UNIVERSITY OF NAIROBI
FACULTY OF THE BUILT ENVIRONMENT AND DESIGN
DEPARTMENT OF ARCHITECTURE

Natural Ventilation in Maternity Hospitals

A Case of Maternity Hospital Buildings in Nairobi, Kenya.

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Ventilation is the profound secret of existence.

Peter Sloterdijk
Philosopher and Cultural Theorist

Image: RIBA International Prize 2021: Friendship Hospital in Bangladesh)

DECLARATION

I declare that this report is my original work and has not been presented for the award of a degree in any other institution to the best of my knowledge.

This research report is presented to the Department of Architecture, for the part fulfilment of the requirements for award of the Master of Architecture degree at the University of Nairobi.

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Abstract

Fresh air in maternity hospital buildings has positive effects on the users such as improved healing for patients and increased productivity of staff. Poor air quality in indoor spaces has been linked with occupant discomfort. Symptoms such as dry skin, lethargy, and nasal inflammation have been linked to suboptimal indoor air quality due to low volumes of fresh air within the spaces, attributed to low air change rates (Eijekelnboom & Bluyssen, 2019). Passive ventilation systems have proven to have the ability to provide high air change rates which provide the necessary fresh air for the wellbeing of patients in maternity hospitals and the general users of the buildings. The recommended air changes per hour for a maternity hospital in general ranges from 6 ACH to 20 depending on the room function. This research sets out to establish the application of natural ventilation in maternity hospitals to achieve the required air changes. Existing literature on natural ventilation for indoor air quality in maternity hospitals is examined with a view to understand ventilation requirements of maternity hospital patient and staff rooms. It studies building ventilation in organized maternity facilities to gauge their effectiveness and establish strategies for application of passive ventilation to provide optimal indoor air quality. It proposes strategies for the use of natural ventilation as the dominant method for provision of fresh air in maternity hospitals. Case studies of selected maternity hospitals are documented and an assessment of their indoor air quality is carried out based on established symptoms of ventilation problems. These markers are analysed against established standards of indoor air quality in maternity hospital rooms. The research also makes a review of documented studies that link indoor air quality to the patient and staff experiences.

The literature suggests a that discomfort and infection rates are diminished when the air quality is fresh. The data shows that in describing indoor air quality for maternity spaces, concentrations of contaminants in the air should be kept at a minimum and the ventilation system should provide for this. In the case of controlled maternity hospital environments minimal mechanical ventilation and air conditioning can be used.

The study concludes that natural ventilation can be used extensively to provide fresh air in maternity hospitals and in controlled patient rooms, minimal mechanical ventilation may be applied.

Key words: maternity hospital, indoor air quality, fresh air, passive ventilation

Contents

List of tables

Table of figures

1 CHAPTER 1

1.1.Background

Ventilation can be defined as the supply and removal of air in a space in order to regulate the concentration of contaminants, moisture or ambient temperature within the space. (ASHRAE, 2007). Acceptable indoor air quality is defined as a state of indoor air where the air comprises 78% nitrogen, 21% oxygen and 1% other gases. Ventilation allows for admittance of fresh air into a space to optimise indoor air quality. This optimizes indoor air quality by supplying adequate amounts of oxygen thereby optimizing the supply of fresh air and mitigating airborne transmission of diseases. (American Lung Association, 2020). Ventilation is a process of supplying fresh air and removing or diluting indoor pollution concentration. (Wahab & Ismail).

Building ventilation in tropic climate is necessary in providing acceptable indoor air quality (IAQ) be removing or diluting bioaerosols that the air could be harbouring. This state of discomfort is often referred to as sick building syndrome (SBS) (Bluyssen P. M., 1991). To examine the kink between air quality and comfort during pregnancy, a study carried out documented abnormal sensitivity to smell, distortions in smell perception and phantom sensations with respect to smell and taste. These were assessed based on questions referring to gestational weeks 12–17 and 30–34 of pregnancy and compared to those of 9–14 weeks postpartum and to non-pregnant women with corresponding time durations and intervals. The results show that abnormal smell and taste perception was reported in 76% of the pregnant women. It is hypothesised that this discomfort is occasioned by pregnancy (Nordin S. et. Al. 2004).

In a maternity hospital, patients who develop airborne hospital acquired infection are at risk of prolonged hospital visits. Few attempts have been made to study the application of passive ventilation strategies for provision of fresh air in maternity hospitals. Most buildings have adopted mechanical ventilation and air conditioning (Yu, 2001). Observable symptoms of poor indoor air quality include overheating, stuffiness, lingering odours, and other self-reported symptoms from the users such as headache and fatigue. Architectural considerations for indoor air quality would be applied to address these problems. Comfortable indoor air quality remains a pertinent issue in maternity healthcare facilities in Nairobi. Moreover, there is still heavy reliance on mechanized HVAC systems in many maternity healthcare facilities to provide fresh air. (Wagenaar & Mens, 2018). New and renovated health care facilities may not have natural ventilation strategies incorporated in the structure of the building. Moreover, many facilities are designed without much consideration for natural ventilation due to factors such as plot size, facility size and geographical location.

In maternal healthcare facilities, the integration of natural ventilation remains wanting. Building orientation in tropical climates is very critical, and the basic rule is: minimise facades facing east and west and take into account local prevailing winds, because of their connection with natural ventilation. (UN-Habitat, 2014). In the Nairobi tropic climate, winds are variable; predominantly north-east and south-easterlies, they may be deflected by local topography and wind velocity rarely exceeds 15 m/s. (Koenigsberger., 1973). A hospital is one of the public utility buildings whose indoor air quality has immediate effects on the users. While positive efforts to curb over heating in hospital buildings have greatly advanced, it is often the case that indoor air quality and freshness remains wanting, leaving heavy reliance on air conditioning. Indoor air quality in tropic climate is a key element of sustainable architecture in tropical climates. The Un-Habitat proposes to minimise facades facing east and west (Fig.1-1) and take into account local prevailing winds, because of their connection with natural ventilation (UN-Habitat, 2014) .

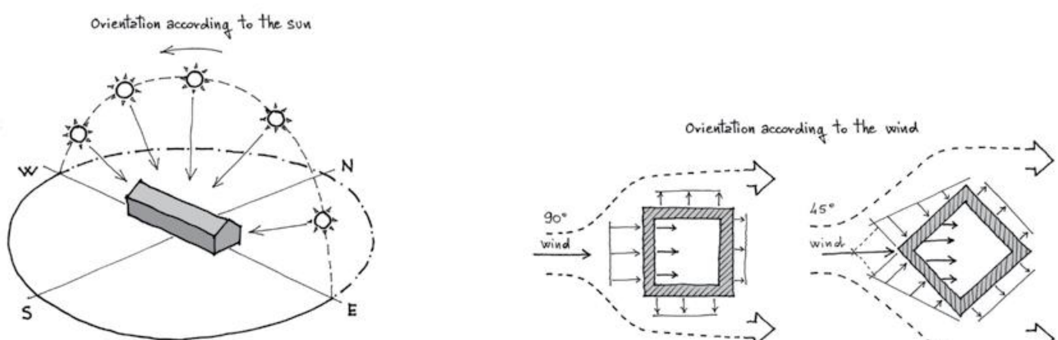


Figure 1-1: Illustration of building orientation according to sun and wind. (Source: (UN-Habitat, 2014)

The term *natural ventilation* is used to indicate the intentional airflow through windows, doors or other openings designed for the purpose, obtained without the use of fans; it is created by pressure differences caused by the wind and/or by temperature differences between the inside and the outside (UN-Habitat, 2014). Natural ventilation affects three issues: health, the energy balance of the building and thermal comfort (UN-Habitat, 2014). Whereas attempts to ensure air freshness have been applied in existing facilities using mechanical heating ventilation and air-conditioning systems, the need to respond to the needs of health, energy balance of the building and indoor air quality requires to be addressed. Natural ventilation could be the dominant method for optimizing indoor air quality so that the use of highly mechanized energy consuming HVAC systems can be minimised and only applied where there is no tenable alternative. The elements of the building envelope are the tools that architects can use to control indoor environmental quality. The fenestrations on the facades and other air inlets can be used to significantly ensure air freshness while increasing air distribution within the various spaces in the hospital.

Maternity hospitals expend a great deal of energy in day to day working operations and treatment using modern systems and technologies. As a result, the different spaces within the facility accumulate a lot of heat and odours that need to be expelled. Air conditioning and mechanical ventilation systems are applied extensively to curb the uncomfortable indoor environment created. Studies have shown that 3-10 percent of all carbon emissions worldwide are produced by healthcare facilities. This is due to efforts by hospital managements to improve indoor environmental quality of the healthcare facility through mechanized control systems (Eckelman et. Al. 2020)

Air movement in hospitals presents challenges unique to hospital environments that are not encountered in other building types. In many cases maternity hospitals are located within a larger hospital environment. Hospital indoor air quality assumes a very important role in the promotion of comfort for patients and resident workers as well as prevention of hospital acquired infections occasioned by convergence of potentially infected people in an enclosed indoor space.

1.1 Indoor Air Quality and Maternity Hospitals in Nairobi

Maternity hospital design is a complex undertaking to create spaces that serve various functions. These include medical applications such as diagnostic and treatment functions, emergency rooms, prenatal and post-natal clinics. Other spaces that serve purposeful activities in a maternity hospital include food services; kitchens and delivery, housekeeping, waiting rooms, storage, meeting rooms, and offices. For this study a five-point scale was created for use in a questionnaire to measure the air quality perceptions of users in these spaces in the present time and in retrospect. A tour of various maternity hospitals in Nairobi revealed the following uncomfortable conditions which could be attributed to poor ventilation design:

i. Air dampness at the time of audit and in retrospect
ii. Stuffiness expressed by the respondents
iii. Uncomfortably warm interior in need of air freshening
iv. Unwanted odour

The buildings surveyed continue to employ the use of air conditioning due to the changing indoor environments. There is need to create a balance of natural ventilation and mechanical ventilation for controlled environments such as a maternity hospital. Even with highly mechanised systems in place, occasions of stuffiness, prevalence of bad odour and the lack of a view out is evident in many maternity

Figure 1-2 Single room Ensuite AKUH

Figure 1-3 Maternity ward with 8 No. Beds

hospitals in our local context. Mechanical ventilation and inward facing fixed windows characterize many hospitals space (Figure 1-2 – figure 1-5). Natural ventilation would be a sustainable alternative for such high expenders of energy.

Figure 1-4 KNH Maternity wing hallway

Figure 1-5: Two ends of the AKUH 3rd floor Maternity wing hallway

In an audit of indoor air quality, it was identified that energy consumption varies strongly from building to building. In practice, it depends more on planning, construction, and management than on climate, building type or HVAC systems. It is thus possible to construct low-energy buildings using different architectural designs and various HVAC systems (Bluyssen, et al., 1996) In a workshop on Indoor Air Quality Management organized by the European Commission, it was identified that the attainment of health and comfort in the indoor environment, combined with energy efficiency, requires both minimization of human exposure to indoor air pollution, i.e., source control, and a well-functioning and energy-efficient heating, ventilating or air-conditioning system (Bluyssen, et al., 1996)

Indoor air quality needs in maternity hospitals differ from other building types due to several factors. These factors include first, the need to restrict air movement in and between the various departments, second; the specific requirements for ventilation and filtration to dilute and remove contamination in the form of odour, air-borne microorganisms and viruses, and hazardous chemical and radioactive substances, third, the different temperature and humidity requirements for various areas, and lastly the design sophistication needed to permit accurate control of environmental conditions. (Ramaswamy, Al-Jahwari, & Al-Rajhi, 2010). It is thus possible to construct low-energy buildings using different architectural designs and various HVAC systems (Bluyssen, et al., 1996). This research report seeks to investigate how this issue can be addressed using passive ventilation strategies such as building orientation, wind catchers, thermal chimneys, wind scoops and stack ventilation.

1.2 Problem Statement

Maternity hospital facilities are usually a department located within a larger hospital or are autonomous hospitals designed as maternity hospitals. In both cases the hospital environment is prone to prevalence of infectious microbes, bad odour, varying temperature and humidity levels. There is a growing body of evidence that the aerial dispersion of some nosocomial pathogens can seed widespread environmental contamination, and that this may be contributing to the spread infection in hospital wards (Beggs et. Al. 2008). Pregnant women need specialized care due to their prevailing physical conditions and the potential for medical complications brought about by pregnancy and child bearing. Pregnant women frequently visit maternity hospitals to access medical care in a safe and secure environment where the medical expertise and technology is at hand to deal with potential complications. However, symptoms of discomfort linked to poor indoor air quality continue to be experienced even in maternity hospitals. Align with other medical responses to pregnancy related discomfort, there is documented evidence of pregnant women needing fresh air to effect immediate relief and alleviate the symptoms of discomfort (Cameron, 2014). During the pregnancy period, there is a significant increase in oxygen demand during normal pregnancy. First, there is a significant increase in demand for oxygen during normal pregnancy. This is because the metabolic rate for pregnant women increases by15% thereby increasing their demand for oxygen. Further, their consumption of oxygen also increases by 20% because of increased circulating blood volume and a 40–50% increase in minute ventilation caused by the need for increased volumes of oxygen (Soma-Pillay, Nelson-Piercy, Tolppanen, & Mebazaa, 2016). Secondly it has been hypothesised that pregnancy is a trigger for nausea and vomiting due to increased olfactory sensitivity. Third, a higher metabolic rate coupled with increased blood volume has been associated with an increase in body temperature. Fourth, the American Society for Psychoprophylaxis in Obstetrics proposed strict behavioural breathing techniques to aid in pain management and promote comfort during labour. (Rebecca Dekker, 2021). These techniques are based on breathing technique pioneered by French obstetrician Fernand Lamaze. In the 1950s, he championed a method for preparing pregnant women with physical and psychological training known as psychoprophylaxis. It includes conscious relaxation and controlled breathing as a supplement to pain medication for the management of contraction pain during childbirth (Frothingham, 2018). These factors all point to the need for adequate fresh air at all times aided by constant air changes effected by permanent, operable and consistent ventilation strategies in the building.

Figure 1-6: Makueni Mother and Child Maternity Hospital (Source: makueni-county-hospital.business.site

According to a report by the Kenya Health Sector Strategic and Investment Plan III of July 2014 – July 2018 (KHSSP III), the government is aiming to ensure 80 percent of essential health infrastructure is available in 30 counties. Capital costs make up 12 percent of the investment and operating costs will make up 80 percent. Further, according to the Sector plan for Health 2013 – 2017, the overall goal of the projects and programs under the Health Sector is to improve the lives of Kenyans by providing health care delivery services (Principle Secretary Ministry of Health, 2013). Within the healthcare delivery environment discussed above, maternal health care plays a key role in ensuring safe and well provided facilities where mothers can get the help that they need. Pregnant women attend antenatal, prenatal and maternity hospital to gain access to a safe and secure environment where the medical expertise and technology is available to provide the necessary assistance, relief and care during both the antenatal period, labour and the postnatal period and to deal with potential complications. The Kenya Demographic and Health Survey reports that communities with a long history of home delivery are increasingly visiting maternity hospitals to access care.

The construction of maternity hospitals in the country is responding to the need for universal maternal healthcare contained in the Nations agenda to provide Universal Health Care countrywide (Kenya National Bureau of Statistics (KNBS), 2014). Increase in population and the number and demand for maternity hospitals has led to demand for building systems to provide fresh air for occupants. Employment of mechanical ventilation systems retrofitted into maternity hospitals, may not provide the required volumes of air per unit time given the ever-present symptoms of discomfort during pregnancy.

Figure 1-7: Multiple bed ward at Makueni Mother and child hospital

Figure 1-8: Aerial view of Makueni Mother and Child maternity hospital (Source: makueni-county-hospital.business.site

Figures 1-6 and 1-8 illustrate the Makueni mother and child hospital which is mainly a maternity hospital. Though largely oriented in the direction of prevailing winds, the deep plan design is evident and can pose challenges in adequate fresh air penetration without further natural ventilation design interventions or mechanical ventilation design interventions. The large and evenly distributes windows may facilitate cross ventilation.

