EVALUATION OF NATURAL VENTILATION CONDITION IN SELECTED HEALTHCARE FACILITIES IN ADAMA CITY, ETHIOPIA.

Jarso Nimani Bizani

A Thesis submitted to

The department of Architecture

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of

Master of Science in Environmental Architecture

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

September, 2022

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APPROVAL OF BOARD OF EXAMINER

We, the undersigned, members of the Board of Examiners of the final open defense by **Jarso Nimani Bizani** has read and evaluated his thesis entitled **"Evaluation of Natural ventilation condition in selected healthcare facilities in Adama city, Ethiopia."** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Environmental Architecture.

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Jarso Nimani Bizani

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This MSc Thesis has been submitted for examination with my approval as a thesis advisor.

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Signature: ______________

Date of submission September 15, 2022

ADVISOR'S APPROVAL SHEET

To: **Architecture department**

Subject: **Thesis Submission**

This is to certify that the thesis entitled **"Evaluation of Natural ventilation condition in selected healthcare facilities in Adama city, Ethiopia"** submitted in partial fulfilment of the requirements for the degree of Master of Science in Environmental Architecture, the Graduate Program of the Department of Architecture, and has been carried out by **Jarso Nimani Bizani** ID. No PGR/19221/12, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Yared Girma (PhD)	________________	______________________
Name of major Advisor	Signature	Date

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LIST OF ACRONYMS AND ABBREVIATIONS

IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
TB	Tuberculosis
WHO	World Health Organization
AMHC	Adama Medical Health Collage
AHC	Adama Health Centre
ACH	Air Change Per hour
NVR	Natural Ventilation Rate
CDC	Centre for Disease Control
SARS	Severe Acute Respiratory Syndrome
HCWs	Health Care Workers
PE	Protective Environment
HVAC	Heat Ventilation and Air Conditioning
CFD	Computational Fluid Dynamics
HCF	Health Care Facility
FOR	Floor to Opening Ratio
OD	Opening Dimension
AVG-NVR	Average Natural Ventilation Rate
AVG-ACH	Average Air Change per Hour
AMHC-AIDW	Adama Medical Health Collage Airborne Infectious Disease Ward
AMHC-G-W	Adama Medical Health Collage General Ward

ABSTRACT

The design of healthcare facilities must provide quality Indoor air quality for the dwellers. It must be designed to have adequate natural ventilation and good air circulation to provide a comfortable indoor environment quality (IEQ) for the patients and workers. In Adama City, many healthcare facilities have poor access to natural ventilation. They have small openings, aren't orientated against the wind, lack cross ventilation, and have limited access to natural ventilation as a result of their poor design. Therefore, the purpose of this study is to evaluate the state of natural ventilation in existing healthcare facilities. To do so, the study have examined the natural ventilation rate (NVR), air change per hour (ACH), flow direction, and floor to opening ratio. Ambient temperature (inside and outside), humidity and air velocity rate were measured under three different types of opening condition for three consecutive days during mid of July and August. The data obtained from the measurement was analysed using MS Excel and calculated using rule of thumb. The result from the analysis indicates that, the corridor spaces and maternal ward has no cross ventilation. Whereas the general ward and airborne infectious disease ward (AIDW) has cross ventilation. The NVR of corridor spaces is 1.43 l/s/m^3. The general wards NVR is 47 l/s/p. Whereas the NVR of AIDW is 61 l/s/p. The ACH value of the corridor spaces are 0.16 in average. The general wards ACH value is 1.8 and 2.12. The AIDW's ACH value is 2.27. According to the standard guidelines of WHO and Ethiopian natural ventilation for infectious control in healthcare standard, the corridor space fulfils almost 60 % of minimum required standard values. The general wards and AIDW fulfil almost 80 % and 40 % of minimum required NVR standards. Which indicates that, the spaces of Corridor, general wards, and AIDW are not up to the standard to provide enough natural ventilation. The research suggested increasing of existing opening dimension and providing cross ventilation will help to achieve the minimum required NVR standard. The optimized result suggests, the corridor space and general ward should double the existing opening dimension and AIDW should have four times larger opening size to achieve the minimum NVR standard. In conclusion, all subjected spaces are not up to the standard to provide enough natural ventilation rate. The modification will enable the spaces to achieve the minimum required value of NVR suggested by the standard. Apart from modification, the access of cross ventilation and proper design orientation will improve the condition of natural ventilation.

*KEY WORD**:** Air change rate per hour, Air velocity, floor to opening ratio, natural ventilation rate, opening dimension.*

CHAPTER ONE

INTRODUCTION

Natural ventilation is one of the most important element of a space that determines functional comfort of the building. Natural ventilation moves outdoor air in to a building and distributes the air with in a building to provide healthy air for breathing and removes the pollutant from the space. Naturally ventilating a space is also the most sustainable, cost and energy efficient way (Mohamed A, Steve Dudek and Neveen Hamza, 2013). Ventilation rate is the main indicator of how the space is ventilating and effective way of showing the magnitude and speed of air flowing through the space.

The recent outbreak of COVID19 pandemic has inspired this research to evaluate the current existing environment of healthcare facilities. Many of our healthcare facilities have failed to function as medication space for the recent pandemic. The main reason is that; they have less access to natural ventilation. Since, airborne infectious diseases need well ventilated space to medicate the patients and reduce the transmission rate among the users.

This study has analysed the natural ventilation condition of healthcare facilities by studying the airflow direction, floor to opening ratio, natural ventilation rate and air change per hour of the healthcare facility spaces found in Adama city. And compare it with the Ethiopian standard of health care facility building codes and analyse whether the current serving facilities can provide the minimum required standard amount of natural ventilation. This paper will also help builders, dwellers, municipalities, architects and other pertinent bodies make wise decisions in selecting the right natural ventilation ways in future projects.

1.1 Background of the study

The complex environment of healthcare facilities requires special attention to ensure healthful indoor air quality (IAQ) to protect patients and health workers against transmission of airborne infectious disease (Mahmoud F. El-Sharkawy and Mohamed E. H. Noweir, 2014). Healthcare facilities must be designed to have adequate ventilation and good air circulation to provide a comfortable indoor environment quality (IEQ) for the patients and workers. It is very important in controlling any infection and contamination, and reduce the potential spreading of airborne diseases in the clinical area while maintaining a clean environment (Chandrasegaran & Badarudin, 2011).

The transmission rate of airborne infectious disease is higher and faster than other diseases, due to its nature. The infectious droplet is transported by air, which accelerates the rate of transmission. Airborne infectious disease and ventilation are very much connected. There is no evidence that shows ventilation prevents the transmission of airborne diseases, but it plays huge role in reducing the rate of transmission (James Atkinson, 2009). In a place where there is less ventilation, the transmission rate of airborne diseases is very high. Ventilating a space will help in removing infectious particle and reduce the risk of transmission. The current pandemic of COVID19 which is still threatening the global health. It has taken more than 6.5 million lives so far (WHO, 2022). The previous related pandemic like TB which took nearly 2 million lives (World Bank, 2006). From the lesson taken from those pandemic is that ventilating a space will help in reducing the transmission of the disease. Especially, in healthcare facilities where there is already high risk of infection and transmission rate.

Ventilation in health care facilities has a profound effect on the well-being of patients and employees in health care facilities (Y.H. Yau, 2010). Health care facilities are not like other space, since it requires special attention due the circumstance of patients' status and the functionality of the space. Comfortable Indoor air quality will make the patients relaxed and balance the metabolism rate which has huge impact on recovery rate of the patients. At this time, ventilation in health care facilities is important as it provides thermal comfort and protection from harmful emissions or airborne pathogenic materials to both patients and health care workers (Yau, 2010). Among the most rapidly transmitted category of diseases, the airborne disease is the deadliest and highly distributed which can cause the huge damaging pandemics in regional and global scale.

Natural ventilation is the most effective and sustainable way of ventilation. It is also the most energy efficient way of ventilation since it works by the law force of nature. It requires no operational and maintenance cost. Natural ventilation is highly preferable for country like Ethiopia, especially hot area like Adama which requires high ventilation in almost every dwelling space of the buildings, especially in hospital areas where there are many users and very crowded.

1.2 Statement of Problem

Natural ventilation is very important in providing fresh air which helps to achieve a healthy and comfortable indoor air quality for the dwellers. It can also help to ensure and support the supply of adequate breathing air, adequate ventilation of contaminants, adequate thermal conditioning and moisture dissipation, and contribute to well-being of the dwellers. Natural ventilation is also one of the most sustainable, cost efficient, energy efficient, with durability, low maintenance cost and best way of ventilating spaces for long time (Mohamed A, Steve Dudek and Neveen Hamza, 2013).

Many of healthcare facilities in Adama city are in a very poor conditions to function as medications Space. The main problem is that their condition and purpose of the construction of the facilities. Many of private owned facilities are originally constructed as residential housing which later converted to private clinics. While government owned facilities are constructed by the concept of low cost and low quality and also the fact that they are always over crowded which makes them perform less that it should be. The major problems with those facilities related to natural ventilation is that; many of those facilities are constructed in densely populated residential area where wind block is very high and the facilities are less oriented towards wind direction. The interior arrangement of the space is also other challenge for the proper air flow in the space. The opening to floor ratio is also another problem with those facilities. The dimension of the windows is very small compared to the volume of the space and number of dwellers. The arrangement of the openings also doesn’t offer for the proper cross ventilation.

In a facility where there is low ventilation condition, the rate of airborne transmission diseases which caused by bacteria, virus, fungi are very high. It also reduces indoor environment quality (IEQ). Which later have huge impact in reducing the recovery rate of patients. Not having enough ventilation will also lead to less comfort for the dwellers and reduce the efficiency of the whole medication process as a whole. Healthcare facilities in Adama city has very low ventilation access. Some of the facilities are designed for residential housing and others are overcrowded. Which makes the abundance of ventilation less with respect to required amount.

Adama city is one of the most known hot cities in Ethiopia with experience of high temperature and studying the natural ventilation has huge advantage for facilities like healthcare. Ethiopia is one of many countries with experiencing the pandemic of airborne disease like TB and currently COVID19. Which we are challenging to this day and our healthcare facilities are not in a good condition to be a good treatment space for related pandemic. As a fact during current pandemic of COVID19 many of the healthcare facilities become unfit and temporary mobile housing was needed to build in many areas. So, this research has tried to find the real ventilation condition of current serving facilities and find out why they failed to fit and recommend the better way of naturally ventilating a space in order to have better facilities for related kind of pandemics in the future.

1.3 Objectives

General objective

To analyse the Natural ventilation condition of healthcare facilities in terms of ventilation rate and opening dimension in Adama city, Ethiopia.

Specific objectives

1. To assess the existing Natural Ventilation condition in different Healthcare facilities with respect to air flow direction and floor to opening ratio.
2. To analyse the Natural ventilating rate with respect to opening dimension.
3. Evaluate the ACH (Air change per hour) relation to Floor to opening ratio.
4. To suggest the optimization in order to increase Natural ventilation rate.

1.4 Research Question

1. How does natural ventilation of healthcare facilities are operating with respect to air flow direction and floor to opening ratio?
2. How natural ventilation rate is operating with respect to opening dimension?
3. How much air change per hour is operating with respect to floor to opening ratio?
4. How can we optimize to potentially increase the Natural ventilation rate?

1.5 Significance of the research

Ventilation is a very important elements of the building which maintains other main actors like temperature, light and humidity in place. Without ventilation it is very hard to call the space comfortable for the users. Ventilation Provides fresh air into a building to ensure good air quality for occupant's health and well-being. Ventilation promotes and directs air movement in the space, removing excessive heat and moisture essential for comfort and well-being. For the facilities like healthcare natural ventilation is the most advised way. Due to its sustainability, cost and energy efficiency. It also requires no maintenance, durable and preferable ways to ventilate spaces.

Healthcare facilities requires appropriate natural ventilation due to the fact that so many health related issues like Air borne diseases which can easily transmit from patients to patients. For instance, we can see from the recent outbreak of pandemic occurred in our country Ethiopia. Decades before, the pandemic of tuberculosis (TB) is our recent memory in which hundreds of people are losing their lives. From the nature of these pandemics we have learned that having a well-ventilated space will help in the treatment and medication of the pandemics, and rate of transmission which is very helpful in so many ways. Naturally well ventilated healthcare facility will have huge role in serving as medication space in the future.

The findings from this research will enable to understand the current natural ventilation condition in our healthcare facilities. Which will help to adjust, maintain and improve the natural ventilation condition of our healthcare facilities. It will also show its impact in improve the medication process and increase the efficiency. It will help both medical and academic community in understanding the current status natural ventilation condition in healthcare facilities and improving the condition through conducting related research in the future.

1.6 Scope of the Research

The research has taken place in Adama city, focusing on two medium private clinics, one public healthcare station and Adama Medical Health Collage (AMHC) located in Adama 12 (Gaada) Kebele. Two facilities each selected from both private owned and government owned in order to have balanced data. The research mainly focuses on the studying natural ventilation condition by analysing the opening condition, natural ventilation rate (NVR) and air change per hour (ACH) in the facilities. The subjected space of facilities are corridor space, general wards, and airborne infectious disease wards. This study is takes place in July and August months of summer season, where there is less windy time in Adama city.

1.7 Limitation

The collected data were limited to single space in every facility. Corridor space in private clinics and wards spaces from government owned facilities. Data was collected only using Anemometer and Hygrometer. Tracing gas was not used due to lack of availability. The collected data was also limited to single measurement per day. In summer season wind speed was very less in Adama city. In order to take balanced data, it was must to wait windy day and took measurements. During the data collecting in ward areas. It was must to wait and measure when all patient bed was occupied. In ward areas, the measurement was also taken during sunny day. Since patients complained when window was open during rainy day. The computation used to analyse natural ventilation condition only covered NVR and ACH.

1.8 Description of the study area

Adama City is one of fast growing cities in the country with an estimated total population of 343,212 (CSA, 2009). Adama is also the second most populous city in Ethiopia. (Cities alliance - cities without slums, 2019-2021). It is situated in Rift valley within Awash River Basin in Oromia Regional State of Ethiopia. It was established in 1916 on flat terrain characteristics and surrounded by plateaus, mountainous and ridged topography along Addis Ababa to Harar road at distance of about 99 km. It is located between8026’15”–8037’00” N,39012’15”-39019’45”E. Altitude of the area ranges from 1623m a.s.l. Average annual rainfall of Adama City is about 866.25 mm. Most of the rain occurs in rainy season (June to September). The minimum wind speed occurs during September (1.65m/s), while the wind with high velocity occurs during December, January and February (3.05-3.2m/s). The mean temperature in the city varies from 11.5 ^{o}C to 31 ^{o}C (Bulti et al, 2017).

