.785, and Furniture with 0.777 taking fifth and sixth position respectively. The responses indicate how sensitive the sources or factors is to the contribution on the poor natural ventilation within the residential buildings in Atwima Nwabiagya Municipal.

Table 5: Internal Pollution

Factors	Mean	RII	Ranks
Special use area	4.78	0.955	1st
Housekeeping activities	4.75	0.949	2nd
Personal activities	4.67	0.934	3rd
Microbiological sources	4.48	0.895	4th
Building materials	3.93	0.785	5th
Furniture	3.89	0.777	6th
Average Mean	**4.42**		

***(Source:** Field survey, 2021)*

4.3. Unplanned Building Design and Usage

From findings depicted in Table 6 on the unplanned building design and usage portrays, the top ranked factors that influence the poor natural ventilations are showed. From the findings, Design/ allocation of space within the building with 0.995 was ranked first followed by Change of use space with 0.978 as second. The third, fourth, fifth, sixth, seventh and eighth ranked were Size of windows or Doors Opening (0.977), Position of the building (0.963), Window position (0.942), Increase number of occupants (0.939), Orientation of building (0.925), Type of window or door(0.922) respectively. This indicates high magnitude of factors have on the poor natural ventilation. When building changes its use for different purpose from its original design, the number of occupants occupying the residence or room, the types of windows, position, design, and size of the room, etc have significant effect on the occupants which redesigning is necessary. Poor siting according to the orientation of buildings within the communities can greatly affect the design and position of openings within the building (Awukuand Wang, 2020).

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Table 6: Unplanned Building Design and Usage *Factors*	Mean	RII	Ranks
Design/ allocation of space within the building	4.79	0.995	1st
Change of use space	4.89	0.978	2nd
Size of windows or Doors Opening	4.89	0.977	3rd
Position of the building	4.82	0.963	4th
Window position	4.71	0.942	5th
Increase number of occupants	4.70	0.939	6th
Orientation of building	4.63	0.925	7th
Type of window or door	4.61	0.922	8th
Average Mean	**4.75**		

***(Source:** Field survey, 2021)*

4.3 Effects of Poor Natural Ventilation

4.3.1 Health Risk

Evidence from the findings shows amazing results of Sick Building Syndrome taking the lead with 0.961, proving to the fact that poor natural ventilation has significant effects on the health of occupants. While Building Related Illness having 0.923ranked second and Legionnaires Disease follows with 0.907 (see table 7). According to Kamoru (2010), when 20% or more building occupants exhibits symptoms, it's generally classified as sick building, mostly if the indications dissolve when out of the building for a period especially weekends. Illness that results from the exposure to a sick building is known as the building related illness, and legionnaire's diseases also the most widely recognized form of BRI infectious disease. In this case occupants are likely to experience these illness or symptoms such as headaches, chest pain, common allergy, asthma, fatigue, skin irritation, irritation of the eyes, nose, throat, sinuses, rashes, etc (Awukuand Wang (2020).

Table 7: Health Risk

Factors	Mean	RII	Ranks
Sick Building Syndrome (Fatigue, itchy skin, headaches, heat)	4.81	0.961	1st
Building Related Illness (Common allergy, asthma, humidifier fever)	4.62	0.923	2nd
Legionnaires Disease (Chest pains, weight loss, dry cough)	4.54	0.907	3rd
Average Mean	**4.66**		

***(Source:** Field survey, 2021)*

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4.3.2 Lower Production

The table 8 shows Human discomfort ranked first with 0.962, while Sleepless night, ranked seconded with 0.876 whiles Tiredness with 0.749 taking the third position. This confirmed with Gerald, (2008) and (Ohba and Lun, 2010), that occupants experience the symptoms or illness, whiles reporting to work, the productivity of the individual and group may be reduced collectively. And it clearly shown that poor natural ventilation to residence has significant effect to productive level at work.