According to the Federation of European Heating, Ventilation and Air-conditioning Association, at least 4 air changes per hour (ACH) is a prerequisite for standard patient rooms intended for patients without infectious diseases. When used for airborne precaution, the ACH should meet the requirement for isolation rooms, where adequate ventilation is obtained at least 6 ACH (equivalent to 40 L/s/patient for a 4 x 2 x 3 m^3 room) (RHEVA, 2019). Passive ventilation has received growing interest due to its ability to deliver adequate air changes per hour using cost effective systems that rely on natural forces such as temperature differences and wind. One of the quantifiable indications of poor indoor air quality is a low air change rate. Other observable indicators of poor indoor air quality identified by Hessa-Kosa et. Al. include ventilation discrepancies; such as closed air supply vents or diverted air flow, unspoken responses regarding perceived air quality such as air purifiers and pedestal fans (Hessa-Kosa, Indoor Air Quality, 2019). According to Symon Et al. there has been limited research examining the design of maternity units geared towards air quality comfort of both patients and staff. (Symon, Paul, & Butchart, 2008). With effective ventilation design the required and recommended air changes per hour and indoor air velocity can be realised. (Santamouris, 2005)

In a review of shared hospital ward ventilation in the tropics by Yau, Chandrasegaran and Badarudin, passive ventilation is derived from the natural forces which drive outdoor air through purpose-built structures such as wind catchers and building envelope openings such as windows, doors and ventilators. Indoor ventilation will vary depending on building design and outdoor climatic conditions relative to the indoor conditions. for tropical climates, evaluation of natural ventilation designs suitable for thermal comfort and infection control, recommend single sided corridors, courtyards and wind tower designs as appropriate for provision of fresh air. New natural passive technologies have also made natural ventilation a viable design strategy to be applied in hospitals and more so when used alongside mechanically assisted systems or with advanced control systems for optimal performance (Yau, Chandrasegaran, & Badarudin, 2011).

This research investigates natural ventilation systems in tropical upland climate in order to improve indoor air change rate to optimise provision of fresh air in maternity hospitals. It studies the importance of fresh air in mitigating the symptoms of discomfort associated with pregnancy that have been linked to lack of fresh air. The symptoms of discomfort in pregnancy which are linked to indoor air quality are reviewed, with the aim of drawing a connection between provision of fresh air and comfort for pregnant mothers. Additional factors that will be investigated include the functioning of passive ventilation methods including cross-ventilation, wind towers, stack ventilation, perimeter fenestrations and interior partitions and openings, atria and courtyards. With this information the study will make recommendation for the design of passive ventilation for maternity hospitals in the tropical upland climate.

1.3 Research Questions:

1. What are the existing natural ventilation strategies in maternity hospitals?
2. How effective are the existing strategies in achieving natural ventilation in maternity hospitals?
3. How can passive ventilation design be used to provide fresh air in the maternity hospitals Nairobi tropical climate?

1.4 Research objectives

1. To establish the existing natural ventilation strategies in maternity hospitals.
2. To investigate the effectiveness of natural ventilation strategies in selected maternity hospitals.

3. To propose passive ventilation strategies for supply of fresh air in maternity hospitals in the Nairobi tropical climate.

1.5 Hypothesis

Sufficient supply of fresh air at all times has a direct and immediate effect on the health and comfort of users in maternal healthcare facilities. The building design can provide a sustainable and lasting solution for comfortable indoor air quality in maternal healthcare facilities through balanced natural and mechanical ventilation systems using structural and non-structural permanent building components geared towards provision of fresh air.

1.6 Justification and Significance of the study

The quality of indoor air has been proven to have an immediate impact on comfort of the users (Bluyssen, et al., 1996). Moreover, the world is coming to terms with the realization that transmission of SARS-CoV-2 is airborne (Dancer, Bluyssen, Yuguo Li, & Tang, 2021). This coupled with the prevalence of sick building syndrome has sparked an interest in building ventilation design. The study will be of interest to developers, governments, building construction professionals, academics and health care service providers. It aims to encourage creation of maternal hospitals with comfortable indoor environments by improving air quality. It puts supply of fresh air through natural ventilation as one of the determining factors in the design process. It also aims to encourage the use of structural elements integrated in the building envelope at the design and construction stage geared towards facilitating natural ventilation. Establishing a good ventilation system would therefore contribute towards better indoor environmental quality.

1.7 Scope and limitations of the study

The case studies will be analysed along the following parameters; design and orientation of fenestrations, indoor air velocity, indoor air flow rate and distribution and exhaustion of used air. Desktop studies will be carried out for other international case studies in similar tropic climates. The theoretical scope of the study is natural ventilation captured in environmental architecture. It is also theoretically bound by maternity hospital units comprising similar spaces.

Owing to the financial and time constraints of the research program study will examine existing buildings in the Nairobi region only. Institutional restrictions also do not allow the positing of data loggers within maternity spaces for extended period of time. Access into maternity wards in use is also restricted due to new regulations introduced to curb the Covid 19 pandemic.

1.8 Study Organization

Chapter one - This chapter identifies the problem of undesirable indoor environments for pregnant women occasioned by poor indoor air quality, in the tropical upland climate of Nairobi, Kenya. It gives a brief history of the problem of suboptimal indoor air quality and its effect on the users. It outlines established parameters of comfortable indoor air quality. It poses the existing challenges observed in the selected case studies and the symptoms identified in maternity hospitals.

Chapter two – This chapter documents a review of literature on indoor air quality, problems occasioned by poor indoor air quality and research on natural ventilation in maternity hospitals. It gives a theoretical framework for the study through analysis of indoor air quality, symptoms causes and consequences of poor IAQ. Natural ventilation is discussed in the context of tropical climate and the Kenya building code. Factors affecting indoor air quality and natural ventilation in maternity hospitals were used to create a framework for fieldwork data collection and analysis. It also discusses the relevant literature on provision of fresh air for indoor air comfort in maternity hospitals. Factors affecting maternity hospital environments are outlined to exemplify the correlation between indoor air quality and the symptoms of discomfort. Literature on how these symptoms can be alleviated is then reviewed with a view of establishing passive design strategies for optimum indoor air quality in maternity healthcare facilities. Inasmuch as ventilation makes a significant contribution to convective cooling and physiological cooling, these are not discussed in this study.

Chapter three – This chapter outlines data collection and analysis methods used for the research study. Both qualitative and quantitative data are collected. Qualitative data is obtained from interviews with facility personnel and observation of the case study hospitals. Quantitative data is obtained through measurements of existing building features and from the building's architectural drawings and mechanical layouts. Primary data will be obtained from local case studies and secondary data from desktop studies of existing literature, academic journals and internet sources which address the issue of indoor air quality, air freshness and air quality need of maternity hospitals. These data are presented in written narrative, photographs, architectural drawings and tables.

Chapter four – this chapter illustrates the data collected in the case studies, the findings of interviews, measurements and observations. This chapter contains the analysis of data collected and used to draw fitting conclusions based on the theoretical and conceptual frameworks The findings are presented to guide conclusions and recommendations for natural ventilation for optimal indoor air quality in maternity hospitals.

Chapter five – conclusions and recommendations; this chapter gives conclusions drawn from the findings in the desktop research and fieldwork. Data collected from the field work informs the conclusions of the findings regarding indoor air freshness. It also proposes areas for further research that would complement the findings of this research.

1.9 Operational definition of terms

Indoor air quality – the quality of indoor air with reference to human comfort. (IAQ)

Air change rate – this is the ventilation rate in m^3/h divided by the volume in m^3 of the enclosed space expressed in air changes per hour. (ACH) (Chartered Institution of Building Services Engineers (CIBSE), 2016)

Fresh air - Clean dry air with the following approximate composition Nitrogen (N_2) 78%, Oxygen (O_2) 21%, Argon (Ar) 1%, Carbon dioxide (CO_2) 0.03% (Max Fordham LLP, 2006)

Natural ventilation - the intentional airflow through windows, doors or other openings designed for the purpose, obtained without the use of fans; it is created by pressure differences caused by the wind and/or by temperature differences between the inside and the outside. (UN-Habitat, 2014). It is also referred to as passive ventilation.

Maternity Hospital - The department of a hospital that provides care for women during pregnancy and childbirth as well as for new-born infants. It may also be an independent institution but with the same facilities as one contained as a wing in a larger hospital.

2 CHAPTER 2: NATURAL VENTILATION AND INDOOR AIR QUALITY FOR MATERNITY HOSPITALS

2.1 Introduction

Adequate ventilation that provides the natural chemical balance of air is necessary for aeration comfort and reducing risks from infectious bio-aerosols in hospital wards. In today's highly mechanized hospital buildings, achieving this using mechanical ventilation has carbon and energy implications (Adamu Z. , 2014). Natural ventilation has proven to be a viable method for supply of fresh air in hospital buildings. Natural ventilation is often limited to window-based designs whose dilution and mixing effectiveness are subject to constraints of wind speed, deep plan designs, interior partitions, and in the case of hospital wards, proximity of patients to peripheral walls (Adamu & Price, 2015). The literature reviewed will be guided by the research objectives outlined in chapter one as follows:

Table 2-1: Research objectives and corresponding literature review objectives

Research objective	Literature review objectives.
Establish the existing architectural natural ventilation strategies in maternity facilities.	Study and document established passive ventilation strategies. Study application of passive ventilation hospital buildings in Tropic climates.
Investigate the effectiveness of natural ventilation strategies in selected maternity hospitals.	Study how the effectiveness of passive ventilation is measured. Study the climate of Nairobi and how to take advantage of it for ventilation design. Explore methods of air exchange that have been used to create comfortable indoor air quality.

Propose passive ventilation strategies for supply of fresh air in maternity hospitals in the Nairobi tropical climate.	Identifying the established limits of air quality comfort. Identify the gaps that exist in ventilation design for provision of fresh air in maternity hospitals. Develop a framework for application in ventilation design for optimal indoor air quality in the indoor environment of a maternity hospital.

Chronic respiratory illnesses such as asthma and conditions such as sick building syndrome have emerged as extensive threats to public health. While a large allopathic medical structure is in place to address illnesses attributed to poor indoor air quality, growing evidence posits that urban planners, architects, public health officials, and the medical fraternity should work together in ensuring healthy indoor environments in hospitals and in other buildings at large to avert these illnesses (Guenther & Vittori, 2013). In a study (P. M. Bluyssen, 1996), these symptoms have been associated with poor indoor air quality. To alleviate symptoms that occur in stressful indoor environments indoor air quality needs to be addressed as, according to the EPA, peoples spend 89% of their time indoors. Further estimates suggest that the level of pollutants indoors is up to five times greater than outdoor levels. Occupant health, complaints of unbearable indoor environments are acutely associated with the present methods of ventilation (Awbi, 2008). This relation is evidenced by the increased risk of infectious disease transmission through recirculated air, contaminated HVAC sources that cause an overall distribution of unwanted pollutants. Stagnant zones in some parts of indoor spaces and on the other hand draughts felt in opposite spaces within the same building are indications of insufficient ventilation effectiveness (Awbi, 2008). Airborne substances comprise complex stimuli that interact on different levels before they are perceived or during perception by occupants. in these cases, there is chemical or physical interaction in the gas mixture, interaction of molecules at the receptor surfaces, that is, olfactory and trigeminal systems, peripheral interaction in the nervous system and, finally, interaction in the central nervous system (Plesen, Bluyssen, & Roulet, 2007).

Natural ventilation for hospitals the overall airflow should bring the used air from the agent sources to areas where there is sufficient dilution, and ideally to the outdoors (World Health Organisation, 2009). In this report, the World Health Organisation gives the following guideline for ventilation in hospitals: 160 l/s/patient (hourly average ventilation rate) for airborne precaution rooms (with a minimum of 80 l/s/patient) (note that this only applies to new health-care facilities and major renovations); 60 l/s/patient for general wards and outpatient departments; and 2.5 l/s/m3 for corridors and other transient spaces without a fixed number of patients; however, when patient care is given in corridors in emergencies, the same ventilation rate requirements for airborne precaution rooms or general wards will apply. In hospital buildings, administrative staff, medical practitioners, visitors and patients spend extensive periods of time in the facilities and are constantly subjected to the building's implicit air quality (Śmiełowska M, 2017). Indoor air quality is affected by outdoor air quality, indoor activities, indoor occupant density, ventilation practices and indoor intrinsic emissions. The presence of vulnerable people and the air consuming characteristics of the ongoing activities emphasise the importance of adequately controlling IAQ in hospitals. Medical practitioners have identified headaches, chronic fatigue, dryness and inflammation of the eyes and skin as common symptoms associated with poor IAQ. (Rollins, et al., 2020).

2.2 Pregnancy and olfaction

The need for comfort ventilation exists when the indoor environment is felt as too warm or study under still conditions (Givoni, 1998). The relevant ventilation parameter for comfort is the air speed over the body, whereas the ventilation parameter for olfaction is air exchange for optimal indoor fresh air. Increased intensity in sense of smell during pregnancy has been hypothesised to be a trigger for nausea and vomiting (Erick, 1995; Heinrichs, 2002). There is a growing body of evidence that increased olfactory sensitivity protects the developing embryo by reducing the likelihood that the mother will ingest toxins. This is achieved by allowing the mother to detect toxins in food and air through increased olfactory sensitivity (Cameron, 2014). Several scientific studies have reported a change in sense of smell during pregnancy. The most consistent source of evidence that the sense of smell of women changes during pregnancy comes from personal accounts given by pregnant women and questionnaire studies. As early as 1895, Zwaardemaker documented that hypersomnia was common in pregnancy, although he also noted that empirical measurements of this occurrence were lacking (Zwaardemaker, 1895). Steiner (1922) reported that a large percentage of pregnant women report a stronger sense of smell, usually in the early months of pregnancy and particularly in the first pregnancy. It has been reported to vary in subsequent pregnancies.

Figure 2-2: Victorian hospital window with a tall sash and a top hopper window operated by a crank e control at nurse height. (Fordham & Thomas, 1996).

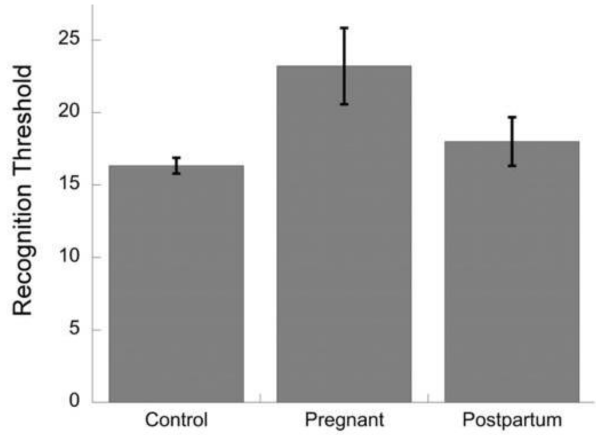


Figure 2-1: Recognition thresholds for non-pregnant, pregnant, and postpartum women.. (Cameron, 2014)

Henssge (1930) described a case study in which a 27-year-old pregnant woman reported that her olfactory "sensitivity increased" and that odour that were "normally imperceptible were now unbearable." Henssge (1930) indicated, in that report, that he encountered frequent cases of such "hypersensitivity" in the early phases of pregnancy and although no psychophysical measurements were made, he stated that "Beyond doubt, the patients experienced these odours in response to genuine stimuli which were imperceptible to people who are not pregnant." (Cameron, 2014). The need to alleviate these symptoms and protect susceptible patients from cross-infection resulting from airborne pathogens is essential in hospitals, especially when patient immunity is either suppressed due to medical procedures or compromised by ailment. Personalised ventilation (PV) is a method of creating a local zone of high air quality around such patients (Price, Cook, & Adamu, 2011). Cameron 2007 posits that approximately two-thirds of pregnant women gauge their sense of smell as higher than normal or as inordinately sensitive or as abnormally sensitive (Nordin et al., 2004). (L., 2008). Another study also found pregnant women rate their sense of smell as more sensitive compared to controls, particularly later in pregnancy and even in the postpartum period (Ochsenbein-Kölble et al., 2007). Figure 2-2 illustrates a comparison of recognition thresholds for a lemon odour using blast-injection technique in a cross-sectional study carried out by Noferi and Giudizi (1946). It shows that thresholds were significantly higher in women in late pregnancy compared to those who are not pregnant and compared to women who were within 2 weeks postpartum (Doty, 1976)

2.3 Indoor Air Quality in hospitals

Indoor environmental quality (IEQ) refers to the quality of a building's interior environment in relation to the health and wellbeing of those who occupy space (Arizona, 2022). Indoor air pollutants emitted inside buildings are derived from the activities of occupants and emissions from materials used in construction and furnishing include CO2 from metabolism and gas appliances, carbon monoxide from poorly maintained gas and other combustion, formaldehyde from fibre boards and foam insulation, moisture, odour (generated as part of metabolism and emitted from furnishings and fabrics), ozone (from electrical appliances normally associated with poor maintenance), particulates, including dust, organic fragments, fibres and smoke particles, volatile organic compounds (VOCs) from furnishing fabrics and household chemical products and, laboratory contaminants (chemicals, biohazards, radioactive products).