Table 01: Summary of weather condition

Weather condition	*High*	*low*
Rain	Jul-Aug	Nov-Dec
Humidity	Jun-Sep	Jan-Mar
Wind speed	Oct-Dec Mar-May	Jun-Sep
Temperature	Nov-May	Jun-Sep
Precipitation	Jun-Sep	Nov-Feb

Figure 01: Study Area

The study area is selected based on the diversity of healthcare facility, and also based on the target of dwellers flow. The study area is half from private owned facilities and half from government owned facilities. The main reason for this is to have balanced outcome and make the survey fair, since Healthcare facilities are owned by both private and government and their status is also by far different. Their nature and history of their construction is also different. Most of the private owned medium clinics are rental houses, which is originally built for residential purposes. While the government owned facilities are built for the purpose of providing healthcare.

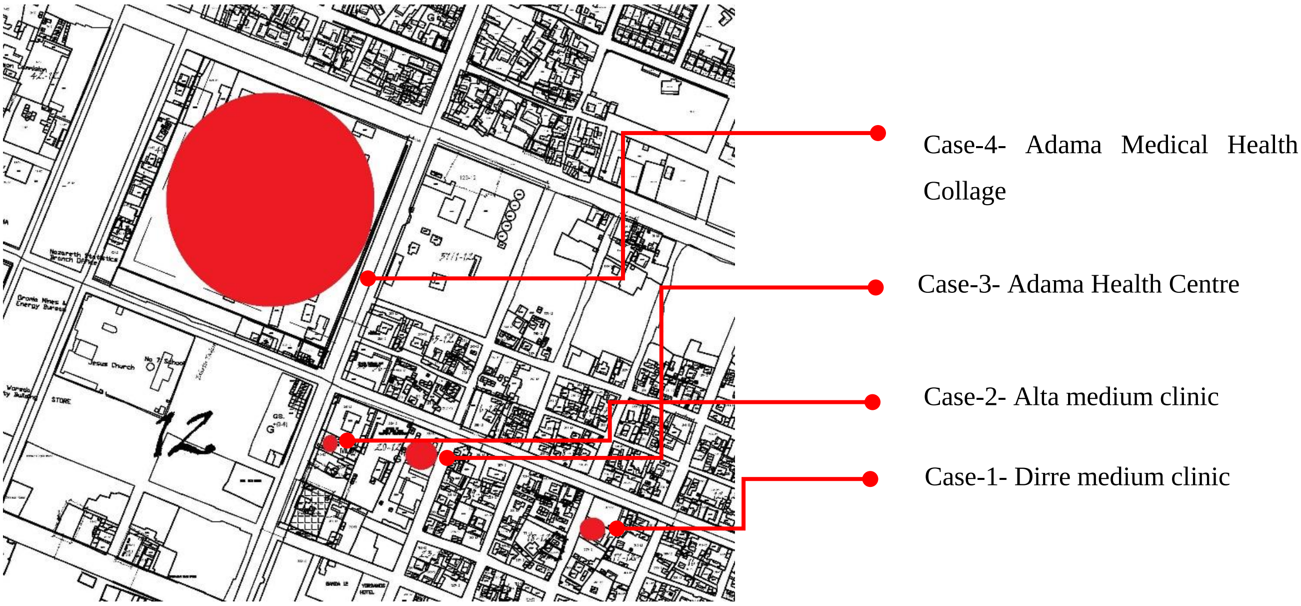


Figure 02: Location of Study area

Case-1- Dirre medium clinic

Dirre medium clinic is located in Geda kebele (12 kebele) around Harambe University. The site is oriented in South West (SW) direction and found in densely populated residential area. The specific space selected from this facility is the corridor space. The corridor is located in the middle of the house and has adjacent spaces which currently function as examination room, reception and waiting area. The corridor has 3 m height, 1.10 m width and 8.3 m length. The outdoor wind break condition is due to its location in densely populated residential area.

Case-2-Alta medium clinic

Alta medium clinic is located in Geda kebele (12 kebele) around Paradise Collage on the main road to St. Mariam church. The site is also oriented in South West (SW) direction. The corridor is located along the main entrance of the house and has adjacent spaces which currently function as examination rooms. The corridor has 3.1 m height, 2.3 m width and 5.1 m length.

Case-3- Adama health center

Adama Health Centre is located in Geda kebele (12 kebele) near Harambe University. The site is oriented in North South (NS) direction. The facility is scaled as medium scale health care center which traditionally known as ‘’Tenatabya’’. The specific space selected from this facility is the maternal ward. It is located around the corner of the main entrance of the facility. On the adjacent side of maternal ward there is two delivery rooms. The other spaces aligned across. The maternal ward has 3 m height, 2.9 m width and 8.15 m length. The design error is the main factor for wind breaker. The exterior wall of the facility is built on border line. Which forced the spaces to have single access to ventilation.

Case-4- Adama medical health collage (AMHC)

Adama Medical Health Collage is located in Geda kebele (12 kebele) in front of Shewa building. The site is oriented in North South (NS) direction. The facility is scaled as Referral Hospital. The specific space selected from this facility is the Internal Medicine ward. The ward has four rooms which functions as general wards and one temporary isolated airborne infectious disease ward. It also has public toilet in the centre of the right side aligned room and wide corridor in the middle. The nurse station, store, and janitor room is found on the other corner of the building. Each room has typical dimension of 3.0 m height, 5.5 m width and 5.8 m length. Trees outside the ward area are the main wind breaker.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Natural ventilation

Natural ventilation is the most sustainable way to provide high airflow rates with low energy consumption (Totaforti.S, 2018). Natural ventilation is derived by natural forces which drive outdoor air through openings such as windows and doors by depending on building design and outdoor climatic conditions relative to the indoor conditions. It also provides certain advantages in terms of capital and operational costs and capable of providing high ventilation rates. (WHO, 2009).

Table 02: WHO, Natural Ventilation for Infection Control in Health-care Settings.

Room type	**Minimum hourly averages natural ventilation rates**
General wards	60 l/s/per patients
Airborne precaution rooms	160 l/s/per patients
Corridors	2.5 l/s/per m^3

2.1.1.1 The driving force of natural ventilation

Two forces can move the air inside the building

- ✓ Wind pressure
- ✓ Stack pressure (buoyance)

Wind pressure

When wind strikes the building it induces a positive pressure on the wind face and negative pressure on the other side. This drives the air to flow through windward openings into the building to the low pressure openings at the other side (WHO, 2009).

Stack pressure (buoyance)

Stack pressure is generated from the air temperature or humidity difference. This difference generates an in balance in the pressure gradient of interior and exterior column causing a vertical pressure difference in the space. When the room air warmer than the outside air, the room air is less dense and rises. Air enters the building through lower opening and scape through upper opening and vice versa (WHO, 2009).

2.1.2 Advantage of Natural Ventilation.

Natural ventilation has so many advantages compared to mechanical systems. It provides high ventilation rate in more economical way since it only uses natural forces and large openings. It is also more energy efficient and creates more access to natural day lighting. Generally, the main advantage of natural ventilation is its ability to provide a very high air change rate at low cost, with a very simple system. Although the air-change rate can vary significantly, buildings with modern natural ventilation systems can achieve very high air-change rates by natural forces (James Atkinson, 2009)

Table 03: Summary of advantages and disadvantages of different types of ventilation systems for hospitals

Advantage &disadvantage	Mechanical ventilation	Natural ventilation	Hybrid (mixed-mode) ventilation
Advantages	Suitable for all climates and weather with air-conditioning as climate dictates.	Suitable for warm and temperate climates — moderately useful with natural ventilation possible 50% of the time	Suitable for most climates and weather
	More controlled and comfortable environment.	Lower capital, operational and maintenance costs for simple natural ventilation	Energy-saving
	Smaller range of control of environment by occupants.	Capable of achieving high ventilation rate Large range of control of environment by occupants	More flexible
Disadvantages	Expensive to install and maintain.	Easily affected by outdoor climate and/or occupant's behaviour.	Maybe expensive.
	Reported failure rate in delivering the required outdoor ventilation rate	More difficult to predict, analyse and design	Maybe more difficult to design
	Potential for noise from equipment	Reduces comfort level of occupants when hot, humid or cold Inability to establish	

	negative pressure in isolation areas, but may be provided by proper design; depends on situation Potential for noise intrusion High-tech natural ventilation shares some of the limitations and disadvantages of mechanical ventilation	

2.1.3 Indoor Air quality

The whole indoor air quality of a healthcare facilities must fit to a better quality to make the dwellers comfortable enough and accelerate the efficiency rate of medication and help the patient both physically and psychologically comfortable enough. It should also ventilate enough by which means possible to prevent rate of contamination in the space and makes the patients and dwellers healthier and safe. However, medicines, medical treatments and cleaning in hospitals can also affect indoor air quality (IAQ). (Chien-Cheng Jung et al., 2014). Healthcare workers, such as doctors, nurses and others, are exposed to infectious diseases which demands work conditions.

A. Temperature

The temperature of the environment within the healthcare facility should meet the thermal comfort requirements of the occupants, especially the patients. One point to consider is that their body temperature regulatory functions are damaged as a result of their conditions. Also, having a pleasant atmosphere assists in healing (Yau, 2010) Hence, a desirable temperature should be maintained at satisfactory comfort conditions. One may also say that it is impossible to satisfy the total comfort of all the occupants in terms of indoor thermal conditions. Comfort also depends on occupants' clothing, activity and air movements. In addition to these variables, patients' physical strength also influences their thermal comfort needs. The temperature of the environment within the healthcare facility should meet the thermal comfort requirements of the occupants, especially the patients. The average room temperature for spaces in Hospital should be 20-22^{0}c.

B. Air movement

Air movement distribution is another indoor condition that needs attention. Airflow pattern is a significant factor affecting the needs of staff and patients in a ward. For instance, droplet transport from patients' respiratory activities is closely related to airflow patterns. In addition, airflow patterns will also affect the thermal comfort of both the staff and patients. Air movement is due to momentum flows from the outlet diffusers and temperature differences. The air distributions can also be enhanced using a different type of outlet arrangement, such as downward ventilation and horizontal airflow (Y.H. Yau, 2010).

C. Humidity

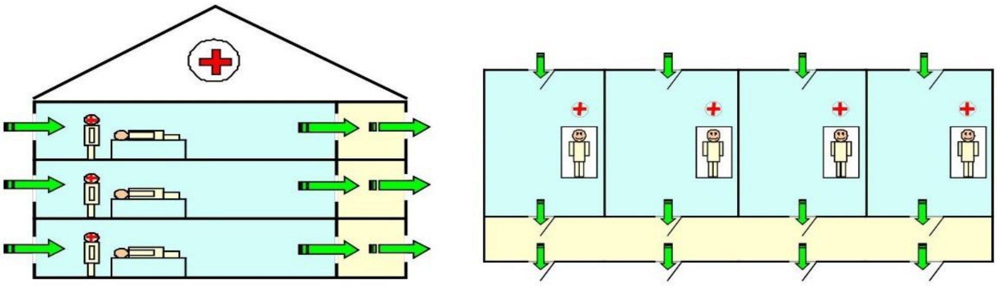
In addition to temperature and air movement, humidity is another internal climate characteristic. Room hygiene and thermal comfort levels are very much related to humidity levels. Humidity levels have some bearing on thermal comfort levels. In most hot areas, the humidity level is a governing factor in the variations of thermal sensations when subjects are exposed to an almost constant room temperature of 23 °C and a room average velocity of 0.07 m/s. However, certain medical conditions require an extreme level of temperature and relative humidity to assist in the healing process. The Humidity rate for healthcare facilities should be between 30% and 70%. Humidity levels also influence the growth and transfer of airborne microorganisms. Additionally, high humidity levels result in moisture being absorbed in building materials (Chandrasegaran & Badarudin, 2011).

2.1.4 Types of Natural Ventilation

There are six basic types of natural ventilation systems: single-side corridor, central corridor, courtyard, wind tower, atrium and chimney, hybrid (mixed-mode) ventilation.

2.1.4.1 Single-side corridor type

In the single-side corridor type of natural ventilation system, the corridor is on one side of the ward. The airflow is a single directional flow either from the ward to the corridor or from the corridor to the ward, depending on the wind incident direction. This single directional flow can help to prevent cross-infection. The design of the windows is crucial for this type of design: it is better to position the windows in line with the ward door to create the path for cross-ventilation (Atkinson, 2009).



Section view Floor plan

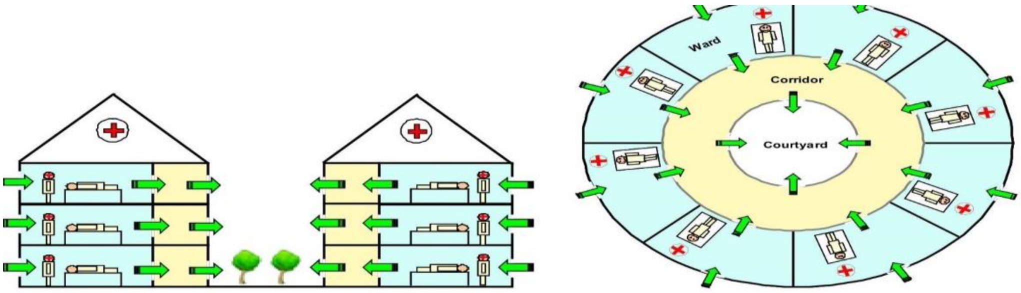
Figure 03: single-side corridor type

2.1.4.2 Central corridor type

The central corridor type of natural ventilation system is derived from the single-side corridor type by adding another series of wards on the other side of the corridor. The possible airflow path would be from one ward to the corridor, and then to the ward on the other side. When the wind is parallel to the windows, adding a wing wall helps to drive the outdoor air to enter the wards first, and exit from the central corridor. A central corridor type of floor layout would result in possibly contaminated air moving from the upstream ward to the downstream ward (Atkinson, 2009).