Table 8: Lower Production

Factors	Mean	RII	Ranks
Human discomfort	4.81	0.962	1st
Sleepless night	4.53	0.876	2nd
Tiredness	3.75	0.749	3rd
Average Mean	**4.13**		

***(Source:** Field survey, 2021)*

4.3.1 Lost in Revenue

The survey result shows that, the respondent's rated High payment of billsas a significant effect of poor natural ventilation of residential buildings with 0. 953. And repairs or replacement with 0.905 ranked second whiles time-consuming exercise having 0.876 ranked third, which literally creates a huge lost mostly on revenue, sake of poor natural ventilation. Poor natural ventilation in a residential building creates discomfort leaving occupants no choice but to rely on mechanical means to be able to create a comfortable and pleasing environment within the residence or room. To achieve those purpose, results to increase on electricity bills and due to constant usage, require regular maintenance or repairs sometimes replaced within short period of usage (Fischer, et al., 2011).

Table 9: Lost in Revenue

Factors	1	2	3	4	5	W	Mean	RII	Ranks
High payment of bills	0	0	7	35	168	1001	4.77	0.953	1st
Repair or replacement	0	0	29	41	140	951	4.53	0.905	2nd
Time-consuming exercise (regular cleaning)	0	1	19	58	132	920	4.53	0.876	3rd
Average Mean							**4.61**		

***(Source:** Field survey, 2021)*

4.3.3 Negative Corporate Image

The below table 10 depicts an overwhelming respondent's rate of putting Negative perception from occupants with 0.903 at first position, followed by Decrease tenancy at second position having 0.898. This indicates that poor natural ventilation in specific landlords building, or room results in decreased tenancy and negative public image or perception for such residence (Kamoru, 2010).

Table 10: Negative Corporate Image

Factors	1	2	3	4	5	W	Mean	RII	Ranks
Negative perception from occupants	0	4	15	59	132	949	4.52	0.903	1st
Decrease tenancy	0	0	21	65	124	943	4,49	0.898	2nd
Average Mean							**4.51**		

***(Source:** Field survey, 2021)*

5. Conclusion

There are many parameters that are involved in natural ventilation, i.e., air temperature, air humidity, air velocity, radiant temperature, skin temperature wind direction, height different of the opening and opening location, orientation of buildings. The study identified factors that contributes to poor natural ventilation in residential buildings. Nineteen (19) factors were identified, which was further grouped into three (3) categories namely unplanned building design and usage, external pollution, internal pollution. Eleven (11) effects were also identified, which was grouped into four (4) categories namely health risk, lower production, lost in revenue, negative corporate image. Most critical factor having effect on the poor natural ventilation of residential building is unplanned building design and usage with the average mean score of 4.75. Health risk has identified as the main effect of poor natural ventilation with average mean score value of 4.61. The wellbeing and health of humans are the utmost priority as supported by the 2030 agenda of sustainable development goal three, thus, ensure healthy lives and promote well-being for all at all ages. It is identified that greater percentage of time are spent indoor; therefore, poor ventilation has a direct effect on the well-being and health of occupants. Hence, a critical concern requiring a pragmatic solution. This study has unearthed the root cause and its effects as anitial step to resolve identified concern.

6. Recommendations

The natural ventilation, its significance, contributing factors and effects have been reviewed per this study, it is recommended that; purpose and use of the building should be design and construct the building to standard requirements. Experienced professionals should be engaged in the design and construction so that buildings can conform to the national building regulation.

Public education should be done by the municipal assemblies on the relevance of using professionals to achieve human comfort in design and construction. Majority of the door and window openings should be oriented with respect to the prevailing south-west breeze. If there is no prevailing direction, openings should be sufficient to provide ventilation regardless of wind direction. Appliance indoors should be put off when not in use to minimize heat generation. Light weight curtains should be mounted at the various openings (Windows and Doors) to avoid dust easy passage into the building and reduce the amount of heat generated within the room. Cleaning and removal of garbage's should be done regularly and proper storage of items within the room or outside the building should done so that the benefits of natural air can be fully enjoyed.

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