Of specific interest in this study is indoor air quality and its effect on human comfort in maternity hospitals. The quality of indoor air has been proven to have an immediate impact on comfort of the users (Bluyssen, et al., 1996). An audit of the relation between indoor air quality of hospital buildings and infection rates, showed that air filtration with high efficiency particulate air (HEPA) filters was effective. However, the rate of infection of patients in rooms with portable filtration did not differ from those without a portable filtration unit (Engelhart et al. 2003). Therefore, more needs to be done to ensure comfort even in controlling infection rate as part of indoor air comfort. In addition, aspects of the air quality have been associated with several self-reported symptoms, such as dry skin, fatigue, nasal inflammation and ocular symptoms (Hellgren et al. 2011; Smedbold et al. 2002; Wieslander et al. 1999). Symptoms were related to low air humidity, a low ventilation rate, presence of mould in the ventilation units, emission of VOCs and high noise levels of the ventilation system. (Eijekelnboom & Bluyssen, 2019).

Hospital environments require particular attention to ensure healthy indoor environments and IAQ to protect patients and healthcare workers against hospital-acquired infections and occupational hazards. Poor hospital IAQ may cause outbreaks of building-related illness such as headaches, fatigue, eye, and skin irritations, and other symptoms (El-Sharkawy & Noweir, 2014). Clean dry air has the following approximate composition: Nitrogen (N_2) 78%, Oxygen (O_2) 21%, Argon (Ar) 1%, Carbon dioxide (CO_2) 0.03% (Max Fordham LLP, 2006). Indoor air in hospitals contains a several particles and gaseous

Figure 2-3 Main Patient ward, Evolve Medical, Holladay, Utah, USA. (Source https://www.blacklabconstruction.com/portfolio-item/evolve-medical/)

contaminants such as carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (CH_2O), total volatile organic compounds (VOCs), respirable suspended particulates, radon, glutaraldehyde ($C_5H_8O_2$), nitrous oxide (N_2O), latex allergens, and total bacterial count. These contaminants are commonly referred to as indoor air pollutants (El-Sharkawy & Noweir, 2014). Carbon monoxide (CO) is exceedingly toxic and combines with haemoglobin to form carboxyhaemoglobin (COHb), which reduces the oxygen supply to body tissues. At elevated levels, symptoms of exposure include headaches, decreased alertness, nausea, fatigue, rapid breathing, chest pain, and impaired judgment (El-Sharkawy & Noweir, 2014). Overall, the purpose of ventilation in any occupied space is to supply fresh air to the occupants and remove used air generated within a confined space. In hospitals, the ventilation system should also help prevent diseases and augment the patients' healing process (H., CHandrasegaran, & Badarudin, 2011). Research has shown that the design of a hospital ventilation and spatial layout, can enhance the health outcome of the patients and provide a better working environment for staff (Ulrich, et. al. 2004). This demonstrates that overall healthcare quality can be partly enhanced by improving hospital building ventilation. Figure 2-4 illustrates a hybrid ventilation system with natural personalised ventilation outlets as well as outward facing fenestrations in the façade.

Since the advent of the hospital "birthing unit" in the late 1970s, the health sector has attempted to apply and even invested in the ability of the physical environment to contribute to the healing process (Christopher Arnold, 2007). Among other physical elements of the hospital environments, air quality in and around the hospital is paramount is aiding healing of patients. Indoor air quality refers to the quality of air within buildings with reference to the health and comfort of building occupants (Environmental Protection Agency, 2021). The need for fresh air ranges from the nominal amounts needed for breathing ($2\ l\ s^{-1}$) to the much higher ventilation rates necessary to control odours (up to

16–32 l s^{-1} is a commonly quoted figure for fresh air needed to mitigate the effects of smoking smells) (Sue Roaf, 2001). Building ventilation is used to maintain indoor air quality at acceptable levels for comfort to be achieved. In order to achieve this objective, controlled rate of flow of air should be applied. The minimum air flow rate is determined by indoor air quality requirements, so that the maximum concentration for every pollutant is lower than the maximum concentration admitted (Santamouris, 2005). The purpose of ventilation is to eliminate airborne contaminants, which are generated both by human activity and by the building itself. These are bad odours, to which people entering the room are very sensitive; moisture, which increases the risk of mould growth; carbon dioxide gas, which may induce lethargy in high concentrations; dust, aerosols and toxic gases resulting from human activity, as well as from the materials of the building (Roulet, 2005).

There are two principles on which natural ventilation is based; cross ventilation and stack ventilation. Cross ventilation is the conventional method of passive ventilation used to supply fresh air in the buildings (Gerd Hauser Prof; Anton Mass Dr; Dietrich Schmidt, 1999). However, in order to drive the system, this natural ventilating system relies on natural forces such as wind availability and direction (Santamouris, 2005). The building design should be oriented to these factors to gain the ventilation. (Izudinshah Abd. Wahab, 2013). Cross ventilation relies on pressure differences outside of the building caused by wind, whereas stack ventilation relies on pressure variations within the building.

The indoor environmental quality of urban buildings is greatly affected by the high concentration of harmful pollutants within buildings. The sources of indoor pollutants are human activity, outdoor pollution and the presence of products and materials that emit a large variety of compounds (Santamouris, 2005). Three basic strategies that may be used separately or in combination are proposed in order to reduce occupant exposure to indoor contaminants: building air-tightening and pressure management; ventilation and air filtration; and contaminant removal (World Bank, 2000). Building air tightness is described as the resistance of the building envelope to infiltration with ventilators closed. The greater the airtightness at a given pressure differences across the envelope, the lower the infiltration.

2.3.1 Indoor Air Quality and well-being in maternity hospitals

Evidence from various studies shows that hospital air quality and ventilation determine the concentrations of pathogens in the air thereby increasing infection rates and creating unbearable indoor environments (Ulrich, et. al 2004). The World health organization defines health as the state of complete physical, mental and social well-being as well as the absence of disease and infirmity. In June 2007, the World Health Organization (WHO) released new guidelines entitled *Infection prevention and control of epidemic- and pandemic-prone acute respiratory diseases in health care — WHO interim guidelines* (WHO, 2007). In this guideline, natural ventilation was considered among the effective environmental measures to reduce the risk of spread of infections in health-care settings (World Health Organisation, 2009). Various documented literature indicates that in order to create a healthy environment for patient recovery and a safe working environment for staff, IAQ plays a vital role as occupants are constantly interacting with the air in different ways and for different functions. Table 2-2 highlights causes, symptoms and consequences of poor indoor air quality were identified and presented in a paper written for the Texas A & M University for the Proceedings of the Tenth International Conference Enhanced Building Operations, Kuwait:

Table 2-2 Symptoms, Causes and Consequences of Poor Indoor Air Quality

Symptoms of poor IAQ	**Causes of poor IAQ**	**Consequences of poor IAQ**
Limited fresh air	Reduced ventilation	Health problems
Temperature and humidity outside comfort zone	Building materials and furnishings	Reduced productivity
Eye, nose and Throat irritation Sick building syndrome	Deferred maintenance	Higher cost to fix problems than to prevent them
Dry facial skin Respiratory infections, asthma Fatigue, headaches Increased allergic reactions	Pesticides, housekeeping supplies, office supplies and chemicals in personal care products	Poor public relations
		Liability issues

Source: (M. Ramaswamy, 2010)

Fluctuation of gonadal hormones is often proposed as an explanation for heightened sense of smell. For example, it is widely understood that fluctuating hormone levels cause the changes in olfactory processing in pregnancy (Doty and Cameron, 2009). The changing levels of the hormone human chorionic gonadotropin (hCG) match the temporal profile of the self-reported changes, indicating that one can rely on personal accounts from pregnant women which show that the largest changes in odour perception occur early in pregnancy (Gard, 1998; Niebyl, 2010; and see Figure 4).

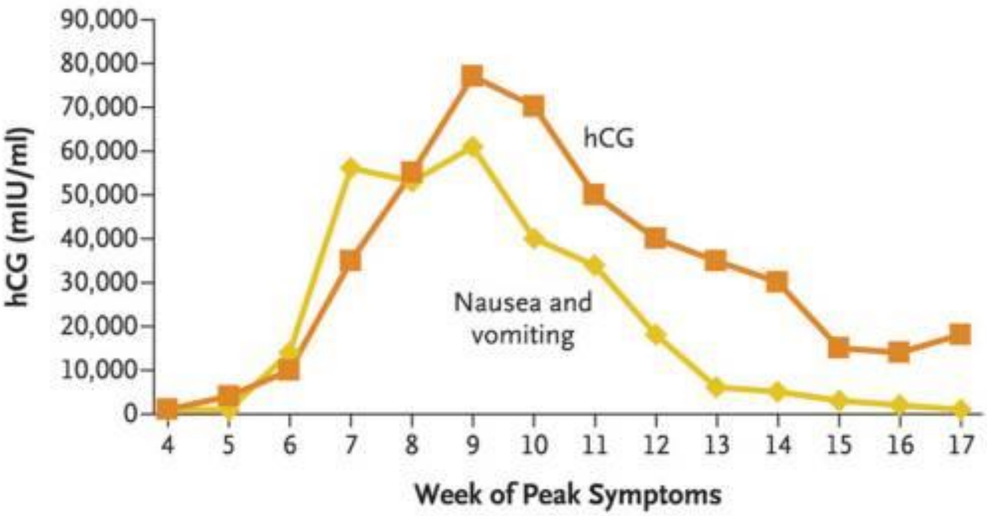


Figure 2-4: Human chorionic gonadotropin (hCG) levels (and reports of nausea and vomiting) as a function of number of weeks of pregnancy. hCG level peaks during the first trimester. From Niebyl (2010), permission received. (Cameron, 2014)

Ambient air contains nearly constant amount of Nitrogen (78% by volume), Oxygen (21%) and Organ (0.9%) with varying amount of carbon dioxide (about 0.3%) and water vapour. Gases other than listed above are usually considered as contaminants. (Ramaswamy, Al-Jahwari, & Al-Rajhi, 2010). In hospitals, contaminants causing poor IAQ can be broadly classified as indoor and outdoor contaminants. Indoor contaminants can be further classified as Chemical contaminants and biological contaminants. Tobacco smoke, Volatile Organic Compounds (VOC), Radon, Inorganic gases, Carbon dioxide, and Nitrogen oxides are some sources of chemical contaminants. Chemical compounds that have a carbon basis and evaporate easily into the air are known as Volatile Organic Compounds ASHRAE Standard 62 (1999) created a standard that requires more fresh air and exhaustion of large volumes of conditioned air. During recent years Demand Controlled Ventilation (DCV) concept is being used in hospital HVAC system design. DCV is a strategy that attempts to reduce the energy used by ventilation systems while maintaining required levels of indoor air quality (IAQ) (Ramaswamy, Al-Jahwari, & Al-Rajhi, 2010).

Air quality in the context of sick building syndrome (SBS) has been examined carefully to establish reliable links to the quality of indoor environments. Sick building syndrome was initially theorised to be principally a problem caused by design flaws occasioned by the type of ventilation system or the depth of a space. It is now understood that facility management and regular maintenance play a key role in curbing sick building syndrome. Occupants tend to be more satisfied if the building can respond quickly to requests for adjustment of indoor conditions depending on the current activities being carried out by the users. At a basic level the building should be able to afford the occupants a degree of user control as provided by openable windows, adjustable blinds and manually adjustable temperature regulators (Max Fordham LLP, 2006). These can be considered along with other passive design features including a narrow floor plan which can aid in effective cross ventilation, strategic positioning of fresh air inlets at a lower level to aid in effective stack-effect ventilation. For a hospital environment the Healthcare Infection Control Practices Advisory Committee (HICPAC) recommends controlling and preventing airborne infection using HEPA-filtered rooms within a hospital. With a view to establish the effect of air quality in hospital environments, a study carried out by Sherertz, et al. in 1987 showed that bone-marrow transplant recipients were found to have a tenfold greater incidence of nosocomial Aspergillus infection, compared to other immune-compromised patient populations, when assigned beds outside of a HEPA-filtered environment (Sherertz, et al., 1987). They posit that air contamination is least in laminar flow rooms with HEPA filters and recommend this approach for operating room suites and areas with ultra clean room requirements such as maternity facilities. Laminar flows are very even, smooth, low velocity airflows that are used in cleanrooms and other settings where high quality ventilation is critical. However, laminar flows are relatively expensive and difficult to achieve because furnishings, vents and other features can create turbulence.) HEPA filters are suggested for healthcare facilities by the CDC and HICPAC, but are either required or strongly recommended in all construction and renovation areas (Sehulster & Chinn, 2003)

Occupants make subtle choices between high temperatures, poor air quality and excess noise which are difficult for mechanical systems to match. Research into health and sick building syndrome has shown that indoor surface pollution comprising dust, debris from shoes and garments, the gases from smoking, eating and drinking and various other sources also contribute to the syndrome (Fordham & Thomas, 1996). In a hospital the building users therefore require accessible and easy to use building features which they can control when needed. Operable windows provide an easy solution for both patients and staff in a facility. When oriented to take advantage of prevailing winds, one can open or close them to adjust the indoor environmental conditions when the need arises. In addition, satisfactory ventilation with regular maintenance is essential in ensuring occupant safety in maternity hospitals.

2.4 Passive Ventilation in Maternity hospitals

Within the healthcare delivery environment, maternal health care plays a key role in ensuring safe and well provided facilities where mothers can get the help that they need. Pregnant women go to hospital to access medical care from prenatal period through to post-natal period. In Kenya, communities with a long history of home delivery are gradually abandoning this practice due to a growing awareness of the potential risks (Principle Secretary Ministry of Health, 2013). With the increasing demand for maternity hospitals, it is essential to better understand comfort and wellbeing in order to create optimal physical environments in maternity hospitals.