2.1.4.3 Courtyard type

Courtyards are traditionally enclosed zones that can help to channel and direct the overall airflow and thus modify the microclimate around the buildings. Based on the relative position of wards and corridor to the courtyard, this type of natural ventilation system can be divided into the inner corridor and outer corridor subtypes. This system can supply more ventilation than the others, as long as the courtyard is sufficiently large. The outer corridor type has an advantage over the inner type, because it can avoid cross-infection via connected corridors by delivering clean outdoor air into the corridor first (Atkinson, 2009)

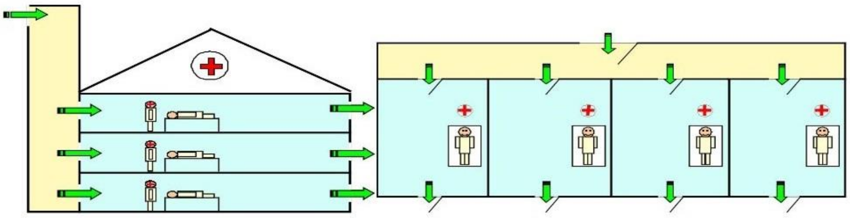


Section view Floor plan

Figure 04: courtyard type

2.1.4.4 Wind tower type

A wind tower type of natural ventilation system can capture the wind at roof level and direct it down to the rest of the building. Weatherproof louvers are installed to protect the interior of the building and volume control dampers are used to moderate flow. Stale air is extracted on the leeward side. The wind tower is normally divided into four quadrants, which can run the full length of the building and become air intakes or extractors depending on wind direction (Atkinson, 2009).

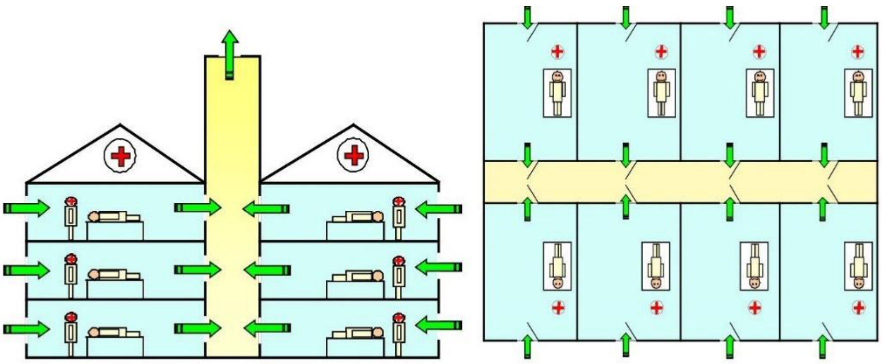


Section view Floor plan

Figure 05: Wind tower type

2.1.4.5 Atrium and chimney type

Direct ventilation of the atrium is detrimental to the ventilation of the storey and the best design is identified as a compromise that provides adequate ventilation of both spaces.



Section view Floor plan

Figure 06: Atrium and chimney type

2.1.4.6 Hybrid (mix-mode) type

A limitation of natural ventilation is that it can sometimes depend too much on the outdoor climate. For example, if the outdoor wind speed is too small or the outdoor temperature is too high, the availability of natural ventilation will be reduced. To overcome this, hybrid (mixed-mode) ventilation can be used. In a simple hybrid (mixed-mode) ventilation system, mechanical and natural forces are combined in a two-mode system where the operating mode varies according to the season, and within individual days, reflecting the external environment and taking advantage of ambient conditions at any point of time. The main hybrid (mixed-mode) ventilation principles are: Switching between natural and mechanical ventilation fan-assisted natural ventilation concurrent use of natural and mechanical ventilation.

2.2 Contextual Review

2.2.1 Hospital Buildings in Ethiopia

The healthcare facility building coverage in Ethiopia is very poor. The proportional distribution of healthcare facility to the number of population is quite less. Currently the number of population is 110 million and the number of facilities is currently, there are 3, 245 health stations, 16,048 health posts and 229 referral hospitals across the country, and 175 more referral hospital currently under construction (Biomed central, 2022). With this un-proportionality of population to facility; many spaces in hospitals and other healthcare facilities are very crowded and suffocated. In this case the space will change from ‘’healing’’ space to ‘’killing’’ space.

The Hospital architecture of Ethiopia is a bit challenging, due to the fact that it has been built in the concept of low cost construction, not relative quality based construction like it should be since it is health care facility. The spaces are very small and always out of standard let alone the condition of Indoor Air Quality (IAQ). The spaces are very suffocated and very hot, sometimes very hard and challenging for the patients to stay in the space; especially around wards where the number of the dwellers is very high. With current issue of COVID-19, other airborne transmitted pandemic the world has suffered from and suffering with, the necessity of ventilated space with excellent IAQ is very important and crucial for healthcare facility to function as ‘’ Healing Space’’.

Like many developing countries the issue to less quality facilities are common in Ethiopia. Specifically related to ventilation condition is very alarming. The design of facilities by itself is one problem, the openings in the space are very small to provide enough air for the patients. The arrangement of spaces is mostly not in a way that ventilation is considered. The other main problem with related to ventilation in healthcare facilities are the way dwellers use openings. Most of the time the openings remain closed to the fear of patients that cold related diseases might engulf them, so most of the time patients or care givers are forced to open the windows. And so many other factors contribute for the poor ventilation conditions in healthcare facilities. Due to this, many of airborne diseases are easily transmits from patients to patients or to other dwellers. All those issues are transforming our healthcare facilities from bad to worst.

2.2.1.1 Healthcare Facilities in Adama

In Adama, there are many healthcare facilities. Some of them are government owned facilities and many of them are private owned facilities. The government owned facilities are mostly two types based on their scale. Hospitals and Health care facilities. The Adama medical health collage Hospital (commonly known as Hailemaryam) hospital is one of the largest hospital in the city as well in nearby areas. It is basically function as referral hospital. Due to its being large scale and public hospital it mostly accommodates many patients; in some case more than its capability. The hospital recently has incorporated new buildings in the compound which made so many changes and help in relieving the density of patients by providing more than quadruple accommodation space, but due to its functional varieties and nonstop flow of patients many of old facilities problem remains as it was. Wards and other accommodation space are still crowded and suffocated. Other government owned facilities are healthcare centres (commonly known as Tenatabya). Those facilities are more or less has the same problem with the previous one. The main reason for this is that, large scale facilities like AMHC converts some of their services to those small scale facilities to reduce their loads. But the scale of those facilities find themselves in difficult to accommodate the scale of the demand and remain as crowded as their partners are into. The second types of healthcare facilities are private owned facilities. They are also categorized based on their scale according to this study in to two. The first one is hospitals. There are few private owned hospitals in Adama, like Adama general Hospital, Rift valley Hospital, Aklesia Hospital, Dirre Godana Hospitals and others. Those facilities are purposely design to function as healthcare facilities and their functional comfort is much better than others. Due to their expensive in medication cost the scale of patient flow is very less compared to others. Due to that many healthcare facilities problems are very less. The second category of private owned facilities are clinics. Based on their scale, they range from primary clinics to higher clinics. Many of this facilities are densely around Geda kebele (12 Kebele). Many of this facilities are not built to function as healthcare facilities rather they are old villa type of residential houses. Due to this, their functional comfort is very less and they are also very crowded. Many of this facilities are owned by Doctors who works in AMHC and many patients uses these facilities in order to get the doctors they want. This factor makes the facilities patient flow very high.

Due to the fact that many of government owned facilities and private owned facilities are overcrowded and has poor design, the natural ventilation condition in those facilities are very alarming and this study found that it is main problem in all scenarios ranging from medical perspective to Architectural perspective and Environmental perspective it considered as main social problem. The outbreak of recent pandemic (COVID-19) inspire this study to take close look at the nature of ventilation condition in our healthcare facilities. The outbreak of COVID-19 has proven that many of healthcare facilities in our country are unfit to function as medication space for this kind of airborne pandemics. So examining the natural ventilation of our facilities and understanding the scale of the problem will make us to provide a better healthcare facility which can function in better way for related type pandemic outbreak in the future.

2.2.2 Natural ventilation and healthcare facilities in developed and developing countries

2.2.2.1 The case of: Ventilation control for airborne transmission of human exhaled bio-aerosols in buildings

A. The impact of ventilation rate

Increasing ventilation rate is believed to reduce the cross infection of airborne transmitted diseases by removing or diluting pathogen-laden airborne droplet nuclei. A higher ventilation rate can dilute the contaminated air inside the space more rapidly and decrease the risk of cross infection (Menzies, 2003) studied the association between tuberculin conversion among HCWs and the ventilation rate in patient care areas. They found that the tuberculin conversion among HCWs was strongly associated with inadequate ventilation in general patient rooms and duration of work (Jiang, 2003) investigated the infection risk of HCWs in different wards with different window sizes in two hospitals during the 2003 SARS outbreak in Guangdong and found that larger ventilation windows showed a lower infection risk. In spite that a higher ventilation rate is able to provide a higher dilution capability to reduce the cross infection, the use of higher ventilation rates also means a higher energy cost for mechanical ventilation. However, there was a lack of strong scientific evidence in recommending a minimum ventilation flow rate for infection control according to (Li, 2004). The balance between decreasing the cross infection risk and reducing the energy consumption is needed. The recommended minimum ventilation rate for airborne infection isolation rooms is 12 air change per hour (ACH), which is originated from the 6 ACH in Center for Disease Control and Prevention (CDC) and then doubled after the 2003 SARS, while it is only 1 ACH for commercial buildings.

Natural ventilation is able to deliver large ventilation rates with a low energy consumption. Compared with mechanical ventilation, natural ventilation can provide much higher ventilation rates (Escombe, 2003) released the earliest publication of suggesting the use of natural ventilation for infection control. They studied different wards in eight hospitals ventilated in Lima and Peru, and found that natural ventilation could provide much larger ventilation rates than mechanical ventilation system did, which helped reduce the airborne contagion, especially with the high ceiling and large windows according to the calculation results of Wells-Riley equation measured ventilation rates in two hospitals, whose wards were naturally ventilated in Hong Kong. Two hospitals are located in downtown and green areas respectively. Results showed that natural ventilation delivered a ventilation rate as high as 69 ACH for cross ventilation and 18 ACH for single-side ventilation when windows were fully open. The hospital located in green had a much higher potential of natural ventilation.

Maximizing the natural ventilation has already been suggested for infection control in resource-limited regions. WHO published a guideline and introduced the usage of natural ventilation for infection control in healthcare settings. Six typical naturally-ventilated hospital wards were discussed in the guideline for reference, i.e., single-side corridor, central corridor, courtyard, wind tower, atrium and chimney, and hybrid (mixed-mode) ventilation (Zhou, 2004) evaluated the performance of different natural ventilation types in hospital wards by numerical simulation, finding that the central corridor ventilation, which has been broadly used in China, has the potential risk to cause cross infections between wards, indicating that it might not be recommended.

It is obvious that increasing the ventilation rate can reduce the risk of cross infection for long-range airborne infections. The impact of ventilation rate on the long-range airborne infection risk has been deeply explored. However, for droplet-borne transmitted diseases, the effect of ventilation does not seem so obvious. The fate of droplets is more governed by gravity and exhalation velocity. Ventilation can influence the evaporate rate by air flow and relative humidity (Zhou, 2004).

B. The impact of air flow direction

Flow direction can control contaminants transport among wards with different functions. Different ventilation strategies may be required for patients with different diseases in hospital. The ideal ventilation system for a general ward or a negative pressure isolation ward is expected to exhaust or dilute contaminants timely and to supply pathogen-free fresh air to HCWs and inpatients efficiently, properly controlling the airflow direction from clean zones to dirty zones is of great importance to prevent the virus-laden aerosols transmitting between rooms.

The establishment of directional flow between zones is achieved through the pressure difference. The protective environment (PE) isolation room utilizes a positive pressure difference to resist the entry of surrounding contaminated air and thus avoid the infection of immune-compromised patients inside. On the other hand, the AII isolation rooms utilize a negative pressure difference to prevent the droplet nuclei generated by infected patients spreading to other zones. However, the negative pressure is only maintained when doors and windows are fully closed. When an isolation room's door is open, the negative pressure difference between the room and corridor will disappear. An anteroom was suggested or required by some guidelines to separate the ward and corridor.

The proper airflow direction is first from corridor to anteroom then to ward then to toilet. The pressure difference can be established through the imbalance of airflow rates. Different requirements of pressure difference or imbalance of airflow rate by different guidelines or design books range from 2.5 to 15 Pa. The required pressure difference of those guidelines seems to be empirical (Li, 2004) considered that the pressure difference should be used to avoid the bi-directional flow which occurs due to temperature difference and wind force. He also calculated the minimum pressure difference to achieve the unidirectional flow and found that the required pressure difference was 0.36 and 9.12 Pa for temperature difference only and for combination of wind and temperature respectively, when temperature was 10 °C and the height of the door was 2.2 m. Decreasing the duration of door opening, raising the air change rate or using a curtain at the doorway were recommended to reduce the inter-room exposure risk.

It should be noted that real engineering construction quality may not realize the design goal. Hong Kong government promptly constructed 558 new negative pressure SARS isolation rooms with more than 1,300 beds in 14 hospitals in 2003. Those isolation rooms were designed according to international guidelines and represented state-of-art technologies in 2003. The principle of designing the new SARS wards was also supported by CFD simulations and a full-scale test room study which were completed by the most experienced heating, ventilation and air conditioning (HVAC) experts of Hong Kong Institute. Field measured the ventilation performance of 38 SARS wards in 9 hospitals after 18 months of operation. And they found that 60% of toilets/bathrooms were operated under wrong airflow directions in spite that most wards met the recommended negative pressure difference of 2.5 Pa between corridor and anteroom (97%), and between anteroom and cubicle (89%). Similar results were also reported by other field studies that up to 50% of the tested isolation rooms failed to provide a negative pressure. The main factors that broke up the negative pressure included inadequate reliability of pressure monitoring and controlling devices, strong diffuser flow directed at the door, interaction with other exhaust ventilation systems and poor airtightness of the suspended false ceiling.

The controlled flow direction is aimed at preventing cross infections between different wards or rooms, indicating that it is an effective method to avoid the long-range airborne transmission among rooms. The methods are commonly used in hospital for controlling the cross infection. In normal commercial offices, the controlled flow direction is generally designed to create a positive pressure in rooms and a negative pressure in toilets, whose goal is to control the indoor temperature and pollutants (Huan Qian and Xiaohong Zheng, 2018).

C. The impact of airflow pattern

Organized a panel comprised of experts from different majors to review the impact of ventilation on airborne infections (Li, 2004). Strong and sufficient evidences of association between airflow and infection spread were found. Smoking test, tracer gas technique, direct aerosol dispersion measurement or CFD simulation were used to test airflow patterns and they agreed well with the spatial distribution of secondary infection. Integrated the Wells-Riley equation into CFD models. The predicted spatial risk distribution in 8A wards in Prince of Wales Hospital agreed well with the spatial infection distribution pattern of SARS cases, indicating that the role of airflow pattern was important for airborne transmission diseases.

Three kinds of ventilation systems were commonly used, i.e., mixing ventilation, downward ventilation and displacement ventilation. Mixing ventilation supplies air with high momentum to make temperature, pollutants distribute uniformly, which is most widely used. For example, the ventilation system in Ward 8A of Prince of Wales Hospital in Hong Kong where the largest nosocomial SARS outbreak occurred in 2003 was of the mixing type. Downward ventilation was recommended by several guidelines for isolation wards. The basic idea of a downward ventilation design is to supply cooler and heavier clean air from a ceiling diffuser with a low velocity. The heavier cold supply air is accelerated by negative thermal buoyancy to push airborne particles down and be removed at the floor level. The “laminar” streams of air are expected to minimize the cross infection risk in isolation wards with a downward ventilation system. This concept was developed from industrial clean rooms and applied in surgical operating rooms in hospitals. The laminar airflow was considered to be promising in isolation wards for its care of hospital patients with low resistance in a positive pressure isolation room. This might be the original idea for extending the downward ventilation to be recommended in isolation wards including infection wards. The engineering control for surgical operating rooms or for immune-compromised hospital patients is focused on supplying fresh air directly to the patient's body (wound) or breathing zone, and prevent surrounding contaminated air infecting the wound. However, the control for airborne infection isolation rooms is to prevent exhaled pathogen-laden droplet nuclei dispersing in the room.

2.2.2.2The case of: Simulation of Natural ventilation in Maiduguri Hospital of Semiarid climate in Nigeria.

Hospitals are place where people seek medical attention to recover from their illness. Multi-bed remains the most complicated of all spaces in hospital because of the nature of patients it accommodates who are often immunosuppressed. Vulnerable patients are prone to infection from indoor air acquired infections in hospital are believed to be product of poor architectural design in terms of building material selection, ventilation system design and climatic situation of an area. According to (Pepper and Carrington, 2009), indoor air pollution is related to emission, accumulation, and assessment of pollutants commonly attributed to poor ventilation and air exchange in building. Sustainable and energy efficient ventilation systems are required for removal of various indoor air pollutants in hospital wards. There are various sources of contaminant in hospitals, including building materials, utility chemicals, external sources and patients themselves. The external source of pollutant in semi-arid climate includes Harmattan dust and mosquito insects, which makes it difficult to achieve effective natural ventilation. Moreover, natural ventilation as a passive and non-energy consuming strategy in relevant to the prevalent energy shortage in Nigeria.

In Nigeria, the electricity demand exceeds the supply and the supply remain unreliable (Sambo, 2008). The total grid installed capacity produced by Nigerian power station was 8,876 MW with only 3,653 MW available as at December 2009, meaning the available power supply is less than 41% of the total installed capacity (Emovon, 2011). In addition to problems such as insufficient transmission network, high population growth combined with underinvestment in the electricity sector have also resulted in increased power demand without any substantial growth in production (EIA, 2012).

Indoor air quality and natural ventilation of Hospital Wards

The quality of indoor air dictates the health status of a space and its occupants, as fresh air quality is critical for healthy indoor environment. Poor indoor environmental qualities are responsible for many health problems due to contaminants concentration including allergies, eye irritations and respiratory problems (Yau, 2011). These contaminants are very difficult to predict as they generate from both indoor and outdoor sources, and contain different types of substances (Hobday, 2011). Natural ventilation is usually driven by natural forces, such as wind, thermal buoyance force owing to variations in indoor and outdoor air density, which force in fresh air from outside through custom-made building envelope openings (Atkinson, 2009). It relies on the pressure differences caused by either wind or buoyance effect created by temperature or humidity difference to move fresh air through buildings. The use of natural ventilation in buildings becomes an increasingly attractive means of cutting energy cost and achieving acceptable quality of indoor environments, due to the improvement on the cost and environmental consequences of energy utilization (Walker, 2010). However, the performance and compositions of ventilation in Hospitals have great impact on the perceived air quality (Hellagren, 2011).

The achievement of acceptable indoor air quality and thermal comfort passively, while excluding unwanted parameters such as, Mosquitoes and Harmattan dust in the semiarid climates is a difficult task that requires a holistic approach. The exclusion of these unwanted parameters are easy to realize when using mechanical means for ventilation, as they need for opening large ventilators to the outside is not required. Regrettably, there is insufficient energy in the study area to cater for such demands. Therefore, there is salient need to explore to the possibility of using natural means for achieving acceptable indoor air quality and thermal comfort.

In conclusion, the study analyses and subsequently explores the possibility of using natural ventilation strategy for achieving acceptable indoor air quality and thermal comfort and to ascertain the major influential factors affecting these strategies. It has been established that, Mosquitoes insects, Harmattan dust, and high outdoor temperatures are the three major factors challenging the design of natural ventilations in semiarid climates. The average total ambient temperatures in the study area are higher than the comfort neutrality temperature throughout the year except for February, August and November, in which temperatures falls within the comfort limits. Moreover, the ventilation rates in the existing Hospital ward measure is below the standard minimum limits of 6 ACH. Fluent computational fluid dynamic (CFD) software has been used in modelling the natural ventilation strategies. The result shows that, the installation of insect screen will result in 70% reduction in air change rate and 8% opening area in relation to building floor area is required to achieve acceptable ventilation rate. Other natural ventilations configuration apart from the cross ventilation will be investigated, with the aim of increasing the air exhaust from the ward and strategies for low energy dust removal. The study mainly focuses on the mosquito's prevention strategies, while the research on Harmattan dusts part of the problem is in progress. Therefore, a methodology has been developed to simulate natural ventilation strategies for acceptable indoor air quality and thermal comfort, excluding mosquitoes and Harmattan dust and without compromising occupants comfort.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Data

Air velocity of the room, indoor and outdoor ambient temperature, Relative humidity in the room and volume of the space was measured. As shown on this figure 10 below, the Air velocity measurement taken from opening areas (window and door) and near the patient bed to have balanced value. The temperature measurement taken from the inside using the devise and outside temperature using the sensitive wire detector placed on the same devise.

These data were collected from two private clinics and two government owned healthcare facilities found in Geda (12 Kebele) in Adama. Only single space was selected from each site. Based on problematic estimation, corridor space was selected from private clinics and wards were selected from government owned facilities. Since private clinics has one corridor in the main house; only single space is selected. In government owned facilities, only wards are selected due the nature of the space in connection to ventilation and airborne infectious disease.

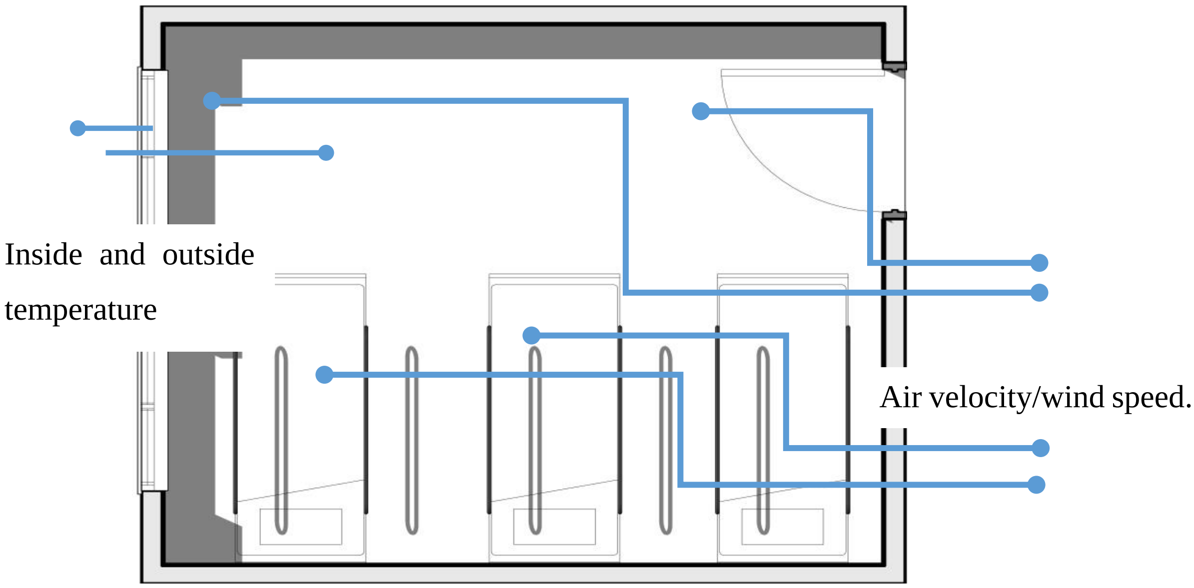


Figure 07: Spots where measurements were taken from

3.2 Methods of Data collection

3.2.1 Physical measurements of environmental variables

The quantitative data collected was primarily taken from the site. The data was collected by preparing a manual table for recording every element necessary for the analysing of the data. The manual consisted of what to measure and where to measure. Elements like, room height, room length, room width, window size, door size, inside and outside temperature, humidity, air velocity, and artificial ventilation system (if it exists) were contented in the measurements manual. The air velocity rate was measured by digital Anemometer (m/s) and the relative humidity of the room, indoor and outdoor ambient temperature were measured using digital hygrometer (temperature and humidity meter) and volume of the space and opening dimension were measured using Meter. The overall ventilation rate condition was based on the wind pressure which raised from the wind direction and opening conditions (door and window) and temperature difference between inside and outside of the space which created stack pressure (buoyancy) which helped in simulating the air flow direction in the spaces.

Taking this into consideration the measurement was taken during the mid of July (for two days) and the beginning of August (for one day). The measurement was taken under three condition of the openings (Door and Window). Meaning; full opening condition, partial opening condition and half closed opening conditions. This measurement was taken during summer season when the weather is already less windy.

Figure 08: Digital hygrometer

Figure 09: Digital Anemometer

The Anemometer was used standing in the middle of the space and near the openings (Door and Window) to have balanced measurement and Hygrometer was used by putting the main devise in the middle of the space and sensitive wire outside the room.

3.3 Sampling techniques and procedures

It is estimated that more than 90 healthcare facilities are found in Adama city. Gada kebele is the most densely populated area for healthcare facilities. Based on patient flow density and estimation of most problematic facility; four sites were selected to collect data. Since the target of this study was to analyse the natural ventilation condition of healthcare facilities, it must include all main types of healthcare facilities from both private owned and government owned facilities. In case of Adama city the densely populated healthcare facilities are the government owned public facilities like referral hospitals (AMHC) and small scale health care centres (AHC). On the other hand, the private owned facilities ranges in different scale from primary clinics to large hospitals.

The private clinics were selected due to their poor construction and design problems. Meaning many of private owned clinics are normal residential houses and the assumption of poor natural ventilation condition was main reason for their selection criteria. While the government owned facilities were selected based on high patient density. Due to this reason both types of facilities were randomly selected from high populated zoning location (Gada kebele).

For instance, most of private clinics were originally designed as old villa type of residential housing and in this kind of designs most of the time the corridor was located in the middle of the house and many of other spaces get air after it passes through the corridor area. So, studying the ventilation condition in this space will show the rate of airflow passes for other spaces. On the other hand, ward areas were selected from government owned facilities. The main selection criteria for this is that, wards are the main area where patients spent much of their time. The other reason was that the nature of patients it accommodates who were often immunosuppressed. Meaning the ventilation condition in this space was very crucial to understand the magnitude of ventilation needed for patients.

In general, the main selection criteria for private clinic rises from the question; can this residential houses provide enough natural ventilation when they serve as healthcare facility?

On the other hand, can wards provide enough ventilation for patients who spent there for long time with their nature of overcrowdings? If so. Will they be better medication space when airborne pandemic like COVID will occur again?

3.4 Research design

This study was designed as quantitative study, aiming to understand the magnitude and condition of natural ventilation. How natural ventilation is operating under existing condition. For instance, studying airflow direction in the space (inlet and outlet). The air velocity in the space and its relation with opening dimension. Among the quantitative research methods, descriptive research was used in this study to describe the natural ventilation condition in healthcare facilities by using appropriate data. In which the natural ventilation with relation to openings were described and examined to what extent it affects each other. Indoor environmental factors like temperature and humidity will also be described in a way that it affects the natural ventilation rate conditions.

3.5 Methods

This research will use different instruments to measure the air flow rate, humidity, indoor and outdoor temperature. The measured data will be analysed using different comparison ranging from different architectural standards, calculations and Ethiopian healthcare standards for ventilation rates.

Table 04: Summary of methods used in this research

No-	Specific Objective	Data used	Methods/Formula
1.	Natural ventilation condition with respect to… (i).Air flow direction.	-Change in temperature(Indoor &Outdoor) -Opening dimension & location	-Using Revit Architecture. - Using floor plan & 3D
	(ii).Floor to opening ratio	Measurement of the openings (Door& Window)	-Using table

2.	(iia)Analyzing NVR	Vair (m/s), OD,Volume (m^3)	VR= 0.8 × V air (m/s) × A inlet (m^2) × 1000 l/ m^3 -Using table
3.	(iiia)Analyzing ACH	Vair (m/s), OD,Volume (m^3)	ACH= $\frac{0.8 \times V\ air\ (m/s) \times A\ inlet\ (m^2) \times 3600\ s/h}{Volume\ (m^3)}$ -Using table
	(iiib)ACH Vs FOR		MS-Excel -Using graph
4.	(iv)NVR Vs OPD		-MS-Excel -Using graph
5	Suggestion for optimization of openings	The same data used in specific objective 1,2,3& 4.	(ii), (iia), (iib), (iiia), (iiib) & (iv)

Legends: V air = average air velocity at inlet (m/s); A inlet= area of smaller inlet (m^2); FOR= Floor to opening ratio; ACH = Air change per hour; NVR = Natural Ventilation rate; HCF = Healthcare Facility; OD-Opening dimension.

N.B:- The effect of human breathing factors in the space is not considered in this study and tracing gas is not used in this study while collecting air velocity data in the space.