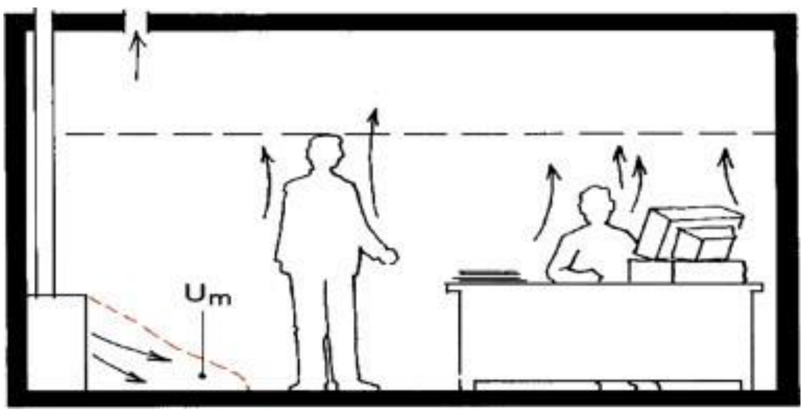


Figure 2-5: Mixing ventilation (Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7116949/

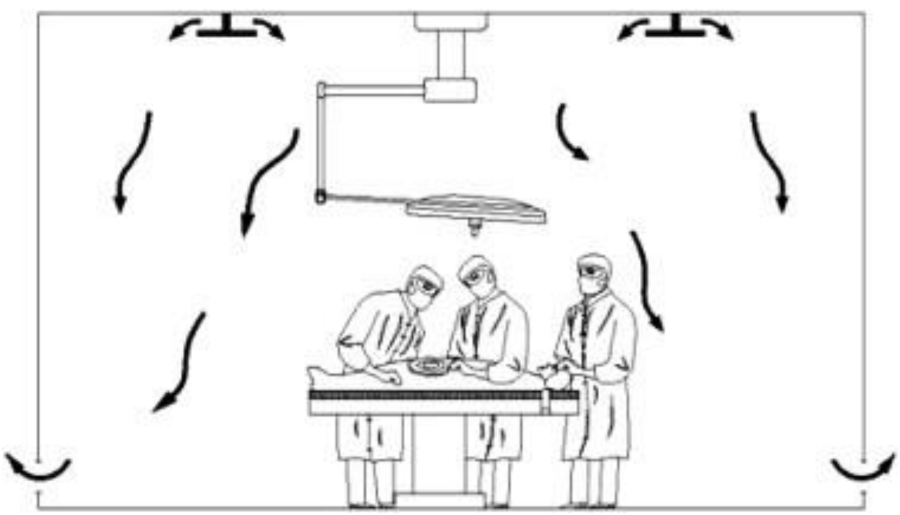


Figure 2-6 Displacement ventilation (Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7116949

Typically, there are two types of ventilation systems practised in hospital wards, namely the mixing type and displacement type. The former supplies air along the perimeter surface of the space, and air is later extracted by the perimeter outlets, as shown in Fig. 2-5. 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. In contrast, the latter supplies air in the most direct way possible to the occupied zone, as illustrated in Fig. 2-6. Conventionally, occupants control building indoor environments and ensure comfort by using simple, elemental means with immediate results. An example, shown in figure 2-1, is the Victorian hospital window with a tall sash and a top hopper window operated by a crank whose control was at nurse height. (Fordham & Thomas, 1996). As more sophisticated systems are developed it is important to try to keep these principles in mind. For instance, opening inlets and outlets for natural ventilation systems that cannot be controlled by the occupants can exacerbate the effects of poor indoor air quality and introduce an element of frustration for the user. For indoor air quality in a maternity hospital admittance of fresh air delivers immediate results for the comfort of users. Fresh air dilutes the indoor contaminants such as carbon dioxide and Volatile organic compounds found in maternity spaces. Controls can, be manual or automatic or some combination of both. For instance, intelligent controls that allow occupants to override automatic systems for limited periods and then readjust according to conditions can provide a versatile system that responds to the frequently changing needs in a maternity hospital. One such system is natural personalised ventilation which is a method of creating a local zone of high air quality around such patients (Price, Cook, & Adamu, 2011). Figures 2-7 and 2-8 illustrate a buoyancy-driven natural ventilation system capable of achieving dilution/mixing. For natural ventilation, air is expected to flow through the building continuously. The factors that influence this flow of air can be considered under the following headings: number of openings, size of openings, position of openings and opening components. Other factors that should be considered with regard to flow of air into the building are the shape, height, orientation and planning. These factors determine the flow of air around the building and the quantity and quality if outdoor air admitted into the building. The external features that affect air flow in building include wind speed, wind direction and dust content. (Szokolay S. V., 2004). The factors; opening component, size of opening, position of openings and external features are discussed below:

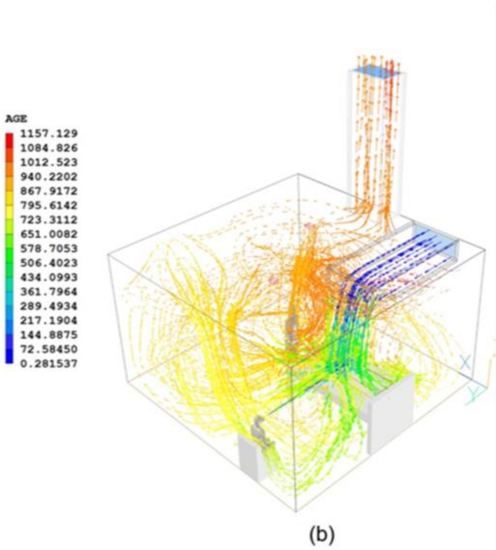


Figure 2-7: Natural personalized ventilation overall mixing regime achieved in the ambient space

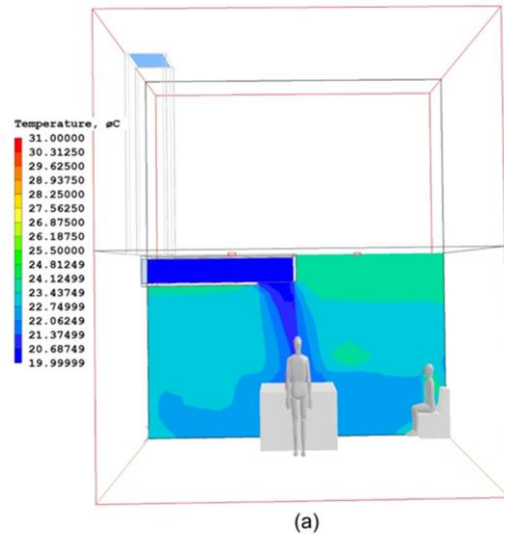
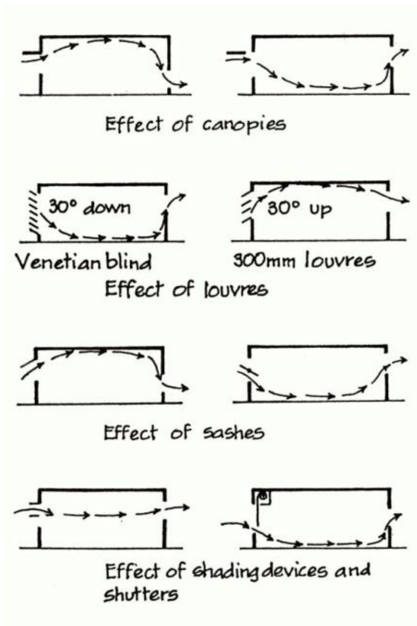


Figure 2-8 Natural personalized ventilation (NPV system showing fresh air delivered to a patient's bed

2.4.1 Opening components, size of opening and position of openings

Windows are the primary and most widespread means in which fresh air is admitted into buildings. The window opening components, size and position determine the velocity and pattern of air flow into a space. Opening components can be external to the building fenestration such as canopies (horizontal shading devices and light shelves) or vertical shading devices, or components within the type of fenestration such as louvers, variously hung windows (e.g., pivoted, top hung, side hung etc.). (Figure 2-8.)

Canopies can direct air flow towards the floor or towards the ceiling when installed as light shelves. Louvers direct air flow depending on their angle of inclination. Sashes deflect air upwards while reversible pivot sashes can deflect it downwards. Side hung windows deflect air towards the hinged side while sliding windows determine the volume of air per square unit depending on the opening width. Occupant-controlled windows are an effective method for supply of fresh air and thereby maintaining indoor air quality as well as thermal comfort when outdoor air is cooler than indoor air. Where inlet and outlet openings are aligned, cross ventilation is effected by wind forces. If the openings are aligned in the direction of the wind, the air passes right through the space, which allows for air to move within the spaces with little to no further induction.



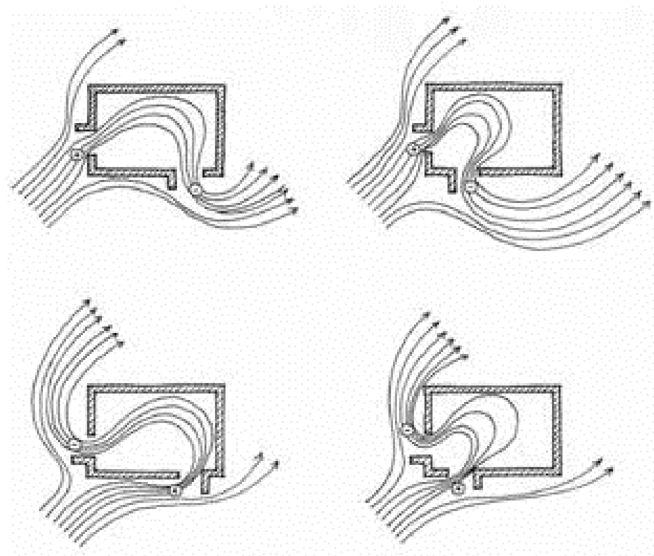


Figure 2-10 Effects of window components on air flow patterns (A. Sealy & C. A. Architects, 1980)

Figure 2-9 Effects of opening position in section on air flow through buildings (UN-Habitat, 2014)

In the event that wind blows obliquely, however, the air movement involves a wider zone and more air movement occurs. If the wind blows parallel to the openings, there is no significant air movement within the space. Positioning of inlets on the windward side and outlets on the leeward side of the building has a clear effect on the pattern of airflow on the pattern and direction of air flow within an enclosure. The incoming air stream usually takes the shortest path of least resistance on its way to the exit. For instance, when openings are situated directly opposite each other on one side of opposite walls or close together on adjacent walls the larger portion of the room remains unventilated. Therefore, openings situated diagonally will allow air flow through the centre of the room. Figure 2-11 describes air flow patterns depending on position of openings relative to the prevailing wind direction.

2.5 Maternity facilities: Space requirements and their ventilation needs

Hospital architecture addresses a building type that offers fundamental and unique design challenges. Maternity hospital facilities, as an architectural typology, can be characterized as a facility that houses the basic spaces designated for the maternity care process. Whether on a downtown site or a pastoral site, the crucial goal of making the building so full of fresh air that disease would not spread within it differentiated hospital design from other building types. Ventilation requirements determined not only who could design the hospital building but what layouts, materials, and structures were allowable. (Kisacky J. , 2017) The maternity hospital brief would mainly contain the following:

a) Doctors' consultation rooms
b) Delivery room,
c) Antenatal accommodation
d) Postnatal accommodation
e) New born nurseries for General care, special care and intensive care

Table 2-3 The maternity unit functional areas grouped under the above zones:

Room designation	Function
Entry/ Reception area	Receiving of visitors
Maternity Inpatient accommodation	bed areas for antenatal and postnatal patients including Bedrooms Ensuites and bathrooms Patient/ visitor lounge areas
Support Areas	Beverage making facilities Bays for storage, Linen, blanket warmer as required, Resuscitation Trolley and mobile equipment Cleaner's room Clean Utility/ Medication Room Dirty Utility Disposal Room Handwashing facilities in corridors, at entries and exits Staff Station Storerooms for equipment and general supplies
Nursery areas	General Care Nursery for well babies Special Care Nursery for babies requiring closer observation and care Intensive Care for new-borns requiring life support. Store rooms for equipment, consumable stock, sterile supplies
Nursery Support Areas	General Care Nursery for well babies Special Care Nursery for babies requiring closer observation and care Intensive Care for new-borns requiring life support.
Staff Areas	areas accessed by staff, including administration and rest areas
Shared Areas	Bathrooms, Treatment room, Visitors lounge and amenities that may be shared with an adjacent unit

Source: (iHFG, 2017)

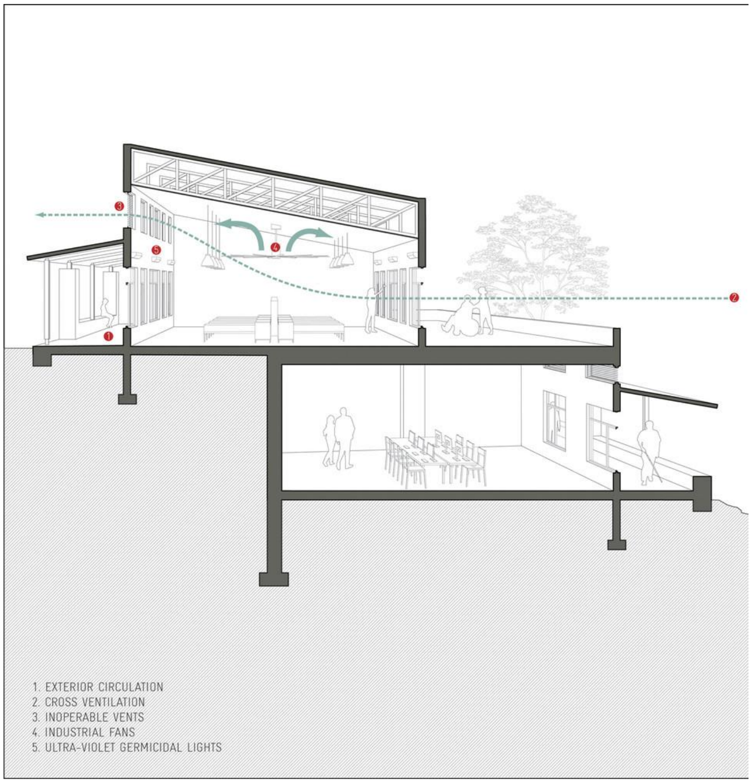


Figure 2-12: Cross ventilation illustrated in Section through Butaro Hospital in Rwanda (Source *https://www.archdaily.com/165892/butaro-hospital-mass-design-group/5015900228ba0d5a4b0002d4-butaro-hospital-mass-design-group-sectional-perspective)*

Natural ventilation solutions for the maternity unit would therefore be based on room level, building level and urban level considerations. Windows would be placed based on building orientation with reference to prevailing wind as well as spatial relationships of the rooms. Maternity hospital sections or autonomous maternity hospitals can be planned in different ways. Ventilation systems are applied to suit the spatial layout used. Maternity units, which consist of specific delivery rooms (or suites) and regular patient rooms for postnatal care, are increasingly designed for comfort of the patients, with shared or ensuite sanitary facilities. For purposes of planning for natural ventilation this section outlines in brief, the spatial requirements for maternity healthcare buildings and maternity departments which offer continual care for mothers and new born babies following a hospital delivery.

A maternity care division usually contains primary care, treatment, inpatient care, administration and procurement. A centralised neonatal provision is located inside or adjacent to the maternity care unit. The basic pattern of flow of caregiving is organized in a series of spaces form the time the mother arrives at the hospital to the time they are discharged. Table 4 outlines the sequence of activities for the delivery period.

For post-natal care Mothers and babies may be accommodated in separate rooms consisting of a maternity ward and nursery or within the same room and would require local neonatal provisions in each room. The maternity units also accommodate spaces for antenatal pregnancy assessment and consultation. These services are preferably located in a different section than the delivery rooms and postnatal patient rooms because of the frequently demanding nature of the consultations and distressing nature of the delivery and post-natal stages.

2.5.1 Facility sizes, layout and orientation

Maternity care facilities are generally divided into smaller units as compared to ambulatory care areas. Smaller wards are preferred because they accommodate fewer patients at a go in one space. It is therefore easier to maintain appropriate standards of hygiene because there is less movement of staff and visitors. Following this planning guideline, the ventilation rate, air flow direction and fresh air distribution can be designed for and controls can be installed to suite particular conditions such as increase in room

population when visitors are accommodated or changes in the weather. Published standards recommend a maximum of 10-14 bed spaces per care unit. The functions may further be divided into care for healthy mothers, care for healthy neonates, care of special neonates and incidental functions. Neonatal care units comprise the following: bed spaces for neonate, dressing areas, baby bathing, weighing points, nurses' duty station, and a trolly standing area.

In the incidental functions area, the following spaces are included: duty station, nurses lounge, kitchenette, doctor's offices, examination and treatment room, clean work room, patient bathroom, day rooms for patients, day rooms for visitors, equipment storage space, staff washrooms, visitors' washrooms, linen cabinets and visitors' consultation rooms. Figure 2-9 illustrates a typical maternity unit showing the spatial relationships of the individual rooms. It adopts a double banked and single banked floor layout. The room depths allow for cross ventilation.

The location of the maternity care facility should ensure a short access route for the mothers and neonates. This ensures that they do not cross other busy corridors in the event that the maternity care facility is within a larger healthcare facility. The obstetrics and maternity care should preferably be on one level to avoid use of lifts, stairs or ramps. By minimizing circulation, one is able to control the air quality and design specifically for the recommended interior ventilation rate, airflow direction, distribution and flow pattern that will effectively alleviate the challenges faced by expectant mothers in prenatal stage as well as the postnatal stages when they are using the facility.