The healthcare facilities where these measurements were taken place had different opening condition and different volume of space and different number of patients. The space where these measurements was taken placed were airborne disease wards, normal wards and corridors. Wards were a main place where ventilation ass very crucial due to the nature of patients it accommodates and the duration of time they spent in the space, so studying the ventilation condition was very important and in case of private clinics; most of private clinics were rental residential housing with normal villa and corridor was the main space where internal spaces gain the cross ventilation access. So studying this space will help in understanding the amount of natural ventilation passes through this spaces and feed other rooms in the house. The ventilation rate of the ward areas was evaluated in terms of number of patients, whereas corridors evaluated in terms of volume of the space. The main reason for this is that wards are the permanent space where many patients' stays for long period of time and the ventilation rate in this spaces was analysed in terms of number of patients. Whereas, the corridor was analysed in terms of volume, because corridor was not a space where patients stay for long, rather it is passing space or feeding space of air for internal rooms; so it analysed in terms of volume.

During this measurement, the value of humidity level indicated the density level of air in the room. Whereas the temperature difference inside the room and outside the room indicated the direction of the air flow. The combined value of the humidity and temperature difference was used to indicate the air flow direction and condition (whether the air enters the room through the lower opening and exit through the upper opening or the other around).

The measurement was also undertaken in three different opening conditions.

- Open window (100%) + Open door (100%)
- Open window (50%) + Open door (50%)
- Open window (0%) + Open door (100%)

Those were the common usage of opening in most of healthcare facilities in different time of the day. Data was collected in the morning time between 10:00-12:00 a.m local time after the doctor's round was finished.

3.6 Types and sources of data

Primary data collection: Primary data has been collected from the healthcare facilities using data collecting manual specifically prepared for this study. The main data collected from the facilities includes, the air velocity in the space, the ambient temperature (both indoor and outdoor), humidity, volume of the space, number of patients and dimension of openings.

Secondary data collection: The secondary data has been collected through international case studies, WHO guidelines and Ethiopian health standards related to the topics. Moreover, different articles published in the topic related to Natural ventilation in healthcare facilities. Books, theories in relation to Natural ventilation and health.

3.7 Data Analysis

3.7.1 Existing Natural ventilation condition with respect to air flow direction and opening floor ratio.

Air flow direction

The data from temperature value of inside and outside the space, and opening location was used to predict the air flow direction in the space (whether the air enters the room below or above the opening and exit through the lower or upper openings). This effect was called stack pressure (buoyance) effect. Which demonstrates where the air flow and how the air flow in between two different air density contented spaces. And it was demonstrated in figure form by preparing the three dimension (3D) of the space using Revit Architecture. The location of the space is presented on floor plan.

Floor to opening ratio (FOR)

The data of the space (length, width and height) was used to draw floor plan of the space. So it could be easy to understand the location of the openings and its dimension. Both floor plan and 3D view was presented in figure form. The dimension of openings (Window and Door) was summarized and its values was converted to floor to opening ratio and defined in percentile scale. The floor to opening ratio result was presented in table form.

3.7.2 Natural ventilation rate (NVR) and Air change per hour (ACH)

Based on the air velocity data collected from the site the natural ventilation rate (NVR) and air change per hour (ACH) was calculated using the rule of thumb. The interrelation of NVR value and opening dimension (OD) was analysed and presented using graph. The ACH vale and its relation with floor to opening ratio (FOR) was also analysed and presented using graph. At last the value of NVR was re-evaluated with the minimum required standard value of WHO & Ethiopian Natural Ventilation for Infection Control in Health-care Settings. The evaluated value with respect to standard was categorized based on the type of space. According to this study three different type of space was selected, those were corridors, General wards and Air borne infectious wards.

According to thumb rule its value was calculated using the following formula.

$$\mathbf{ACH} = \frac{0.8 \times \text{V air (m/s)} \times \text{A inlet (m}^2\text{)} \times 3600 \text{ s/h}}{\text{Room volume (m}^3\text{)}} \quad \text{.................................... Equation (1)}$$

Where,

ACH = Air change rate (measured as volume of room/Number of patient's air change per hour)

V air = average air velocity at inlet (m/s)

A inlet= area of smaller inlet (m^2)

Volume = volume of room (m^3)

NVR refers to the amount of inflow air per unit time (l/s). It was also calculated using the rules of thumb.

NVR (l/s) = 0.800 × V air (m/s) × A inlet (m^2) × 1000 l/m3 ……………………...Equation (2)

Where,

V air = average air velocity at inlet (m/s)

A inlet= area of smaller inlet (m^2)

Having this, the natural ventilation rate of every space was calculated and their values were summarized and compared with the standard of healthcare facility ventilation rate and the results were evaluated whether the ventilation rate in the space is up to the standard or not. The minimum required standard of natural ventilation rate for healthcare facilities are mentioned as below. For natural ventilation, the following minimum hourly averaged ventilation rates should be provided:

- 160 l/s/patient (hourly average ventilation rate) for airborne precaution rooms.
- 60 l/s/patient for general wards and outpatient departments.
- 2.5 l/s/m3 for corridors and other transient spaces without a fixed number of patients.

This study will try to analyse the existing natural ventilation condition by analysing the condition of air flow direction and opening to floor ratio. It will also analyse the natural ventilation rate in the space and amount of Air change per hour. From all this the main evaluation method used will be by comparing the amount of Natural ventilation rate with standard and evaluate whether the space fits for the function it subjected to.

3.7.3 Optimization of the Openings size

Suggestion for the optimization of the openings were made by computing for the modification of the existing Natural ventilation condition. This minor modification was grasped from results in specific objectives. Following that, (ii) floor to opening ratio, (iia) natural ventilation rate, and (iiia) ACH are computed to see the difference between the newly suggested optimized opening condition and existing opening condition.

CHAPTER FOUR

RESULT AND DISCUSSION

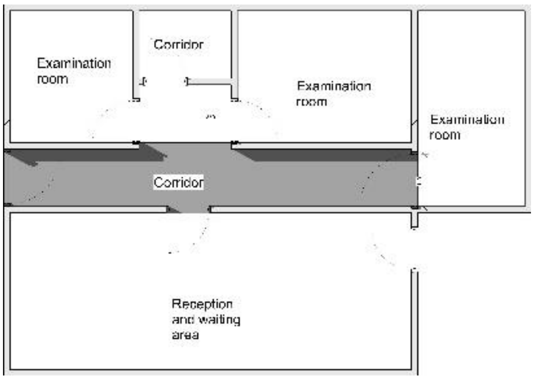
4.1 Result

4.1.1 Natural ventilation condition with respect to Air flow direction and floor to opening ratio

4.1.1.1 Air flow direction

4.1.1.1.1 Case-1

The corridor in Dirre medium clinic has only one-way access to natural ventilation which is through the back door; which serves as both inlet and outlet direction for the air. The other door on the adjacent sides which remains closed for most of the time. The average temperature value inside space is 26.10 C and outside is 25.60 C which indicates that the air enters the space through lower level and escape through upper level. There is no insect nest, no curtain, and no artificial ventilation system in the space.



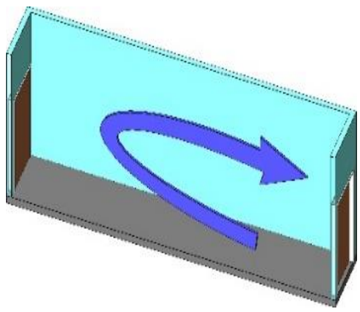
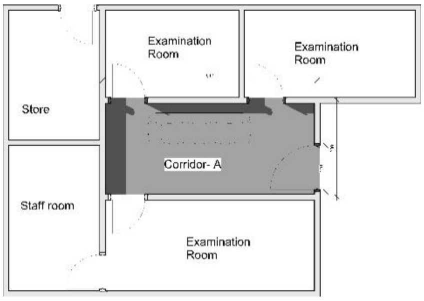


Figure 10: Floor plan of Dirre M. clinic   Figure 11: Air flow direction of Dirre M. clinic

4.1.1.1.2 Case-2

The corridor in Alta medium clinic has also one-way access to natural ventilation through the front door; which serves as both inlet and outlet direction for the air. The other door on the adjacent sides' remains closed for most of the time. The average temperature value inside space is 26.1^0 C and outside is 25.7^0 C which indicates that the air enters the space through lower level and escape through upper level. There was no insect nest, no curtain, and no artificial ventilation system in the space.



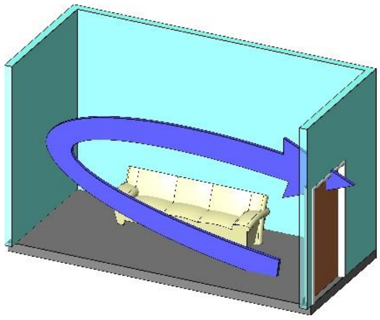
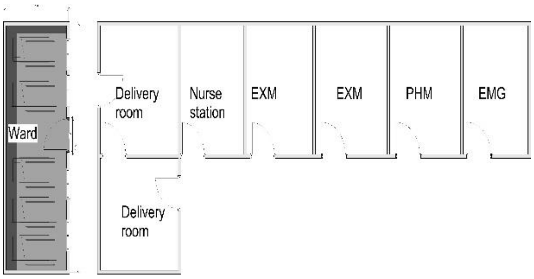


Figure 12: Floor plan   Alta M. clinic   Figure 13: Air flow direction of Alta M. clinic

4.1.1.1.3 Case-3

The maternal ward in Adama health centre has only access of natural ventilation is through 1.2m wide narrow corridor found between the delivery room and the ward itself. It has four windows and 0.8 m wide entrance door which all aligned on one side. There is no cross ventilation in the space. The average temperature value inside space is 25.9^{0} C and outside is 25.7^{0} C which indicates that the air enters the space through lower level and escape through upper level. There is no insect nest, no curtain, and no artificial ventilation system in the space. It accommodates around 5 beds.



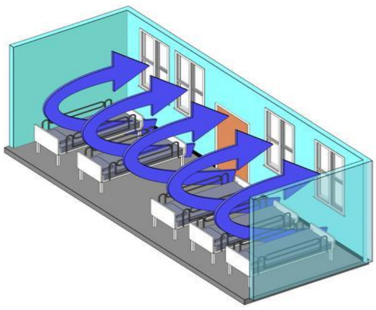


Figure 14: Floor plan of Adama health centre   Figure 15: Air flow direction

4.1.1.1.4 Case-4

The ward in Adama medical health collage has two windows opposite to the door. The 1.85 m wide corridor facilitates the cross ventilation for the space. The average temperature value inside space is 25.8^{0} C and outside is 25.4^{0} C which indicates that the air enters the space through lower level and escape through upper level. There is no insect nest, no curtain, and no artificial ventilation system in the space. It accommodates around 6 beds each, and 30 beds in total.

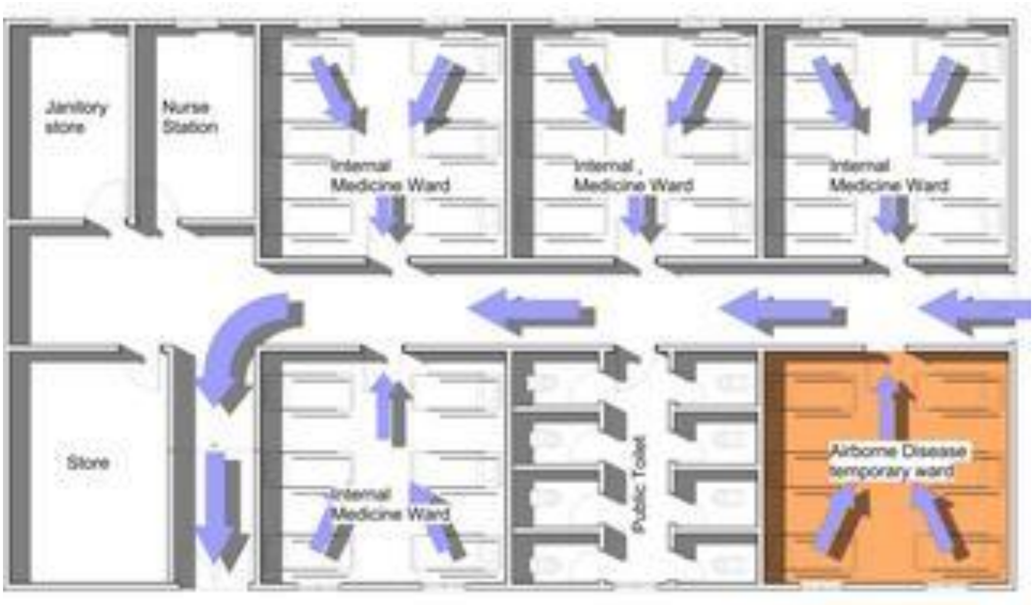


Figure 16: Floor plan & Air flow direction

4.1.1.2 Floor to opening ratio (FOR)

4.1.1.2.1 Case-1

The corridor in Dirre medium clinic has only one door which is considered as opening access for ventilation. The four adjacent doors are not considered because they remain closed throughout the day. They will only be opened and closed when patients or doctors enter or exit. There is no window or other means of opening that natural ventilation can access. The floor area is 6.93 m^2 & small opening area is 1.89 m^2 . Which makes its opening to floor area ratio 27.20%.

Table 05: Floor to Opening ratio of Dirre medium clinic.

Name of the facility	**Name of space**	**Length**	**Width**	**height**	**Floor area**	**Opening area**	**F.O.R/ %**
Dirre medium clinic	Corridor	8.3m	1.1m	3.0m	6.93 m^2	1.89 m^2	27.20 %

4.1.1.2.2 Case-2

The corridor in Alta medium clinic has only one door which is considered as opening access for natural ventilation. The three adjacent doors are not considered because they remain closed throughout the day. They will only be opened and closed when patients or doctors enter or exit. There is no window or other means of opening that ventilation can access. The floor area is 11.7 m^2 & small opening area is 2.0 m^2. Which makes its opening to floor area ratio 17.09 %.

Table 06: Floor to Opening ratio of Alta medium clinic.

Name of the facility	Name of space	Length	Width	Height	Floor area	Opening area	F.O.R/ %
Alta Medium clinic	Corridor	5.1m	2.3m	3.1	11.7 m^2	2.0 m^2	17.09 %

4.1.1.2.3 Case-3

The maternal ward in Adama health centre has five opening access to Natural ventilation. One is 0.8m wide door. The others are typical four windows with only quarter of it is open for ventilation. The others are fixed which can only access light. The floor area is 24.45m^2, small opening area is 1.6m^2 and its opening to floor area ratio 17.09 %.

Table 07: Floor to Opening ratio of Adama health centre.

Name of the facility	Name of space	Length	Width	Height	Floor area	Opening area	F.O.R/ %
Adama health center	Maternal ward	8.15m	2.9m	3.1m	24.45 m^2	1.6 m^2	6.54 %

4.1.1.2.4 Case-4

The internal medicine ward is selected from Adama medical health collage. The rooms in the ward are typical in size. The ward has two kinds of room in the ward. One is only for patients with airborne disease cases. The other four are for general internal medical cases. Each room has two identical windows and one door which places opposite to each other. The floor area of each room is 31.9 m^2, small opening area is 2.0 m^2 and its opening to floor area ratio 8.15 %.

Table 08: Floor to Opening ratio of Adama medical health collage.

Name of the facility	Name of space	Length	Width	Height	Floor area	Opening area	F.O.R/ %
Adama medical health collage (AMHC)	General ward rooms	5.8m	5.5m	3.0m	31.9 m^2	2.0 m^2	8.15 %
	Airborne infectious disease ward	5.8m	5.5m	3.0m	31.9 m^2	2.0 m^2	8.15 %

4.1.2 Natural Ventilation rate (NVR) and Opening Dimension (OD)

4.1.2.1 Natural Ventilation rate result of Corridor Spaces in Dirre medium clinic and Alta medium clinic

The value of air velocity is measured on the site from three different locations in the space. And the measurement condition is also undertaken through three different opening condition of door and window as mentioned in table 09. The natural ventilation rate is calculated using the data value of air velocity and dimension of openings in the space. The daily value of natural ventilation rate is summarized in daily average value which mentioned below the others. The natural ventilation rate of each day has been converted to final average value. Which is the average value of the three days' result. According to the result the three days' average value for the corridor space of Dirre medium clinic is 1.34 l/s. While the three days' average value of corridor found in Alta medium clinic is 1.52 l/s. Both results show, the value of NVR is below the minimum required standard value.

Table 09: Natural Ventilation rate of Dirre medium clinic and Alta medium clinic.

Name of Facility	Day-1-NVR			Day-2-NVR			Day-3-NVR			AVG-NVR	OD
Dirre medium clinic	**D**	**W**	NVR	**D**	**W**	NVR	**D**	**W**	NVR	1.34l/s	1.89 m^2
	100%	100%	1.96l/s	100%	100%	3.02l/s	100%	100%	2.26l/s		
	50%	50%	1.36l/s	50%	50%	2.11l/s	50%	50%	1.36l/s		
	0%	100%	0.00l/s	0%	100%	0.00l/s	0%	100%	0.00l/s		
		AVG1	1.1 l/s		**AVG2**	1.71l/s		**AVG3**	1.2 l/s		
	D	**W**	NVR	**D**	**W**	NVR	**D**	**W**	NVR	1.52l/s	
	100%	100%	2.24l/s	100%	100%	2.88l/s	100%	100%	3.20l/s		

Alta medium clinic	50%	50%	1.6 l/s	50%	50%	1.98l/s	50%	50%	1.92l/s		2 m^2
	0%	100%	0.00l/s	0%	100%	0.00l/s	0%	100%	0.00l/s		
		AVG1	1.28l/s		**AVG2**	1.60l/s		**AVG3**	1.7 l/s		

N.B. The numeric value of NVR mentioned in the table is considered per volume (m^3).

Legend: NVR- Natural Ventilation rate; AVG-NVR- Average natural ventilation rate; OD-Opening dimension; AVG- Average

4.1.2.1.1 Natural Ventilation rate result Vs Opening dimension

According to the result value of Natural ventilation rate and opening dimension. The relation between the values is summarized in Figure 20. In a corridor space of dirre medium clinic with 1.89 m^2 opening area, the ventilation rate is 1.34 l/s. whereas the 2 m^2 opening area of Alta medium clinic's corridor the natural ventilation rate is 1.52 l/s. Meaning for 0.11 m^2 opening difference there is 0.18 l/s natural ventilation rate difference.

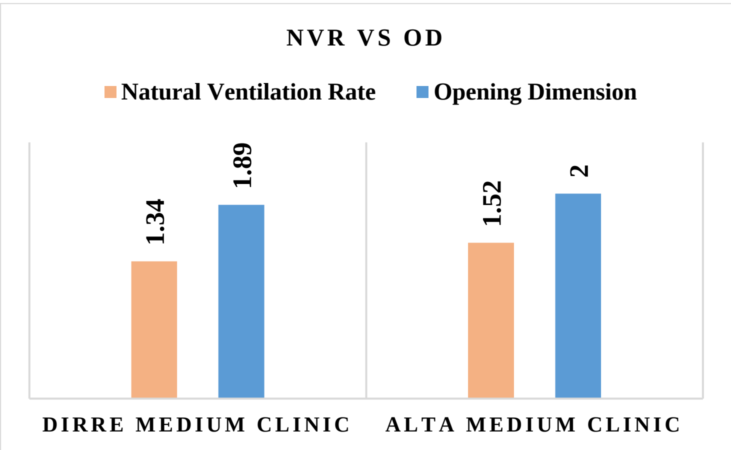


Figure 17: NVR result Vs opening dimension of Dirre and Alta medium clinic

Legend: NVR- Natural Ventilation rate; OD- Opening dimension

4.1.2.2 Natural Ventilation rate result of Ward Spaces in Adama health centre and Adama medical health collage

Natural ventilation rate in general wards and airborne infectious ward has two different evaluating values. The type of ward in Adama health centre is maternal ward. Whereas the wards in Adama medical health collage has Airborne infectious disease room beside the other four rooms which is considered as general wards. The same measurement locations and the same opening conditions are used in ward areas as mentioned in table 10. According to summarized average value of each day. The three days' average value of Adama health centre maternal ward is 35.5l/s. whereas the general wards in Adama medical health collage is 58.8l/s and value for Airborne infectious disease ward is 61.1l/s. All results show, the value of NVR is below the minimum required standard value.

Table 10: Natural Ventilation rate of wards in Adama health centre and Adama medical health collage.

Name of Facilities	**Day-1-NVR**			**Day-2-NVR**			**Day-3-NVR**			**AVG-NVR**	**OD**
Adama health centre	D	W	NVR	D	W	NVR	D	W	NVR	35.5l/s	1.6 m^2
	100%	100%	57.6l/s	100%	100%	61.4l/s	100%	100%	64 l/s		
	50%	50%	23 l/s	50%	50%	34.5l/s	50%	50%	38.4l/s		
	0%	100%	11.5l/s	0%	100%	12.8l/s	0%	100%	16.6l/s		
		AVG1	30.7l/s		**AVG2**	36.2l/s		**AVG3**	39.6l/s		
Adama medical health collage-G/Ward	D	W	NVR	D	W	NVR	D	W	NVR	58.8l/s	2 m^2
	100%	100%	99.2l/s	100%	100%	91.2l/s	100%	100%	76.8l/s		
	50%	50%	65.6l/s	50%	50%	57.6l/s	50%	50%	51.2l/s		
	0%	100%	46.4l/s	0%	100%	20.8l/s	0%	100%	20.8l/s		
		AVG1	70.4l/s		AVG2	56.5l/s		AVG3	49.6l/s		
Adama medical health collage-(AIDW)	D	W	NVR	D	W	NVR	D	W	NVR	61.1l/s	2 m^2
	100%	100%	109 l/s	100%	100%	96 l/s	100%	100%	76.8l/s		
	50%	50%	68.8l/s	50%	50%	62.4l/s	50%	50%	51.2l/s		
	0%	100%	49.6l/s	0%	100%	16 l/s	0%	100%	20.8l/s		
		AVG1	75.7l/s		AVG2	58.1l/s		AVG3	49.6l/s		

N.B. The numeric value of NVR mentioned in the table is considered per patients.

Legend: NVR- Natural Ventilation rate; AVG-NVR- Average natural ventilation rate; OD-Opening dimension; AVG- Average; AIDW-Airborne infectious disease ward

4.1.2.2.1 Natural Ventilation rate result Vs Opening dimension

According to the result value of Natural ventilation rate and opening dimension. The relation between the values is summarized in Figure 21. In maternal ward of Adama health centre with 1.6 m^2 opening area, the ventilation rate is 35.5 l/s. whereas the 2 m^2 opening area of Adama medical health collage general ward is 58.81 m^2 and 61.1 m^2 in airborne infectious disease ward. Meaning for 0.4 m^2 opening difference there is 24.45 l/s natural ventilation rate difference.

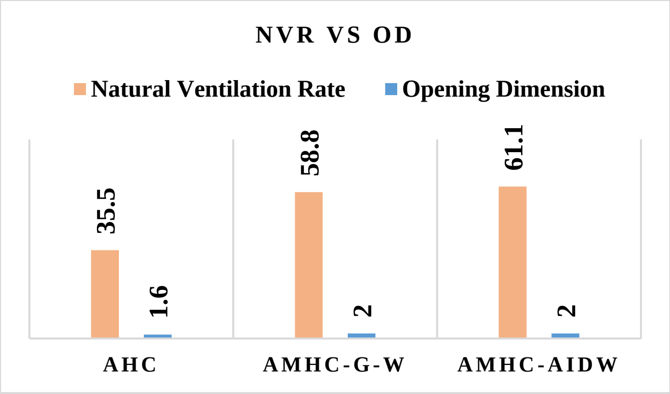


Figure 18: Natural ventilation rate result Vs opening dimension of AHC and AMHC

Legend: AHC- Adama health centre; AMHC-G-W- Adama medical health collage general ward: AMHC-AIDW- Adama medical health collage airborne infectious disease ward

4.1.3 Air change per hour (ACH) and Floor to opening ratio (FOR)

4.1.3.1 Air change per hour (ACH) result of Corridor Spaces in Dirre medium clinic and Alta medium clinic

The ACH value of corridor space is also calculated using the rule of thumb. The measurement location and measurement condition is also the same with the NVR. What makes it different is that ACH is considered in terms of volume of the space. It is calculated using data of smallest window opening, air velocity, and volume of space. The daily value of ACH is summarized as shown in table 11. According to the ACH result of three days' average value for the corridor space of Dirre medium clinic is 0.17. While the three days' average value of corridor found in Alta medium clinic is 0.15.

Table 11: Air change per hour result of Dirre medium clinic and Alta medium clinic.

Name of Facilities	**Day-1-ACH**			**Day-2- ACH**			**Day-3- ACH**			**AVG-ACH**	**FOR**
Dirre medium clinic	**D**	**W**	ACH	**D**	**W**	ACH	**D**	**W**	ACH	0.17	27.2 %
	100%	100%	0.26	100%	100%	0.4	100%	100%	0.3		
	50%	50%	0.18	50%	50%	0.28	50%	50%	0.18		
	0%	100%	0.00	0%	100%	0.00	0%	100%	0.00		
		AVG1	0.14		**AVG2**	0.22		**AVG3**	0.16		
Alta medium clinic	**D**	**W**	ACH	**D**	**W**	ACH	**D**	**W**	ACH	0.15	17 %
	100%	100%	0.2	100%	100%	0.29	100%	100%	0.32		
	50%	50%	0.16	50%	50%	0.19	50%	50%	0.19		
	0%	100%	0.00	0%	100%	0.00	0%	100%	0.00		

AVG1	0.12	**AVG2**	0.16	**AVG3**	0.17

Legend: ACH - Air change per hour; AVG- ACH - Average Air change per hour; FOR- Floor to opening ratio; AVG- Average

4.1.3.1.1 Air change per hour (ACH) result Vs Floor to opening ratio (FOR)

According to the value of ACH and FOR of the space. The relative relation between ACH and FOR is summarized in Figure 22. The three days total ACH average value of corridor space in Dirre and Alta medium clinic is 0.17 and 0.15. The Floor to opening ratio of Dirre medium clinic is 27.2%. Whereas the Alta medium clinics Floor to opening ratio is 17%. With this result for 9.8% Floor to opening ratio difference there is 0.02 ACH value difference.

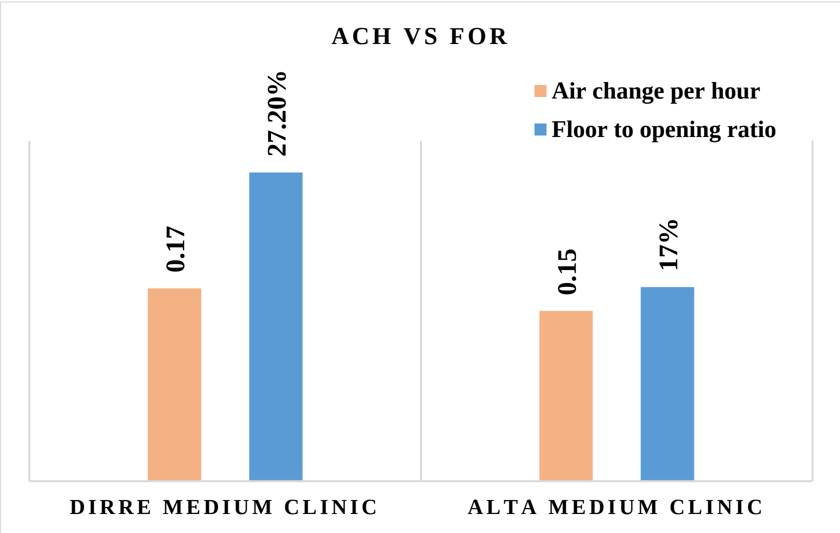


Figure 19: ACH result Vs Floor to opening ratio of Dirre and Alta medium clinic

4.1.3.2 Air change per hour (ACH) result of ward spaces in Adama health centre and Adama medical health collage

The ACH value of ward space is also calculated using the rule of thumb. The measurement location and measurement condition is also the same with the NVR. ACH of ward area is calculated using data of smallest window opening, air velocity, and volume of space. The daily value of ACH is summarized as shown in table 12. According to the ACH result of three days' average value for the maternal ward space in Adama health centre is 1.8. Whereas the ACH value for general wards and Airborne infectious disease ward in Adama medical health collage is 2.12 and 2.27 respectively.

Table 12: Air change per hour (ACH) result of wards in Adama health centre and Adama medical health collage.