Following Cullender and Chiara's description of a birthing unit, in order to contain noise within birthing rooms and to provide adequate levels of confidentiality and low sound in other areas, (Fig 2—12) the ventilation distribution ductwork should be designed to minimised the transmission of sound from one area to another by suitable routing or separate distributions. The department of health building notes on Maternity care facilities states that natural ventilation can be ducted for rooms that require higher levels of privacy. Any ductwork attenuators required should be designed and installed to avoid the harbouring of bacteria and for ease of cleaning. Each maternity theatre suite should have its individual air handling plant and also its own standby power control. In delivery rooms and recovery areas where analgesic and anaesthetic gases are exhaled, the ventilation rate should be of sufficient capacity to control substances within the appropriate occupational exposure limits.

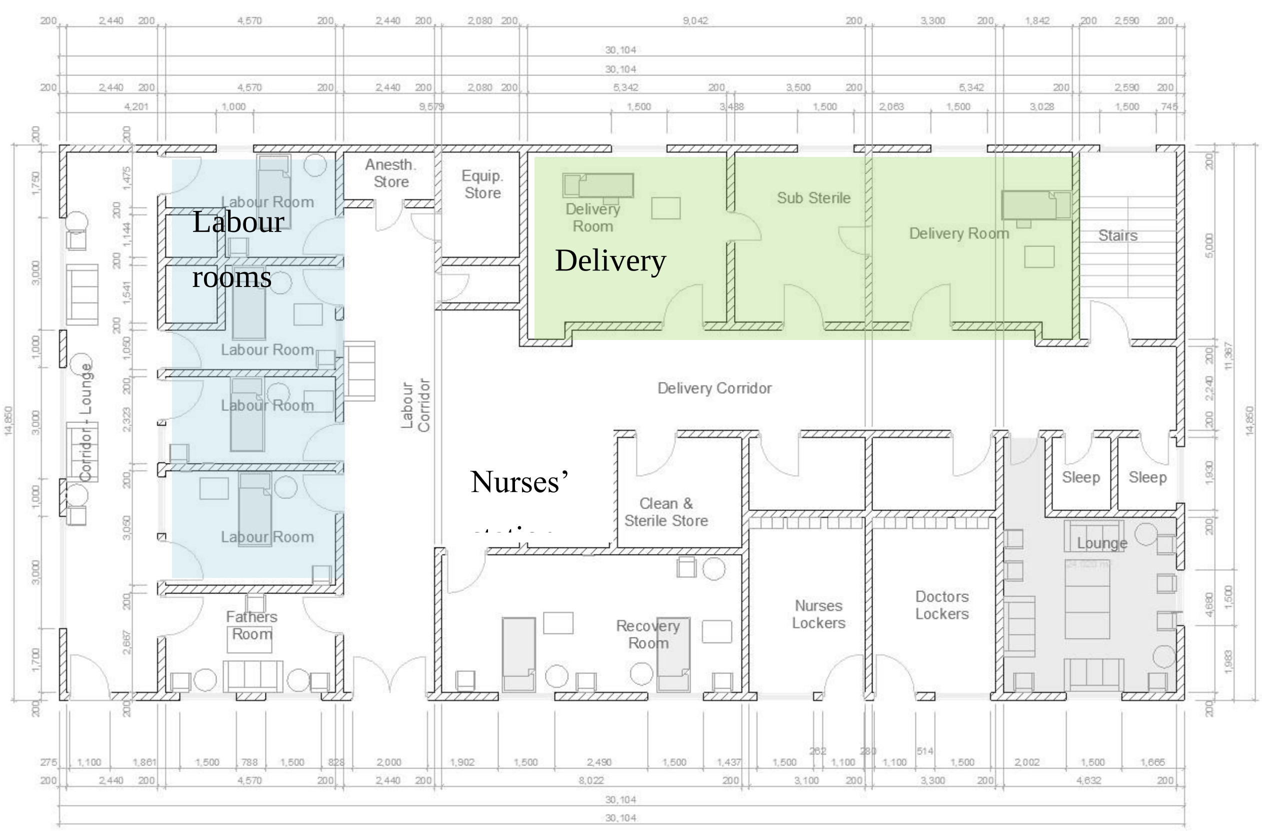


Figure 2-13 Functional arrangement of a delivery suite Source: (Callender & Chiara, 1983)

In order to optimize the ventilation efficiency to minimize the amount of ventilation required, consideration should be given to low-level extract at the bedhead in recovery areas and to proprietary scavenging systems in birthing rooms. (Department of Health, 2013). The department of health also give birthing room ventilation design criteria as follows:

Table 2-4: Birthing room ventilation design criteria (Source: (Department of Health, 2013).

	Ventilation	**Air change rates per hour**	**Pressure (Pascals)**	**Supply Filter**	**Noise (NR)**	**Temperature (^{0}C)**
Birthing Room	Supply and extract	15	Negative	G4	NO	18-25
Comments	In birthing rooms, the use of anaesthetic gas is controlled on demand by the patient. This may result in significant leakage that – in order to reduce staff exposure – will need to be controlled by establishing a clean air-flow path. A supply at high level at the foot-end of the bed with extract at low level at the head-end will provide such a path.					

2.6 Factors affecting provision of fresh air in tropical maternity spaces:

Factors of indoor air in a hospital can be classified as follows: outdoor air and microclimatic factors (temperature, relative humidity, air velocity, air change, etc.); facility management activities (management and maintenance activities, ventilation systems, HVAC, cleaning and disinfectant activities, etc.); design features (room dimensions, furniture, finishing materials, etc.); and human occupancy and medical activities (users' presence, their health status, and medical activities carried out in inpatient rooms) (Settimo & Capolongo, 2019). With these in mind, building professionals, managers, and hospital staff have a strategic role on defining strategies for maximum fresh air supply to curb discomfort and hospital acquired infections. The use of natural ventilation and HVAC systems with constant appropriate air changes, selection of furniture and building materials with low volatile organic compound (VOC) emissions, regular and conscious maintenance, medical activities, and cleaning procedures that take place inside the hospital compliments the factors that affect provision of fresh air in maternity hospitals. For the above to be achieved, site planning for optimal ventilation and passive design considerations should be applied as discussed here below:

2.6.1 Site planning

Planning for ventilation begins with the site layout, building setbacks internal corridors and several other factors of the building layout relative to the site. The particular technique and design for natural ventilation systems for various buildings differs based on building type and local climate. However, the amount of ventilation critically depends on the careful design of internal spaces, and the size and placement of openings in the building. The ventilation potential of a building depends on the wind speed around the building site. At the building level, natural ventilation is affected by the building's immediate context. At the room level, adequate ventilation in the various rooms within a building depends on the external environment as well as the spatial layout, compactness, shape and configuration of the building. The ratio of the building envelope surface area to the volume of internal spaces determines its exposure to ambient air. A spread-out plan offers better opportunities for natural cross-ventilation through flexibility in design of the space. Generally, the more spread out the building is, and the more irregular its shape, the better its potential for cross-ventilation. As the area of the external walls for a given floor area enlarges, more opportunities to provide openings for air supply from different directions are created. In addition, a spread out building provides more opportunities for direct and independent ventilation to the various rooms of the building. (Givoni, 1998). Consequently, acceptable indoor air quality is maintained by replacing used indoor air, with fresh outdoor air. Site planning recommendations for optimal natural ventilation are as follows:

i. Maximising passive ventilation by orienting the building perpendicular to the prevailing winds. When wind flow prevails parallel to the building, wind ventilation can be induced by architectural features such as wind scoops or casement window configuration.
ii. Naturally ventilated buildings should have a narrow floor plate. Air distribution in deep plan buildings using natural ventilation requires structural building elements to occasion further air movement inside the building. Internal partitions to corridors and other rooms usually slow down moving air after it is admitted into the building.
iii. A spread out building has a higher potential for single-banking of its rooms and thus better cross-ventilation
iv. With a compact building, cross-ventilation is hindered or difficult to achieve with ease as the layout may demand double or triple banking of its room in its planning.

2.6.2 Design features and Building elements

Admittance of fresh air into a building in an urban environment is influenced by several factors. When designing for ventilation building level, urban level and room level considerations are made. At the building level, positioning of inlets on the windward side and outlets on the leeward side of the building has a marked effect on the pattern of air flow on the pattern and direction of air flow within an enclosure. This can be observed both in plan and a cross-section through the building. The incoming air stream usually takes the shortest path of least resistance to the outlet. For instance, when openings are situated directly opposite each other on one side of opposite walls or close together on adjacent walls the larger portion of the room remains unventilated. Therefore, openings situated diagonally will allow air flow through the centre of the room. Figure 2-14 describes air flow patterns depending on position of openings relative to the prevailing wind direction. Opening components influence the velocity and pattern of air flow into a space. These components can be external to the building fenestration such as canopies (horizontal shading devices and light shelves) or vertical shading devices, or components within the type of fenestration such as louvers, and variously hung windows. Openings between rooms such as transom windows, louvres, grills or open plans are techniques used to complete the air flow circuit through a building.

Canopies direct air flow towards the floor or towards the ceiling when installed as light shelves. Sashes deflect air upwards while reversible pivot sashes can deflect it downwards. Side hung windows deflect air towards the hinged side while sliding windows determine the volume of air per square unit depending on the opening width. (Roaf, Fuentes, & Thomas, 2001) windows that have controls operated by occupants are a preferred and an effective method for maintaining fresh air in buildings and thermal comfort conditions

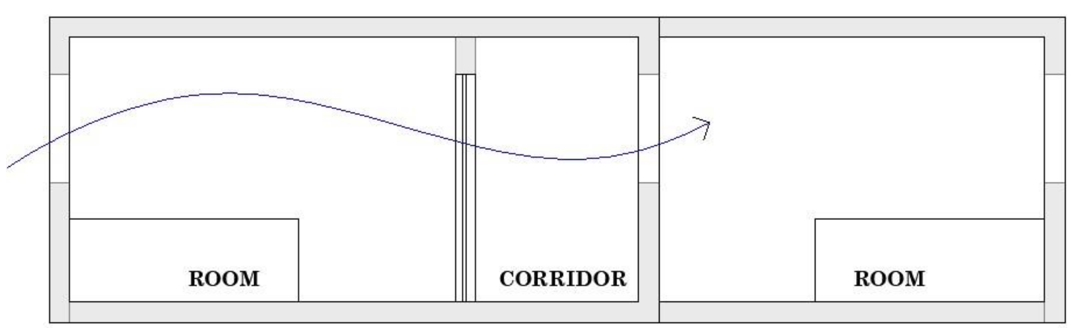


Figure 2-14: Double banked corridor (Source Author)

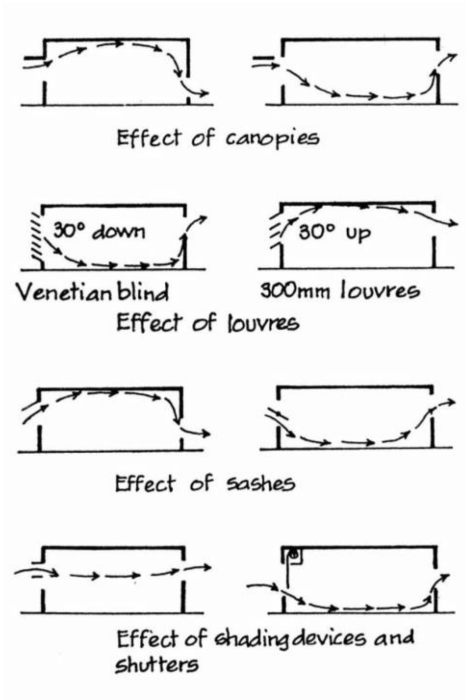


Figure 2-16 Effects of window components on air-flow patterns

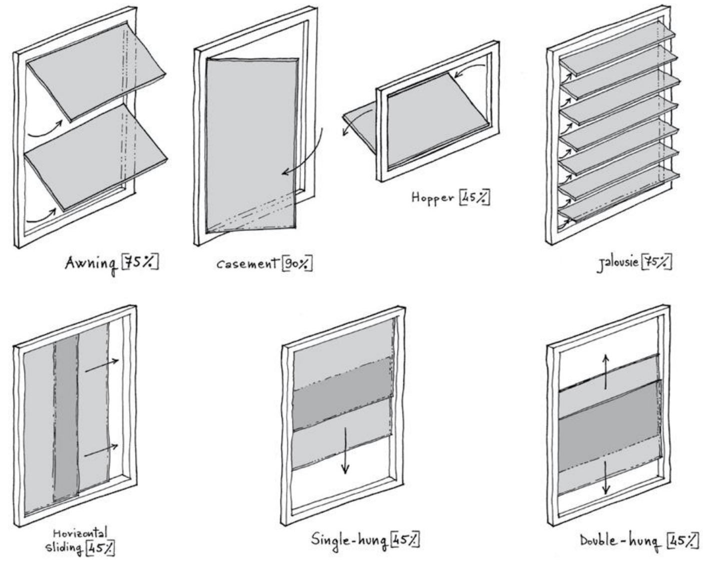


Figure 2-15:Different window types; the effective open area (permeability) as percentage of opening area position of openings. (Butera, Adhikari, & Aste, 2014).

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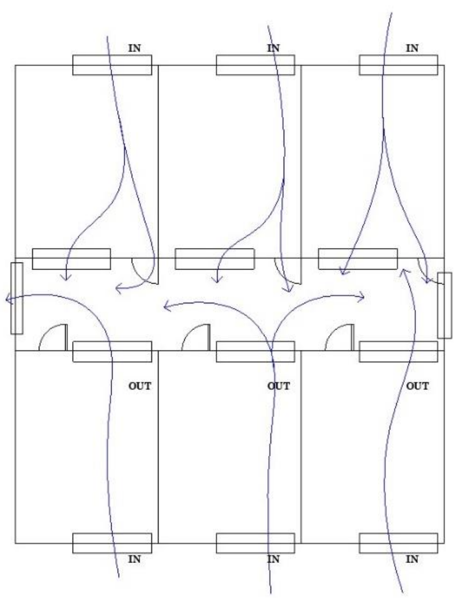


Figure 2-17: Double banked Corridor (Source Author)

The Kenya Building Code regulations stipulate that every room must have at least one fenestration for light and ventilation and that all fenestrations must have an area of at least 10% of the floor area of the room. The open space outside a window of any room must be at least 2.4 meters away from any boundary. communication with the external air may be obtained through a ventilated corridor or passage which itself has an external wall through which adequate ventilation to the external air is provided, or the council may accept a flue communicating the room directly to the external air as part of the means of providing through-ventilation: provided that, in all cases permanent ventilation shall be approved in one external wall. The Local Government (Adoptive By-Laws) (Building) Order 1968 (2020, Building code part 155 section (3))

Natural ventilation is more economically desirable because it applies free natural forces and built-in structural elements that incur little to no maintenance costs. Natural ventilation will provide high air exchange rates in tropical climates wind adequate wind forces. Different patterns of natural ventilation can be applied as follows: single side corridor, double banked corridors, courtyard layout and wind tower type and atrium and chimney system.

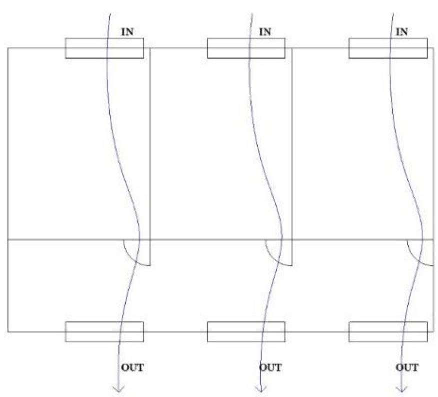


Figure 2-18 Single banked hallway (Source Author)

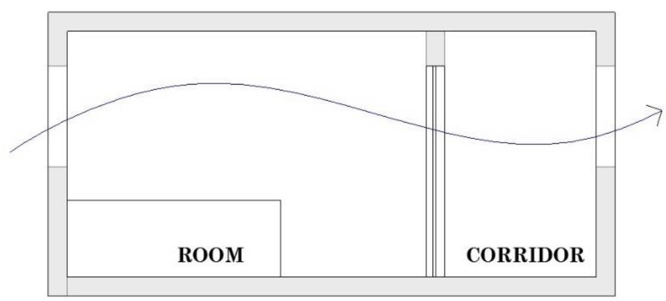


Figure 2-19: Single banked corridor Section (Source Author)

The maternity hospital can be oriented to benefit from the natural driving forces of air movement; wind and stack effect. The design and orientation of fenestrations takes into consideration these driving forces, and the paths taken by moving air in the facility can be identified as in figure 2-11.

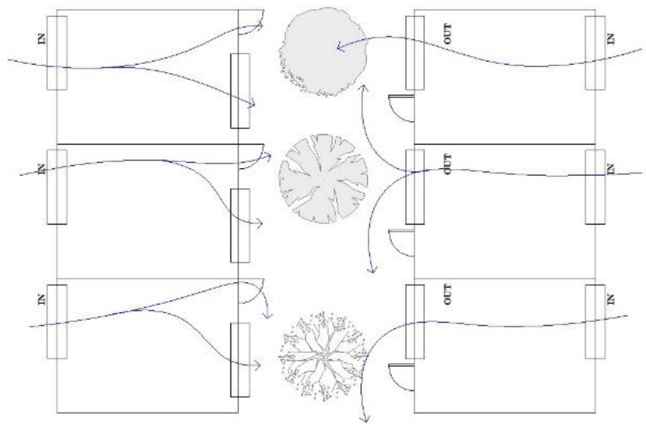


Figure 2-20: Courtyard plan (Source Author)

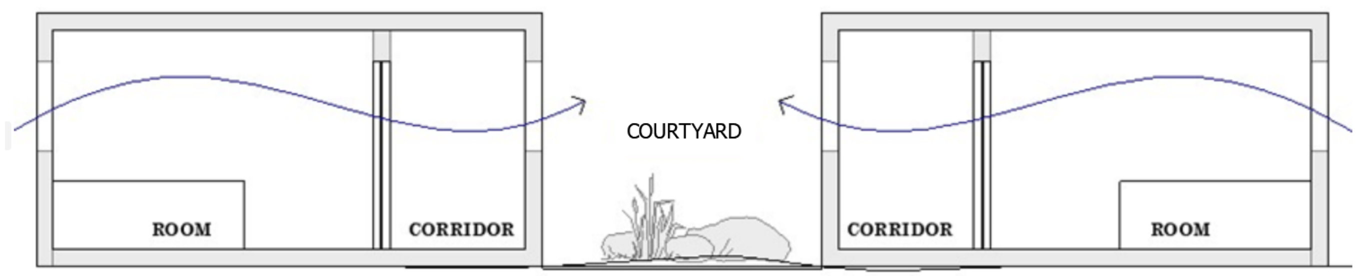
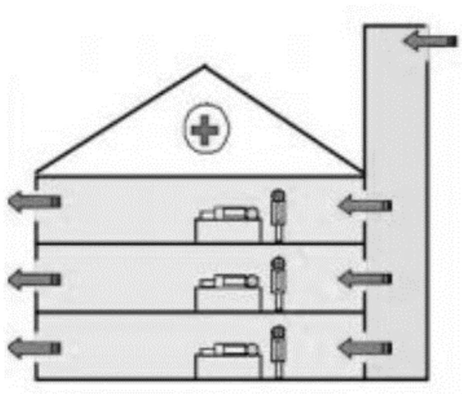


Figure 2-21: Courtyard Section (Source Author)



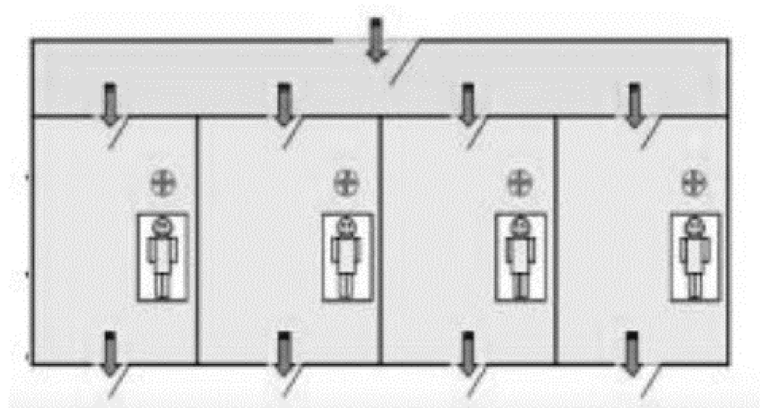
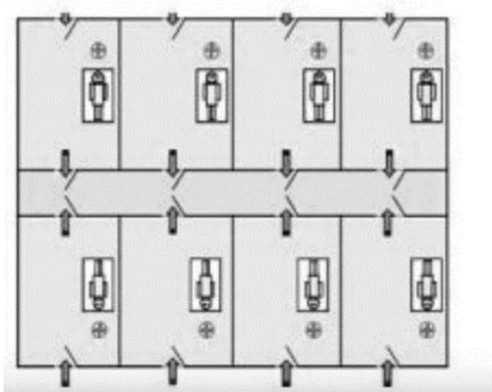


Figure 2-22: Wind tower section *Figure 2-23: Wind tower layout plan*



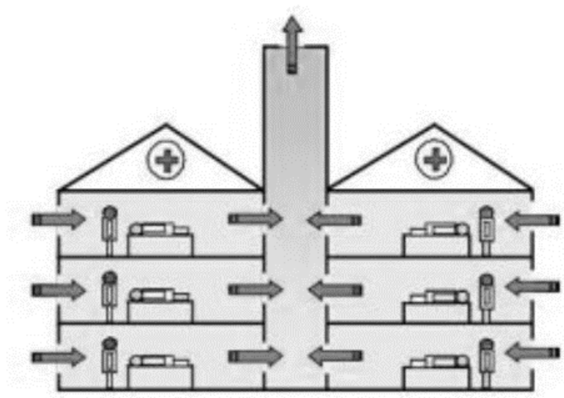


Figure 2-24: Atrium and chimney type plan *Figure 2-25: Atrium and chimney type section*

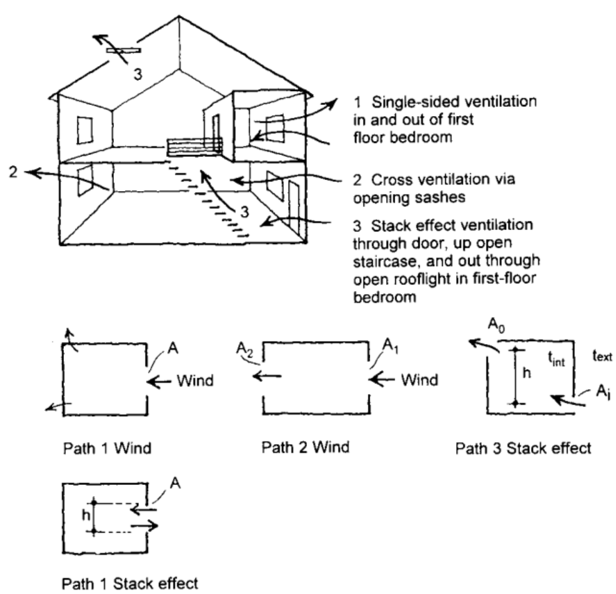


Figure 2-26: Paths of indoor air movement - Path 1 Single sided ventilation; Path 2cross ventilation via opening sashes; Path 3 Stack effect ventilation

At an urban environment level, topography of a site affects the regional and local wind where a building is to be located. This can be quantitatively assessed for optimal ventilation design. On flat ground without obstructions wind speed varies as a function of surface roughness of the ground and height above sea level. Moreover, at the same altitude wind velocity is greater in open countryside than in an area with high building density. Wind measurements taken by weather stations, situated in a given topographical context are used at design stage to inform decisions on window placement and mitigation measures. Changing this context also changes the speed, which also changes, in the same site, in relation to the height.

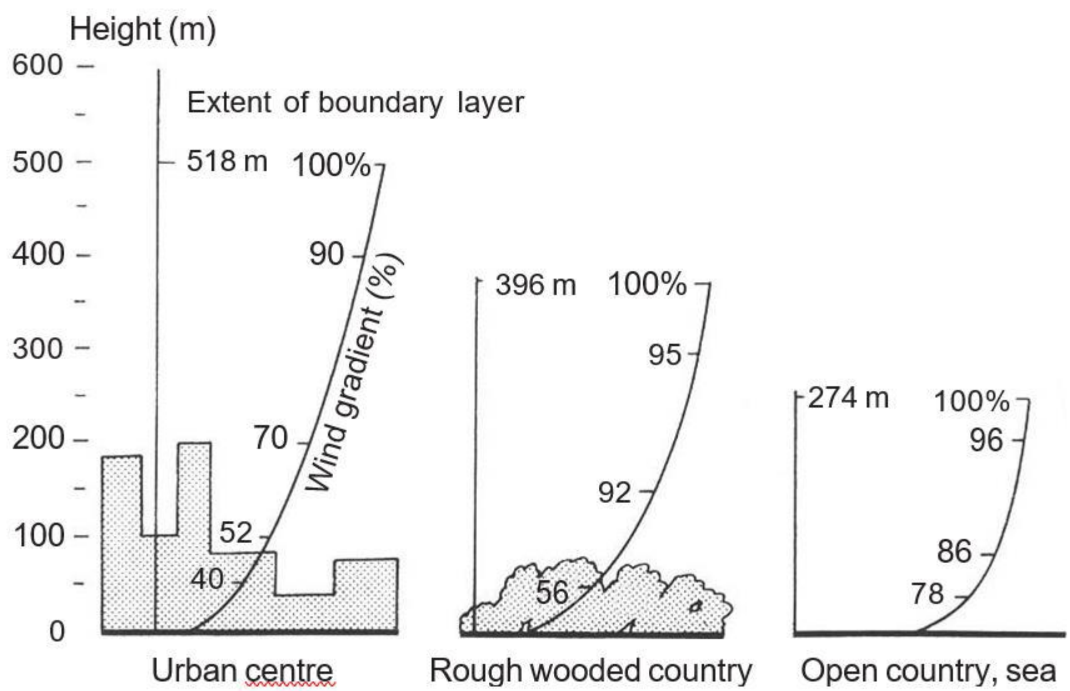


Figure 2-27: Wind Velocity profiles (Szokolay S. V., 2004)

As shown in figure 2-14, wind is mitigated by the ground surface and turbulent movement occurs nearer to the ground, forming a border layer above the ground. The depth of this boundary layer depends on the surface and on objects sitting on the surface; it varies from about 270m over open country to over 500m over a city area. All buildings are and most activities take place in this boundary layer. Topography may deflect the wind, but may also affect precipitation. The air mass over cities is likely to be warmer than in the surrounding countryside, differences (heat island intensities) up to 10K have been measured. This effect is most pronounced when there is little or no wind, especially after sunset. Microclimatic controls can serve two purposes: control the wind conditions in outdoor spaces and to assist building performance by ameliorating outdoor conditions adjacent to the building. According to Roaf et. al., 2001, vegetation can be used to better external conditions to ensure that fresh air is obtained from an uncontaminated source. (Figure 2-15)

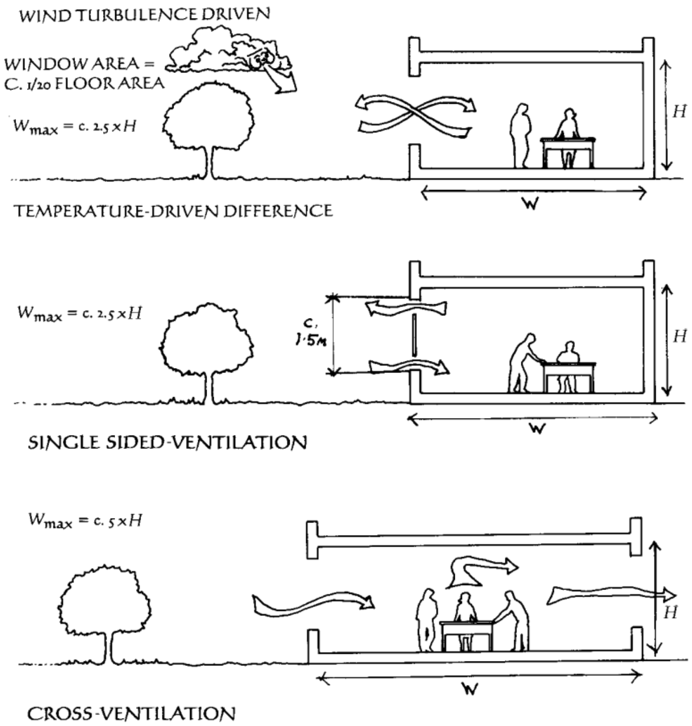


Figure 2-28: Effect of vegetation on temperature driven air exchange (Source: (Roaf, Fuentes, & Thomas, 2001)

Passive conditioning of outdoor air has the benefit of windbreaks; to lessen the impact of strong winds and reduction of dust.

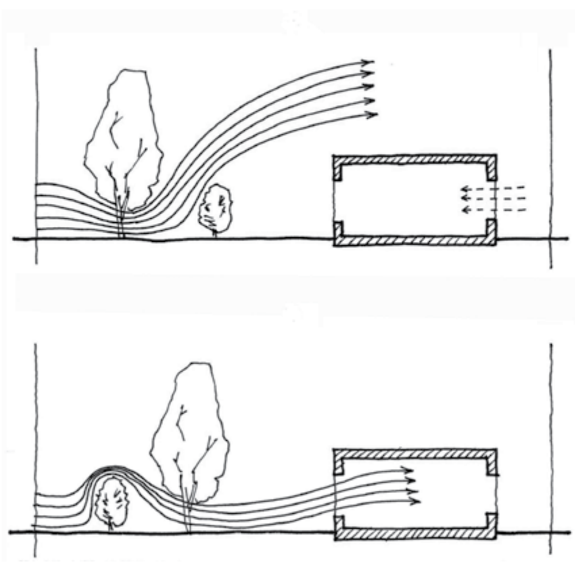


Figure 2-29: Effect of wind on trees with high canopies and of bushes ((Butera, Adhikari, & Aste, 2014)

2.6.3 Natural Ventilation for maternity hospital buildings

A maternity hospital describes the department within a hospital or an autonomous hospital facility that provides specialised care for women during pregnancy and childbirth as well as for new born infants. It may also be an independent institution but with the same facilities as one contained as a wing in a larger hospital. According to the Chartered Institute of Building Services Engineers (CIBSE) the recommended air changes per hour in a hospital is six to eight air changes per hour. This indicates that any healthcare facility should have proper mechanisms to ensure that this requirement is met. For maternal and neonatal facilities infection control and prevention of sick building syndrome is paramount in providing comfortable Indoor Air Quality. The nett effect of ventilation should produce an indoor environment that provides fresh air and effectively exhausts unwanted odours. Optimal indoor air quality eliminates observable physical consequences of uncomfortable indoor air quality such as sick building syndrome, fatigue and headaches.

As discussed in the literature surrounding provision of fresh air for prenatal, maternity and post-natal care, provision of fresh air can be a tool that address several of the sources of discomfort for expectant mothers. The increased need for rest, sleep, and heightened sensitivity to certain smells during the prenatal period can be alleviated by fresh air. These cause great discomfort for the mothers and in some instances can trigger headaches and nausea (Nordin S. et. Al 2004). In designing maternity hospitals ventilation design should consider reports of heightened sense of smell during pregnancy, reported by the target patients. the majority of pregnant women report increased olfactory sensitivity thereby acutely requiring comfortable and fresh air within the hospital. (Cameron, 2014). Furthermore, studies have shown links between a woman's exposure to specific air particles during pregnancy and the risk of preterm births or low birth weight. This is referred to as maternal fine particulate matter exposure and has been identified as a possible risk factor contributing to pregnancy and birth complications (Malley et. Al. 2017).

According to the World Health Organization publication on Natural Ventilation for Infection control in Health-Care Settings, the following are the main recommendations given for how to design, construct, operate and maintain an effective natural ventilation system in hospitals.