Name of Facilities	Day-1-ACH			Day-2- ACH			Day-3- ACH			AVG ACH -	FOR
Adama health centre	**D**	**W**	ACH	**D**	**W**	ACH	**D**	**W**	ACH	1.8	6.5 %
	100%	100%	2.92	100%	100%	3.12	100%	100%	3.25		
	50%	50%	1.17	50%	50%	1.75	50%	50%	1.95		
	0%	100%	0.58	0%	100%	0.65	0%	100%	0.85		
		AVG1	1.55		**AVG2**	1.84		**AVG3**	2.01		
Adama medical health collage-G/Ward	**D**	**W**	ACH	**D**	**W**	ACH	**D**	**W**	ACH	2.12	8.15 %
	100%	100%	3.69	100%	100%	3.39	100%	100%	2.56		
	50%	50%	2.44	50%	50%	2.15	50%	50%	1.73		
	0%	100%	1.73	0%	100%	0.77	0%	100%	0.65		
		AVG1	2.62		**AVG2**	2.10		**AVG3**	1.65		
Adama medical health collage-(AIDW)	**D**	**W**	ACH	**D**	**W**	ACH	**D**	**W**	ACH	2.27	8.15 %
	100%	100%	4.05	100%	100%	3.57	100%	100%	2.86		
	50%	50%	2.56	50%	50%	2.32	50%	50%	1.91		
	0%	100%	1.85	0%	100%	0.6	0%	100%	0.77		
		AVG1	2.82		**AVG2**	2.16		**AVG3**	1.85		

Legend: ACH - Air change per hour; AVG- ACH - Average Air change per hour; FOR- Floor to opening ratio; AVG- Average; AIDW-Airborne infectious disease ward.

4.1.3.2.1 Air change per hour (ACH) result Vs Floor to opening ratio (FOR)

According to the value of ACH and FOR of the space. The proportional relationship between ACH and FOR is summarized in Figure 23. The three days total ACH average value of maternal ward space in Adama health centre and Adama medical health collage (G-W & AIDW) is 1.8, 2.12, and 2.27. With their flooe to opening ratio of 6.5% and 8.15%. With this result for 1.65% Floor to opening ratio difference there is 2.06 ACH value difference has been recorded.

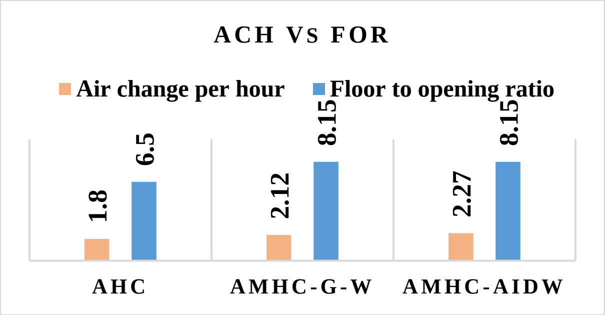


Figure 20: Air change per hour result Vs Floor to opening ratio of AHC and AMHC (G-W & AIDW)

Legend: ACH- Air change per hour; FOR- Floor to opening ratio; AHC- Adama health centre; AMHC-G-W- Adama medical health collage general ward; AMHC-AIDW- Adama medical health collage airborne infectious disease ward.

4.1.4 Natural ventilation rate (NVR) Vs Standards

In this study three different spaces of in healthcare facility is selected. The corridor spaces in private medium clinics, the general wards in Adama health centre and Adama medical health collage. And also the airborne infectious diseases ward. The natural ventilation rate is compared with health care standards of both WHO and Ethiopian healthcare standards based on their type of space. They will be categorized as corridor space, general ward and airborne infectious disease ward. All three of them have different ventilation rate value to be evaluated with.

4.1.4.1 NVR results of corridor space in Dirre and Alta medium clinic Vs standards

The natural ventilation rate is evaluated with the minimum standard amount of rate required for corridor space for health care facilities. According to the result 1.34 l/s/m^3 rate of Dirre medium clinic is counts 53.6 % of minimum natural ventilation required. Alta medium clinic NVR is 1.52 l/s/m^3 which covers 60.8 % of minimum required value. The average NVR of both corridors is 1.43 l/s/m^3. Which indicates that the corridor space in Adama healthcare facilities accounts 57.2% of 2.5 l/s/m^3 standard NVR required.

Table 13: NVR results of corridor space in Dirre and Alta medium clinic Vs standards

Name of the facility	NVR	AVG-NVR	Minimum standard of NVR	Percentile scale of NVR	Percentile scale of AVG-NVR
Dirre medium clinic	**1.34 l/s**	**1.43 l/s**	**2.5 l/s**	**53.6 %**	**57.2 %**
Alta medium clinic	**1.52 l/s**			**60.8 %**	

N.B. The numeric value of NVR mentioned in the table is considered per volume (m^3).

4.1.4.2 NVR results of wards in Adama health centre and Adama medical health collage Vs standards

The minimum NVR required for general wards is 60 l/s/patients according to the standards. The natural ventilation rate is evaluated with the minimum standard amount of rate required for general ward space for health care facilities. According to the result 35.5 l/s rate of Adama health centre counts 59.1 % of minimum natural ventilation required. Whereas Adama medical health collage (G-Ward) NVR is 58.8 l/s which covers 98 % of minimum required value. The average NVR of both corridor is 47.15 l/s. Which indicates that the ward space in Adama healthcare facilities accounts 79.1 % of 60 l/s NVR required.

Table 14: NVR results of wards in Adama health centre and Adama medical health collage Vs standards

Name of the facility	NVR	AVG-NVR	Minimum standard of NVR	Percentile scale of NVR	Percentile scale of AVG-NVR
Adama health centre	**35.5 l/s**	**47.15 l/s**	**60 l/s**	**59.1 %**	**79.1 %**
Adama medical health collage (G-Ward)	**58.8 l/s**			**98 %**	

N.B. The numeric value of NVR mentioned in the table is considered per patient.

4.1.4.3 NVR results of ward in Adama medical health collage (AIDW) Vs standards

The minimum NVR required for Airborne infectious disease ward is 160 l/s/patients according to the standards. According to the result Natural ventilation rate of Adama medical health collage (AIDW) is 61.1 l/s which covers 38.18 % of minimum required value. Which indicates that the airborne infectious disease ward space in Adama healthcare facilities accounts 38.18 % of 160 l/s NVR required.

Table 15: NVR results of ward in Adama medical health collage (AIDW) Vs standards

Name of the facility	NVR	Minimum standard of NVR	Percentile scale of NVR
Adama medical health collage (AIDW)	**61.1 l/s**	**160 L/S**	**38.18 %**

N.B. The numeric value of NVR mentioned in the table is considered per patient.

4.1.5 Optimization of the Opening size

Result presented in table 14 & 15 above indicated that, the increase dimension of openings increases the rate of natural ventilation in the space. According to literatures balanced floor to opening ratio increases the rate of natural ventilation and ACH by providing enough natural air in to the volume of the space. Taking these into consideration, earlier computation (NVR & ACH) are computed again by doubling the area (m^2) of the opening dimension to see the difference. Table 16. Below shows the difference in NVR & ACH value when the area (m^2) doubles.

Table 16: Optimization of the Opening sizes.

Name of the facility	Floor area	Opening area	FOR	NVR	ACH
Dirre medium clinic	10.89 m^2	1.89 m^2	27.2 %	1.34 l/s	0.17
		3.78 m^2	54.4%	2.68 l/s	0.34
Alta medium clinic	11.7 m^2	2 m^2	17 %	1.52 l/s	0.15
		4 m^2	34%	3.04 l/s	3.0
Adama health center	24.45 m^2	1.6 m^2	6.5 %	35.5 l/s	1.8
		3.2 m^2	11%	71 l/s	3.6
AMHC (G-ward)	31.9 m^2	2 m^2	8.15 %	58.8 l/s	2.12
		4 m^2	16.3%	117.6 l/s	4.24

Legend: Optimized values

Existing values

The result of optimized values indicates that increasing the area of openings increases the amount of natural ventilation rate (NVR) and air change per hour (ACH). As shown in Table 16 doubling the opening area in the space doubles the value of floor to opening ratio. Which resulted in doubling both NVR & ACH.

4.2 Discussion

4.2.1 Natural ventilation condition with respect to Air flow direction and opening to floor ratio

Air flow patter is a significant factor affecting dwellers through infectious droplet transportation and affecting the thermal comfort (D.chandrasegaran & Badarudin, 2010). In a city like Adama where there is very high temperature throughout the year. The air flow pattern plays a great role in clearing contaminated air in the space and reduce the transmission rate of disease in healthcare facilities. The airflow direction in private clinic's corridor and maternal ward in Adama health centre is the same. The air flow pattern is relatively unidirectional and the air inlet and outlet access in one. Meaning after the air enters the space it circulates in unidirectional pattern and exit in the same direction. In corridor of private clinics, the adjacent doors along the corridor is closed most of the time. So, their role in affecting the air flow pattern is relatively low. Since the inside temperature higher than the outside temperature; the air enters the space in lower opening and exit in upper opening. There was no artificial ventilation system in the space that may divert the direction of air flow in the space. The case of Adama medical health collage's ward different from the rest. The air flow pattern is linear. Meaning the air enters the room through window and exit through door. There is cross ventilation in this ward.

In order to improve air flow pattern in the space, having cross ventilation is best way to have uniform pattern of air flow in the space. Cross ventilation will also increase the amount and speed air that flows through the space. It will also increase effective way of removing pollutants and creates fair distribution of air in the space.

Floor to opening ratio is significant factor to determine the amount of air in a given volume of space. As shown on the result floor to opening ratio of ward areas are less than 10%. And that of corridor space is in average 22%. This shows that the ward area has very small opening dimension. Which leads to less air flow in the space. According to many studies, it is recommended that the floor to opening ratio is 30-35 % in tropical climate areas. Balanced opening to floor ratio will also help in increasing the access of natural light.

4.2.2 Natural ventilation rate (NVR) and Air change per hour (ACH)

Natural ventilation rate and ACH in the space depends on different things from both inside and outside factors. Opening dimension, types and location of the window, cross ventilation condition, usage of openings, window's curtain, and insect nests are some of the inside factors. Windbreakers (trees, walls), adjacent building, and outside weather conditions are some of outside factors. Those all factors combined can determine the natural ventilation rate & ACH value in the space. From all this, both ACH & natural ventilation rate mainly dependent on the opening size and floor to opening ratio. Both factors determine the magnitude of air that enters the space and distributed per volume in the space.

Natural ventilation rate in a corridor space of Dirre medium clinic with 1.89 m^2 opening area, the ventilation rate is 1.34 l/s. Whereas the 2 m^2 opening area of Alta medium clinic's corridor the natural ventilation rate is 1.52 l/s. Meaning for 0.11 m^2 increase in opening size there is 0.18 l/s increase in natural ventilation rate. Whereas, in maternal ward of Adama health centre with 1.6 m^2 opening area, the ventilation rate is 35.5 l/s. whereas the 2 m^2 opening area of Adama medical health collage general ward is 58.81 m^2 and 61.1 m^2 in airborne infectious disease ward. Meaning for 0.4 m^2 increase in opening size there is 24.45 l/s natural ventilation rate increase. The result indicates that an increase in opening size increases the natural ventilation rate.

The ACH result of the corridor space in Dirre and Alta medium clinic have ACH value of 0.17 and 0.15 and their Floor to opening ratio is 27.2% &17%. Which indicates that 9.8% increase in floor to opening ratio resulted in 0.02 increase in ACH value. Whereas, the ACH value of maternal ward in Adama health centre and Adama medical health collage (G-W & AIDW) is 1.8, 2.12, and 2.27 and their floor to opening ratio of 6.5% and 8.15%. According to the result, 1.65% increase in floor to opening ratio resulted in 2.06 increase in ACH value. Which indicates increase in floor to opening ratio will increase the value of ACH

The value of NVR and ACH is directly proportional to the opening dimension and floor to opening ratio. As mentioned on optimization of opening, increasing the opening area will result in increasing of floor to opening ratio. Which indicates that increase in opening area will result in increasing of inlet air in the space and higher value of air per volume of space. In this study, the proportional value of NVR and ACH had been affected due to other factors. For instance, the proportional increase value of NVR between corridor and ward area has been affected by the location of openings and orientation of the building. In corridor space 0.11 m^2 increase in opening size resulted in 0.18 l/s. whereas in ward areas 0.4 m^2 increase of opening resulted in 24.45 l/s increase in NVR. In proportional scale 24.45 l/s should have been 0.65 l//s, but the orientation of the building and cross ventilation in the space creates the proportional value difference. In case of Adama medical health collage, the ACH result of general patient room and airborne infectious disease patient room is different; even though they both located in the same ward. The reason for this is that. The airborne infectious disease patient's room is located on the north corner of the ward; which faces the wind direction.

According to the WHO (2009) and Ethiopian standard (2014) of Natural ventilation for airborne infectious disease prevention and control in healthcare setting. The minimum value of natural ventilation will be evaluated with the result of this study. According to the requirement of the standard every circulation spaces like corridor, waiting area, and other must have 2.5 $l/s/m^3$ value of natural ventilation rate. General wards must have 60 l/s/patient, and airborne infectious wards must have minimum natural ventilation rate of 160 l/s/patient. According to the result, Dirre and Alta medium clinic have natural ventilation rate of 1.34 $l/s/m^3$ and 1.52 $l/s/m^3$. Compared to the standard they only fulfil 53.6 % and 60.8 %. The average NVR of both corridors is 1.43 $l/s/m^3$. Which indicates that the corridor space in Adama healthcare facilities accounts 57.2% of 2.5 $l/s/m^3$ minimum standard required. The NVR result of Adama health centre and Adama medical health collage (G-Ward) is 35.5 l/s/patient and 58.8 l/s/ patient. Compared to the standard they fulfil 59.1 % and 98 %. The average NVR of both wards are 47.15 l/s/patient. Which indicates that the general ward in Adama healthcare facilities accounts 79.1 % of 60 l/s/patient minimum standard required. Whereas the Natural ventilation rate result of Adama medical health collage (AIDW) is 61.1 l/s/patient. Which indicates that the airborne infectious disease ward space in Adama healthcare facilities accounts 38.18 % of 160 l/s/patient minimum standard required.