First for natural ventilation, 160 l/s/patient (hourly average ventilation rate) for airborne precaution rooms (with a minimum of 80 l/s/patient) (note that this only applies to new health-care facilities and major renovations), 60 l/s/patient for general wards and outpatient departments; and 2.5 l/s/m3 for corridors and other transient spaces without a fixed number of patients should be provided as the minimum hourly averaged ventilation rates. However, when patient care is undertaken in corridors during emergency or other situations, the ventilation rate requirements for airborne precaution rooms or general wards will apply.

Second, the design must take into account fluctuations in ventilation rate. This means that the rate of ventilation within the spaces can change throughout the day as shown by the specific wind rose; the speed and direction changes with time. Therefore, there may be a need for mechanical ventilation to occasions increased amounts of fresh air admitted, faster exhaustion of used air or indoor air velocity. When natural ventilation alone cannot satisfy the recommended ventilation requirements, alternative ventilation systems, such as hybrid (mixed-mode) natural ventilation should be considered, and then if that is not enough, mechanical ventilation should be used.

Third, when designing naturally ventilated health-care facilities, overall airflow should bring the air from the agent sources to areas where there is sufficient dilution, and preferably to the outdoors. Finally for spaces where aerosol-generating procedures associated with pathogen transmission are conducted, the natural ventilation requirement should, all the above recommendations should be followed (World Health Organisation, 2009)

Ventilation requirements may vary between specific rooms within the larger scheme due to specialized purposes. ASHRAE standards 2011 states (Per Paragraph 7.1.1.c): “For spaces that required positive or negative pressure relationships, the number of air changers can be reduced when the space is unoccupied, provided that the required pressure relationship to adjoining spaces is maintained while the space is unoccupied and that the minimum number of air changes indicated is re-established anytime the space becomes occupied.” (ASHRAE, 2007)

2.6.4 Maternity facility layout design and ventilation strategies.

A study of published space design guidelines for different spaces in the maternity unit is presented. This will give a guide towards recommendations for air changes for supply of fresh air. The selected room below is a single bed ensuite ward room.

A: *Composition when mother is hospitalized: the patient bed is positioned under the hospital bed head panel and the cradle is placed next to it; rooming-in for the mother's partner is provided on an extensible chair.*

B: *Composition when baby is hospitalized: the cradle is placed under the hospital bed head panel and the mother (if healthy) sleeps on a patient bed next to it; rooming-in for the mother's partner is sometimes provided on an extensible chair.*

(Wagenaar & Mens, 2018)

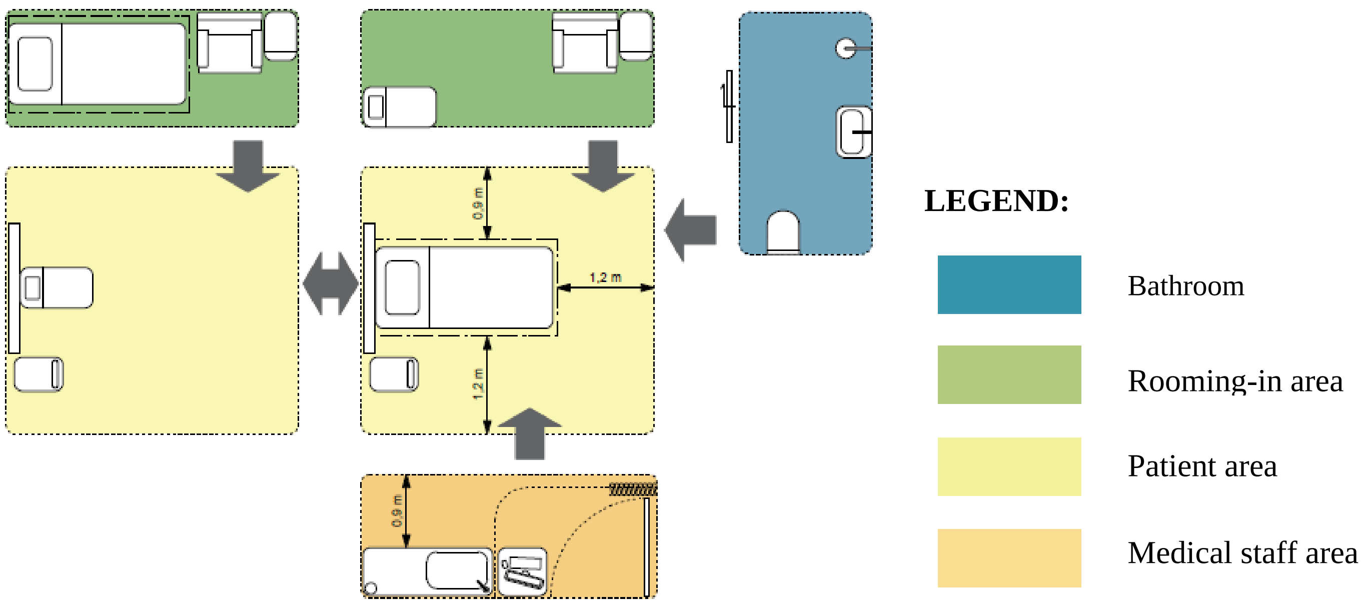


Figure 2-30: Maternity/neonatology suite with typical components:
rooming-in area (green), patient area (yellow), medical staff— area (brown), patient bathroom (blue)

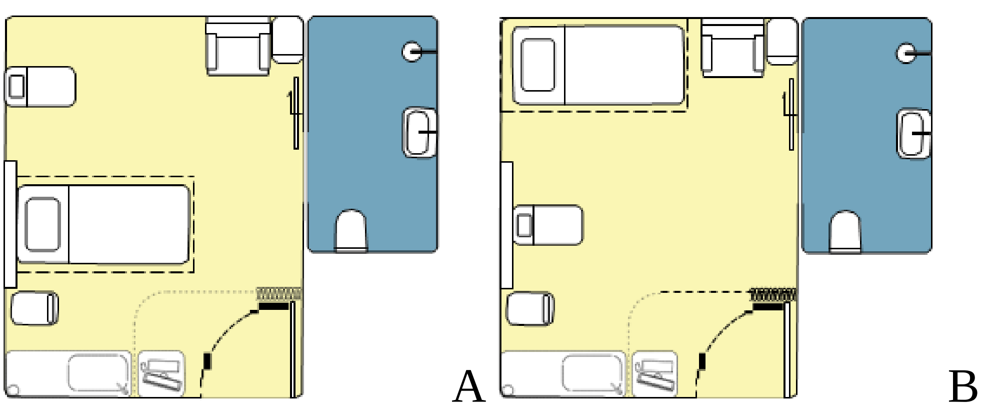


Figure 2-31: A and B as described above

Table 2-5: Recommended Air changes per hour for maternity facilities

ROOM DESIGNATION	ROOM VOLUME	AIR CHANGES PER HOUR (ACH)
Single room ensuite	75	6-10
6 bed capacity wards	108	6-10
Patients' washrooms	45	10
Nurses' station	90	8-12
Doctor's office	60	8-12
Theatre	90	10-20
Visitor's lounge	75	4-6
Delivery room	75	20
Father's lounge	60	4-6

(Hall & Greeno, 2007)

2.6.5 Air Velocity for maternity hospitals

The recommended interior air velocity is between 0.15 and 0.50 m/s for comfort of users. Sedentary tasks such as desk work fall within the range of 0.15m/s to 0.30 m/s, whilst more vigorous work, shop work and manufacturing, between 0.30m/s and 0.50 m/s. These statistics are intended to provide air freshness as well as to relieve stagnation without noise distraction from air movement equipment. (Hall & Greeno, 2007). According to the chartered Institute of Building Services Engineers (CIBSE) the recommended air changes per hour in a hospital or 6 – 8 ACH for wards, 10-15 for X-ray rooms and 15-20 for sterilizing rooms. (CIBSE 2016). To respond to the special needs of pregnant mothers the building design should be fitted with controls that are easy to adjust when the need arises.

Ducting and outlet diffusers for conveyance and exhaust of air through could produce distraction in form of noise. This should be maintained at an unobtrusive level. Noise emanating from air ducts and ventilation equipment may be muffled and unnoticed in the event that the room activities produce much more sound. In this case background noise will render sound from air movement unnoticeable. For design purposes, a smaller duct size will give greater air velocities. However, since duct noise increases with increase in air velocity, some regard must be made for acceptable ducted air noise levels and the following table provides some guidance:

Table 2-6: Acceptable ducted air noise levels (Source: (Hall & Greeno, 2007)

Situation	**Ducted air velocity**
Very quiet, e.g., sound studio, library, study, operating theatres	1.5 – 2.5 m/s
Fairly quiet, e.g., private office, habitable room, hospital ward	2.5 – 4.0 m/s
Less quiet, e.g., shops, restaurant, classroom, general office	4.0 – 5.5 m/s
Non-critical, e.g., gyms, warehouse, factory, department store	5.5 – 7.5 m/s

2.6.6 Supply and exhaust air paths

The supply and exhaust air paths provided in the buildings design are the pathways used by fresh air to reach interior spaces inside a building. The supply and exhaust paths can be local or central. A local supply and exhaust air path indicates that several inlets and outlets are distributed along the building envelope. These are incorporated within the building during the design stage. A central inlet and outlet air path necessitates horizontal and vertical ducts and compartments within the building to dispense the ventilation air to the anticipated locations. A centralised airflow paths facilitates recovery of indoor heat, preheating and filtering, which is more difficult to provide for with local airflow paths. Comparatively, local paths offer greater flexibility for future changes as they usually are organized in a modular manner (e.g., inlets located in narrow horizontal bands at every floor level across the width of the façade) and are not encumbered with being linked to a dedicated distribution network in the interiors. Fan assisted systems are used in both cases, whereas in hybrid systems using natural and mechanical ventilation, the mechanical system is often used in combination with a natural system with distributed air paths.

In a maternity hospital, it is expected that pregnant women would converge in the provided indoor spaces. Natural ventilation in this case would be ideal for constant provision of fresh air for occupants. Due to convergence of people in the spaces awaiting to be attended to fresh air dilutes exhaled air and odours. The supply and exhaust air paths are expected to maintain proper indoor air quality and improve the performance of building occupants by maintaining comfortable air temperature appropriate to the needs of pregnant women, removing excess heat, pollutants and odours arising from localized sources. Medical equipment, medical procedures and various activities undertaken within a maternity hospital all at once can produce unwanted odours faster than other hospital departments. Therefore, maternity hospitals require higher rates of air exchanges as accumulation of unwanted air is compounded by the increased demand for fresh air. Local Exhaust Ventilation (LEV) is applicable for spaces such as kitchens, washrooms, administration offices and server rooms, to move heated, cooled or humidity-controlled air around a building, prevent condensation and mould growth within the building fabric, support the efficient operation of processes, remove contaminated air and provide fresh air to replace exhausted air.

If a Local Exhaust Ventilation (LEV) system is supplied as part of a strategy to control airborne contaminants hazardous to health, it is important to ensure that supplied air comes from an uncontaminated area. Design for ventilation will ensure air intakes are not sited in contaminated areas or near where contaminated discharged air is exhausted. Likewise, ensure discharge exhaust air is kept away from doors, windows and other air inlets. Where possible, it is important to ensure that air comes from a fresh source, flows past the worker and the work activity and onwards to the extraction point.

When localised exhaust ventilation system is applied as part of a strategy to control airborne contaminants found in maternity hospitals, supplied air should come from an uncontaminated source. Ventilation design for ventilation ensures air intakes are not sited in contaminated areas and also ensures they are located further away from where contaminated discharged air is expelled. Likewise, discharge exhaust air should be kept away from openings which serve as air inlets. air must always come from a fresh source, and when admitted should flow past occupants and as well as hospital equipment and out through the extraction point.

2.7 Types of mechanical Ventilation systems

Ventilation systems can be classified according to their purpose and how that purpose is fulfilled. The function could be ventilation or air-conditioning. For ventilation the method of fulfilling the purpose could be supply, extraction or both, and in the case for air-conditioning it could be using variable air volume, dual ducts, local coils, etc. for this section the study considers supply and extraction for purposes of ventilation.

2.7.1 Extract only mechanical ventilation systems:

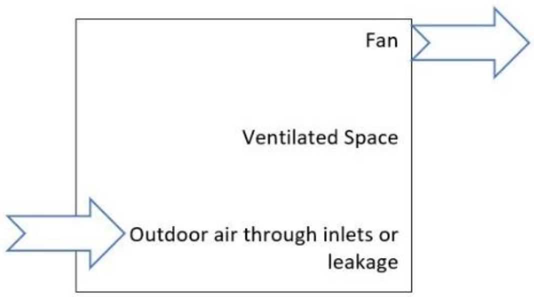


Figure 2-32: The principle of extract only ventilation system

This method extracts indoor air through ducts or using fans by creating pressure differences to occasion admittance of fresh outdoor air from uncontaminated sources. It extracts contaminants as close as possible to the source. Filters may be installed upstream within the fan to keep the ducts clean. The internal air pressure therefore being lower than the external one, the extracted air is replaced by outdoor air. The air flow path created by extract only systems should reduce the risk of creating draughts by locating air inlets closer to the location where it is required.

2.7.2 Supply only mechanical ventilation systems:

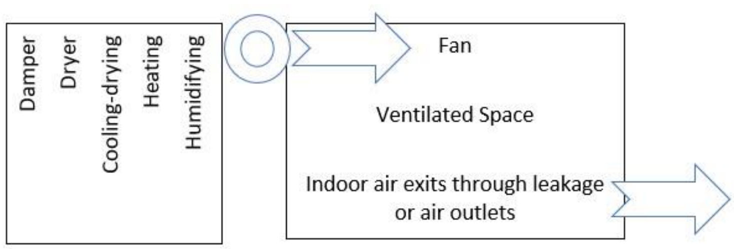


Figure 2-33: Principle of supply only mechanical ventilation system

A supply only system works by diluting indoor air by introducing fresh air into a space (Figure 8). The purpose is to introduce conditioned air into the space that needs ventilation. This air could be purified, heated, cooled, moistened or dried out. This system increases indoor air pressure forcing the indoor air to leave the space by exfiltration through the building envelope. Air outlets in designated positions may be installed to favour the desired airflow pattern.

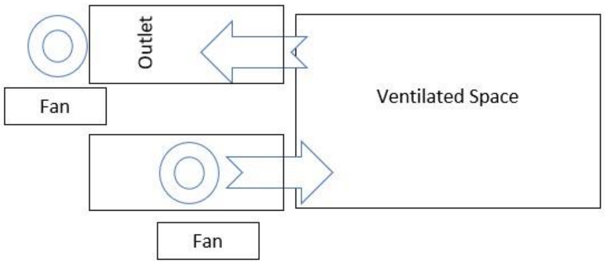


Figure 2-34: Principle of balanced mechanical system.

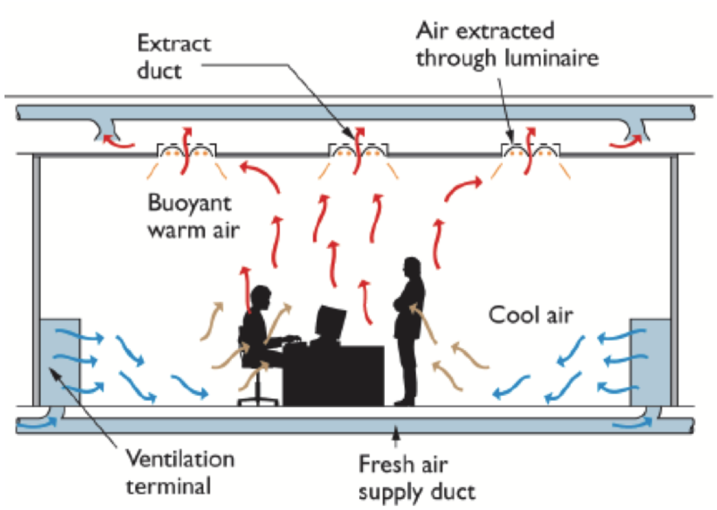


Figure 2-35 Typical air flow pattern of displacement ventilation. Source: https://www.thegreenage.co.uk/mechanical-ventilation-in-buildings/

2.7.3 Supply and extract (Balanced) Mechanical ventilation systems

A balanced mechanical ventilation system applies supply fans to admit fresh air and extractor fans to remove vitiated air. It allows for balanced indoor air pressure and improved control of airflow pattern. Ducts are used to supply air in different levels of a building, using underfloor displacement ventilation that supplies fresh air through floor mounted or low-level wall mounted ventilators within the rooms. When the internal temperature is high, fan assisted extracts work by enhancing the air movement to exhaust latent heat. These systems may also include filters to ensure a higher standard of indoor air quality, coupled with heating and/ or cooling coils. In designing using supply and extract ventilation systems, extract outlets should be distributed to avoid cold draughts. The number and size of inlets should be installed based on the recommended air changes for the room size and anticipated destiny.