The outcome of the result shows, all subjected spaces are not up to standard. The natural ventilation rate of corridor spaces fulfils 57.2 % of the minimum standard value. The general and airborne infectious ward score 79.1 % and 38 18 % of minimum standard values. Which shows that the status of existing facilities is at alarming stage. Based on the concept of optimization od opening as mentioned in the previous chapter; doubling the size of the opening will double the value of natural ventilation rate. The outcome of the optimized value will be more than 100 % for corridor and general wards. But for airborne infectious disease ward, the opening size should be four time larger than the existing opening size to achieve the minimum standard value of 160 l/s/patient.

4.2.3 Optimization of opening dimension

The result of suggested optimization of opening dimension is quite promising. According to the result, doubling existing opening dimension has improved the natural ventilation rate in subjected space. The natural ventilation rate result of subjected spaces is very poor. The optimization result indicated, by doubling the existing opening dimension the NVR value has doubled. According to the optimization result; the NVR value of corridor space has increased from 1.34 $l/s/m^3$ &1.52 $l/s/m^3$ to 2.68 $l/s/m^3$ & 3.04 $l/s/m^3$. Which indicates that, the optimized result has achieved the minimum required value of NVR suggested by the standard (2.5 $l/s/m^3$). The optimization result of ward areas also showed the same sequential result. The NVR value has increased from 35.5 l/s/p & 58.8 l/s/p to 71 l/s/p & 117.6 l/s/p. which also indicates, the optimized result has achieved more value that the minimum required value of NVR suggested by the standard (60 l/s/p).

The suggestion of optimizing opening dimension has also doubled the value of air change per hour (ACH) and floor to opening ratio. Which indicates, the optimization of opening dimension has hugely improved the availability of air in the space & balanced the size of opening per volume of the space. The optimization result also indicates; the existing subjected space can have higher value of NVR by doubling the existing opening dimensions. It also indicates; more than minimum value of NVR suggested by the standard can be achieved when the existing opening dimension doubled. In addition to this, if cross ventilation access could be achieved, the NVR will be improved more than this. In general, by optimizing the existing opening dimension and providing cross ventilation access; the suggested minimum amount of NVR can be achieved.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Most of the findings in the previous chapter conclude that all subjected space in Adama healthcare facilities are not up to the standards. NVR & ACH values implicate the airborne infectious disease ward is the list performing ward fulfilling 38.18% of minimum required standard value. Compared to other wards it should have be the better performing ward due to the nature of patients it occupies. The reason for this is that, the design of the ward and types of opening is typical with other general wards. And the standard comparing NVR value is almost three times larger than general ward. The corridor spaces also fulfil almost half percent of minimum required standard value. This is due to, lack of cross ventilation in the space. The inlet and outlet of air is by the same opening. The other reason is that the location of the facilities is in densely populated residential area where large wind breakers. The general wards have fulfilled 79.1 % minimum required standard value. But still have better performance compared to others. The main reason is that the space has cross ventilation and its orientation is towards wind direction.

Since this study is carried out in only summer season of the year, when wind lower in Adama. These facilities are not in worse position of performance. By increasing the opening size and facilitating cross ventilation, a remarkable improvement could be achieved as computed results of suggested optimized opening indicate. By doubling the opening size of currently existing one, it is possible to achieve the required minimum standard value. Apart from optimization of existing openings, spatial orientation and cross ventilation should be implemented on design of healthcare facilities to provide enough natural ventilation for patients and workers.

5.2 Recommendation

- Institution responsible for design and construction of healthcare facilities should always consider opening size, orientation, cross ventilation and other design amenities apart from the cost.
- The Ethiopian healthcare setting standards should be updated to provide specific ACH value for all major spaces in healthcare facilities.

- It will make remarkable benefit for academic and medical community if further researches continued to work on different seasons and in other healthcare facility's spaces.
- Further research that involve usage of tracing gas should be proceed in order to fully understand the performance of natural ventilation in healthcare facilities.
- Incorporating standards that set natural ventilation rate in reference into EBCS (Ethiopian Building Code Standard).

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APPENDIX

Annex - 1

Field data

Day-1

Day and time	**Name of Facility & Type of space**	**Room height**	**Room length**	**Room width**	**Door size**	**Window size**	**Change in Temperature**		**Wind speed W-window D-door w/s-wind speed (m/s)**			**Number of patients**	**Artificial ventilation**
July, 15th 09:00 09:40	Dirre medium clinic	3.0 m	8.3 m	1.1 m	2.1m * 0.9m	*	IN 26.2	OUT 25.8	W	D	w/s	*	*
									100 %	100 %	0.0013		
									50%	50%	0.0009		
									0%	100 %	0.0		
July, 15th 10:00 10:45	Alta medium clinic	3.1 m	5.1 m	2.3 m	1 m * 2 m	*	IN 26.6	OUT 25.8	W	D	w/s	*	*
									100 %	100 %	0.0014		
									50%	50%	0.001		
									0%	100 %	0.0		
July, 16th 09:00 09:40	Adama health centre	2.9 m	8.15 m	3.0 m	0.8m * 2.0m	(0.5 m *0.8 m)*4 windows	IN 26.3	OUT 25.9	W	D	w/s	5 patients	*
									100 %	100 %	0.027		
									50%	50%	0.09		
									0%	100 %	0.00		
July, 17th 09:00 09:40	Adama medical health collage (AMHC)	3.0 m	5.8 m	5.5 m	1.0m * 2.0m	(0.5 m * 1.0 m)*2 windows	IN 25.5	OUT 25.0	W	D	w/s	6 patients	*
									100 %	100 %	0.062		
									50%	50%	0.041		
									0%	100 %	0.029		
July, 17th 10:00 10:45	(AMHC) AIDW	3.0 m	5.8 m	5.5 m	1.0m * 2.0m	(0.5 m * 1.0 m)*2 windows	IN 25.7	OUT 25.1	W	D	w/s	6 patients	*
									100 %	100 %	0.068		
									50%	50%	0.043		
									0%	100 %	0.031		

*Legend: *- Doesn't exist.*

Day-2

Day and time	Name of Facility & Type of space	Room height	Room length	Room width	Door size	Window size	Change in Temperature		Wind speed W-window D-door w/s-wind speed (m/s)			Number of patients	Artificial ventilation
July, 25th 09:15 09:55	Dirre medium clinic	3.0 m	8.3 m	1.1m	2.1m * 0.9m	*	IN 26.1	OUT 25.3	W	D	w/s	*	*
									100 %	100 %	0.002		
									50%	50%	0.0014		
									0%	100 %	0.00		
July 26th 09:05 09:45	Alta medium clinic	3.1 m	5.1 m	2.3m	1 m * 2 m	*	IN 25.8	OUT 25.0	W	D	w/s	*	*
									100 %	100 %	0.0018		
									50%	50%	0.0012		
									0%	100 %	0.00		
July 27th 10:00 10:45	Adama health centre	2.9 m	8.15 m	3.0m	0.8m * 2.0m	(0.5 m *0.8 m)*4 windows	IN 25.5	OUT 25.0	W	D	w/s	5 patients	*
									100 %	100 %	0.48		
									50%	50%	0.23		
									0%	100 %	0.11		
July, 28th 09:00 09:55	Adama medical health collage (AMHC)	3.0 m	5.8 m	5.5m	1.0m * 2.0m	(0.5 m * 1.0 m)*2 windows	IN 25.9	OUT 25.2	W	D	w/s	6 patients	*
									100 %	100 %	0.057		
									50%	50%	0.036		
									0%	100 %	0.013		
July, 28th 10:00 10:45	(AMHC) AIDW	3.0 m	5.8 m	5.5m	1.0m * 2.0m	(0.5 m * 1.0 m)*2 windows	IN 25.5	OUT 25.0	W	D	w/s	6 patients	*
									100 %	100 %	0.06		
									50%	50%	0.039		
									0%	100 %	0.01		

*Legend: *- Doesn't exist.*

Day-3

Day and time	Name of Facility& Type of space	Room height	Room length	Room width	Door size	Window size	Change in Temperature (°C)		Wind speed W-window D-door w/s-wind speed (m/s)			Number of patients	Artificial ventilation
Aug,11th 09:00 09:30	Dirre medium clinic	3.0 m	8.3 m	1.1 m	2.1m * 0.9m	*	IN 26.2	OUT 25.8	W	D	w/s	*	*
									100 %	100 %	0.0015		
									50%	50%	0.0091		
									0%	100 %	0.00		
Aug,11th 10:15 10:55	Alta medium clinic	3.1 m	5.1 m	2.3 m	1 m * 2 m	*	IN 26.0	OUT 26.5	W	D	w/s	*	*
									100 %	100 %	0.0020		
									50%	50%	0.0012		
									0%	100 %	0.00		
Aug,12th 09:15 09:55	Adama health centre	2.9 m	8.15 m	3.0 m	0.8m * 2.0m	(0.5 m *0.8 m)*4 windows	IN 25.9	OUT 26.4	W	D	w/s	5 patients	*
									100 %	100 %	0.050		
									50%	50%	0.030		
									0%	100 %	0.013		
Aug,13th 09:20 09:50	Adama medical health collage (AMHC)	3.0 m	5.8 m	5.5 m	1.0m * 2.0m	(0.5 m * 1.0 m)*2 windows	IN 26.0	OUT 26.6	W	D	w/s	6 patients	*
									100 %	100 %	0.043		
									50%	50%	0.029		
									0%	100 %	0.011		
Aug,13th 10:20 10:50	(AMHC) AIDW	3.0 m	5.8 m	5.5 m	1.0m * 2.0m	(0.5 m * 1.0 m)*2 windows	IN 26.0	OUT 26.6	W	D	w/s	6 patients	*
									100 %	100 %	0.048		
									50%	50%	0.032		
									0%	100 %	0.013		

*Legend: *- Doesn't exist.*

Annex – 2

Calculated data

Day-1

Summary	Dirre medium clinic	Alta medium clinic	Adama health centre	Adama medical health collage	(AMHC) Airborne disease temporary ward
Floor area	10.89 m^2	11.7	24.45 m^2	31.9 m^2	31.9 m^2
Small opening area	1.89 m^2	2 m^2	1.6 m^2	2.00 m^2	2.00 m^2
Floor to opening ratio	27.2 %	17 %	6.5 %	8.15 %	8.15 %
Volume of space	27.39 m^3	36.27 m^3	70.9 m^3	96.57 m^3	96.57 m^3
VR (100%-100%)	1.96 l/s	2.24 l/s	34.56 l/s	99.2 l/s	108.8 l/s
VR (50%-50%)	1.36 l/s	1.6 l/s	19.2 l/s	65.6 l/s	68.8 l/s
VR (0%-100%)	0.00	0.00	10.24 l/s	46.4 l/s	49.6 l/s
Average Ventilation rate (VR)	**1.1 l/s**	**1.28 l/s**	**30.72 l/s**	**70.4 l/s**	**75.7 l/s**
ACH (100%-100%)	0.26	0.20	2.92	3.69	4.05
ACH (50%-50%)	0.18	0.16	1.17	2.44	2.56
ACH (0%-100%)	0.00	0.00	0.58	1.73	1.85
Average-ACH	**0.146**	**0.12**	**1.55**	**2.62**	**2.82**

Day-2

Summary	Dirre medium clinic	Alta medium clinic	Adama health centre	Adama medical health collage	(AMHC) Airborne disease temporary ward
Floor area	10.89 m^2	11.7	24.45 m^2	31.9 m^2	31.9 m^2
Small opening area	1.89 m^2	2 m^2	1.6 m^2	2.00 m^2	2.00 m^2
Floor to opening ratio	27.2 %	17 %	6.5 %	8.15 %	8.15 %
Volume of space	27.39 m^3	36.27 m^3	70.9 m^3	96.57 m^3	96.57 m^3
VR (100%-100%)	3.02 l/s	2.88 l/s	61.44 l/s	91.2 l/s	96.00 l/s
VR (50%-50%)	2.11 l/s	1.92 l/s	34.56 l/s	57.6 l/s	62.4 l/s
VR (0%-100%)	0.00	0.00 l/s	12.8 l/s	20.8 l/s	16.0 l/s
Average Ventilation rate (VR)	**1.71 l/s**	**1.6 l/s**	**36.26 l/s**	**56.5 l/s**	**58.13 l/s**
ACH (100%-100%)	0.40	0.29	3.12	3.39	3.57
ACH (50%-50%)	0.28	0.19	1.75	2.15	2.32
ACH (0%-100%)	0.00	0.00	0.65	0.77	0.60
Average-ACH	**0.22**	**0.16**	**1.84**	**2.10**	**2.16**

Day -3

Summary	**Dirre medium clinic**	**Alta medium clinic**	**Adama health centre**	**Adama medical health collage**	**(AMHC) Airborne disease temporary ward**
Floor area	10.89 m^2	11.7	24.45 m^2	31.9 m^2	31.9 m^2
Small opening area	1.89 m^2	2 m^2	1.6 m^2	2.00 m^2	2.00 m^2
Floor to opening ratio	27.2 %	17 %	6.5 %	8.15 %	8.15 %
Volume of space	27.39 m^3	36.27 m^3	70.9 m^3	96.57 m^3	96.57 m^3
VR (100%-100%)	2.26 l/s	3.20 l/s	64.00 l/s	68.8 l/s	76.80 l/s
VR (50%-50%)	1.36 l/s	1.92 l/s	38.40 l/s	46.4 l/s	51.20 l/s
VR (0%-100%)	0.00	0.00	16.64 l/s	17.6 l/s	20.80 l/s
Average Ventilation rate (VR)	**1.20 l/s**	**1.70 l/s**	**39.68 l/s**	**44.2 l/s**	**49.60 l/s**
ACH (100%-100%)	0.30	0.32	3.25	2.56	2.86
ACH (50%-50%)	0.18	0.19	1.95	1.73	1.91
ACH (0%-100%)	0.00	0.00	0.85	0.65	0.77
Average-ACH	**0.16**	**0.17**	**2.01**	**1.65**	**1.85**

Annex – 3

Specification of instruments used in the research

A, Digital Hygrometer (Humidity & Temperature meter) **Specifications**	**Remark**	
Temprature range	Indoor	10°C - 50°C (14°F - 122°F)
Outdoor	-50°C - 70°C (-58°F - 158°F)	
Temperature resolution	0.1 °C/ °F	
Humidity range	20%RH – 99%RH	Less than 40% :*dry*, more than 70% :*wet* and 40%-70% & 20 °C-25 °C : *comfort* signal appear on the screen of the instrument
Humidity accuracy	±5%RH	
Humidity resolution	±1%RH	
Calendar	1999/1/1 – 2048/12/31	
Battery	AAA 1.5V	