2.8 Types of Natural Ventilation system

These are building components used to realize natural ventilation within a building. They encompass both strictly natural and mixed ventilation strategies. Both systems are applied through architectural possibilities including building orientation towards prevailing winds, wind towers, wind scoops, thermal chimneys, stack ventilation, atria and courtyards. Distinctions in the natural ventilation concepts can be brought about by height and shape of the building. Vertical distances between inlets and outlets are significant in utilizing thermal buoyancy for stack effect to succeed as a passive ventilation strategy. For instance, a tall building would more easily utilize a wider variety of structural ventilation shafts and principles than a low-rise building. In order to designate appropriate passive ventilation strategies, buildings can be classified by height to distinguish between high-rise buildings (more than 10 storeys), medium-rise buildings (3–6 storeys) and low-rise buildings (1–2 storeys). Spread out and linear building forms apply single-sided or cross ventilation principles, while more compact buildings use stack ventilation either by incorporating atriums or chimneys.

2.8.1 Wind scoops

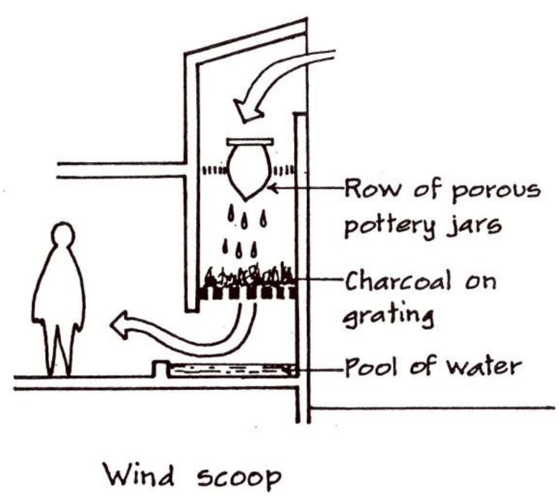


Figure 2-36: Wind Scoop (Source (A. Sealy & C. A. Architects, 1980)

The solutions to providing wind driven ventilation are often "simple", traditional forms, which if developed at an early stage of the design process can produce low energy, low maintenance buildings. Buildings are being now being designed to both capture fresh air, using wind scoops, and extract the air via wind towers. These traditional devices can be adapted and improved to provide a simple and effective means of ventilation for even the most demanding buildings. (G.S. BATTLE, 2000).

2.8.2 Building orientation with reference to prevailing winds

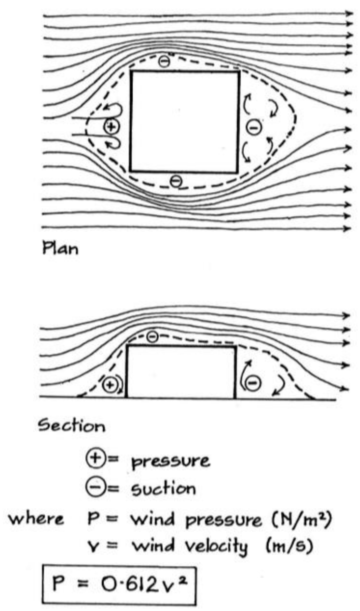


Figure 2-38: Wind pressure on buildings Source (A. Sealy & C. A. Architects, 1980)

Positioning and layout of a building to take advantage of the site climate, particularly prevailing winds promotes application of passive ventilation strategies. When building fenestrations on the wind ward side are perpendicular to the wind direction the greatest pressure on building is generated. Fenestrations may also be placed in niches created to harness wind in the event that they cannot be placed on the wind ward elevation. This makes it possible to achieve greater indoor air velocities. An angle of incidence of 45 degrees for instance reduces the wind pressure by 50%. Therefore, in order to take advantage of the wind, a study of local wind speeds should be carried out so as to orient the building to have openings facing the direction of wind. According to Givoni (1998), wind admitted through wind ward-oriented perimeter fenestrations increases the average indoor air velocity thereby providing an improved distribution of fresh air.

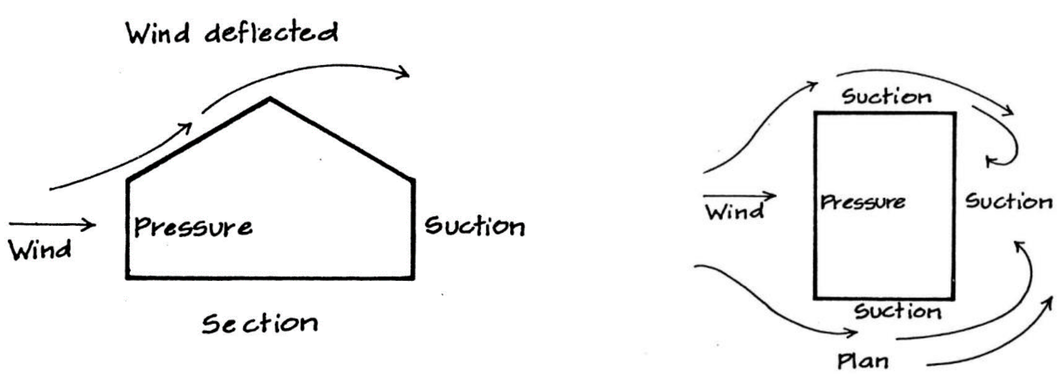


Figure 2-37: Wind pressure and suction on buildings (Plan and Section) Source (A. Sealy & C. A. Architects, 1980)

Greater wind velocity created along the windward faces creates a broader wind shadow. This leads to an increase in the negative pressure which results in increased indoor air flow. When wind strikes a building, it exerts pressure on the building. In response to the existing climatic condition in tropical climates wind pressure is responsible for air flow through buildings. Stack effect and wind pressure often act at the same time to create air movement within buildings. Wind pressure and stack effect often act together to create air movement within buildings. When wind strikes a building, it exerts pressure on the building. The pressure exerted is directly proportional to the square of the wind velocity. The slowing down of air forms a relatively stagnant mass of air on the windward face of the building. The wind is deflected above and around this mass. Stagnant air masses are formed on other surfaces of the building. The combined effect of pressure on the wind ward side and suction on the leeward side effects air flow thorough the building. Therefore, an inlet on the wind ward side and an outlet on any of the leeward sides would encourage this process. These inlets and outlets are carefully incorporated in the building enveloped.

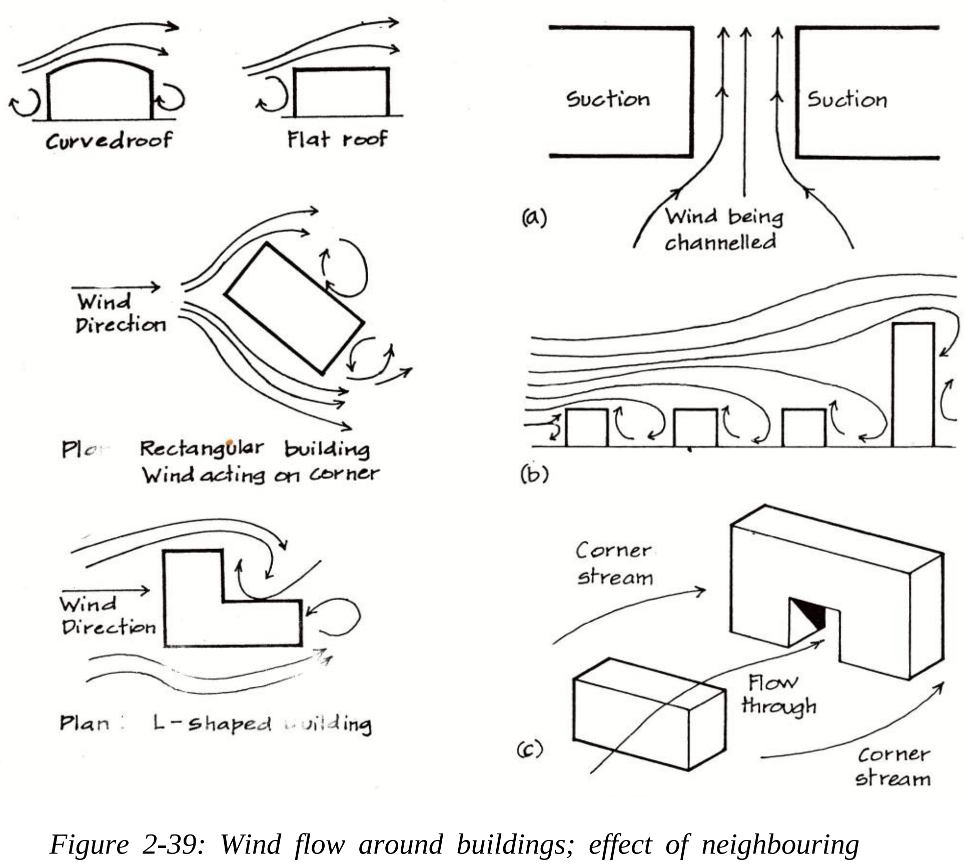


Figure 2-39: Wind flow around buildings; effect of neighbouring buildings on wind flow: a) channelling of wind; b) interaction of low and Highrise buildings and c) wind flow around buildings (Source: (Szokolay S.)

For provision of fresh air, it is documented that any and all air introduced into the building for purposes of provision of fresh air should be from an uncontaminated source to effectively determine that wind entering a building through fenestration is from an uncontaminated source the use of passive conditioning of outdoor air can be applied. (Figure 2-38). This can be done through wind breaks, reduction of dust, and natural air conditioning using wind catchers and scoops configured to include cooling and filtering elements. Building configuration is also used to create suction and wind pressure, which in turn enhances admission of fresh air and cross ventilation.

2.8.3 Wind towers

Wind towers or wind catchers are small towers installed on top of buildings to catch wind flowing at a higher level at relatively high speeds.

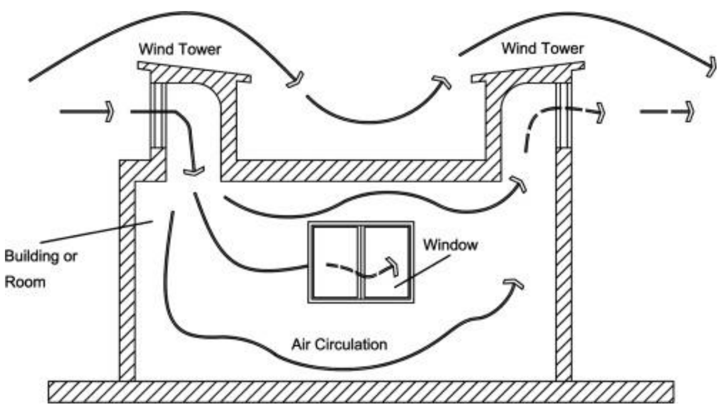


Figure 2-40: Wind tower design concept (Source: (A.R.Dehghani-sanija, M.Soltani, & Raahemifard, 2015)

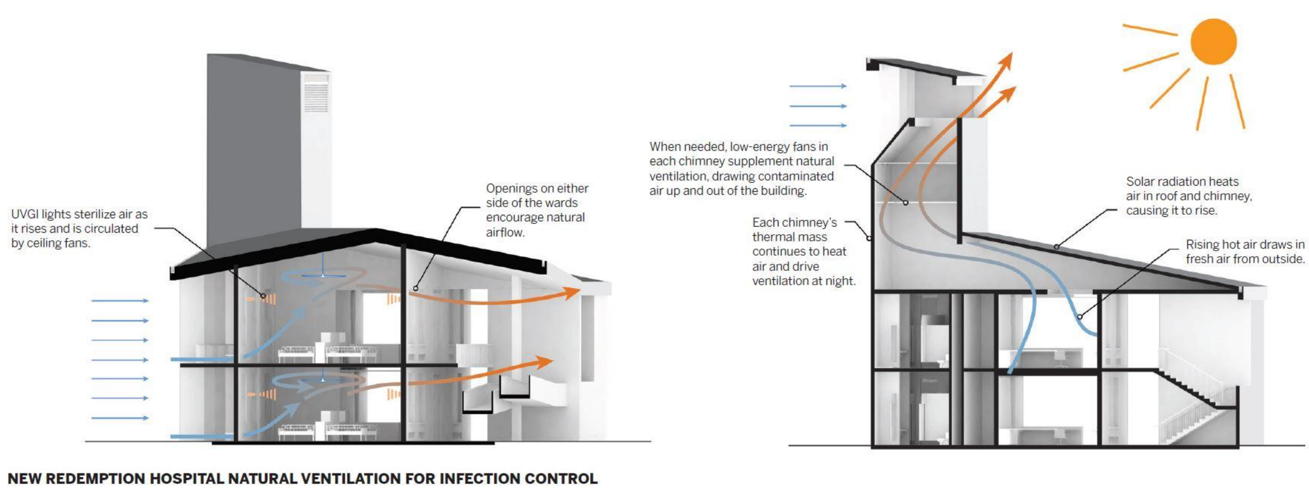


Figure 2-41: Wind tower design for New Redemption Hospital, Caldwell, by MASS Design group.

Wind towers are installed on top of the buildings, in the direction of the maximum wind speed in the region. If the desired wind speed is accessible in several directions, additional wind towers can be installed in several positions. The proposed wind towers can also have mechanised systems to allow them rotate in the direction of the highest prevailing wind speed. In the case of tropical upland climate with varying wind speeds; when the wind speed is low, a solar chimney can be installed in another part of the building in the opposite direction. to improve the efficiency of the system by occasioning air movement through temperature difference.

2.8.4 Stack ventilation

Stack ventilation depends on thermal forces and temperature differences to produce air movement towards an outlet.

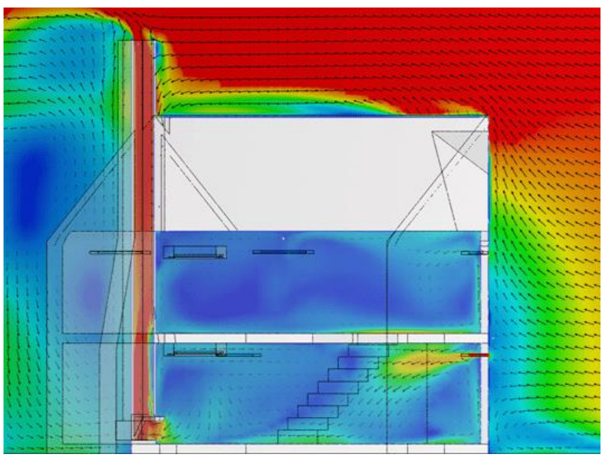


Figure 2-42: Airflow velocity through a chimney in ventilation simulation of a winter environment. This image illustrates how stack ventilation, through external and internal pressure and temperature differences, creates a natural ventilation system.

A systematic monitoring study carried out by the Building Research establishment (BRE) concluded that air-flow rates achieved in under typical weather conditions of a wind speed of 4 metres per second and a temperature difference of 10 °C ranged from 25 cubic metres per hour (m^3/h) to 75m^3 per hour. (Stephen, 1994). Stack ventilation allows a room to be self-ventilating taking in air through fenestrations in the façade and exhausting it through exhausts in the roof if higher up in the building. Air movement by stack ventilation is generated by differences in air temperature. Stack ventilation (also known as stack effect or chimney effect) creates airflow using the natural force that emerges from changes in air pressure, temperature, and density levels between corresponding internal and external environments.

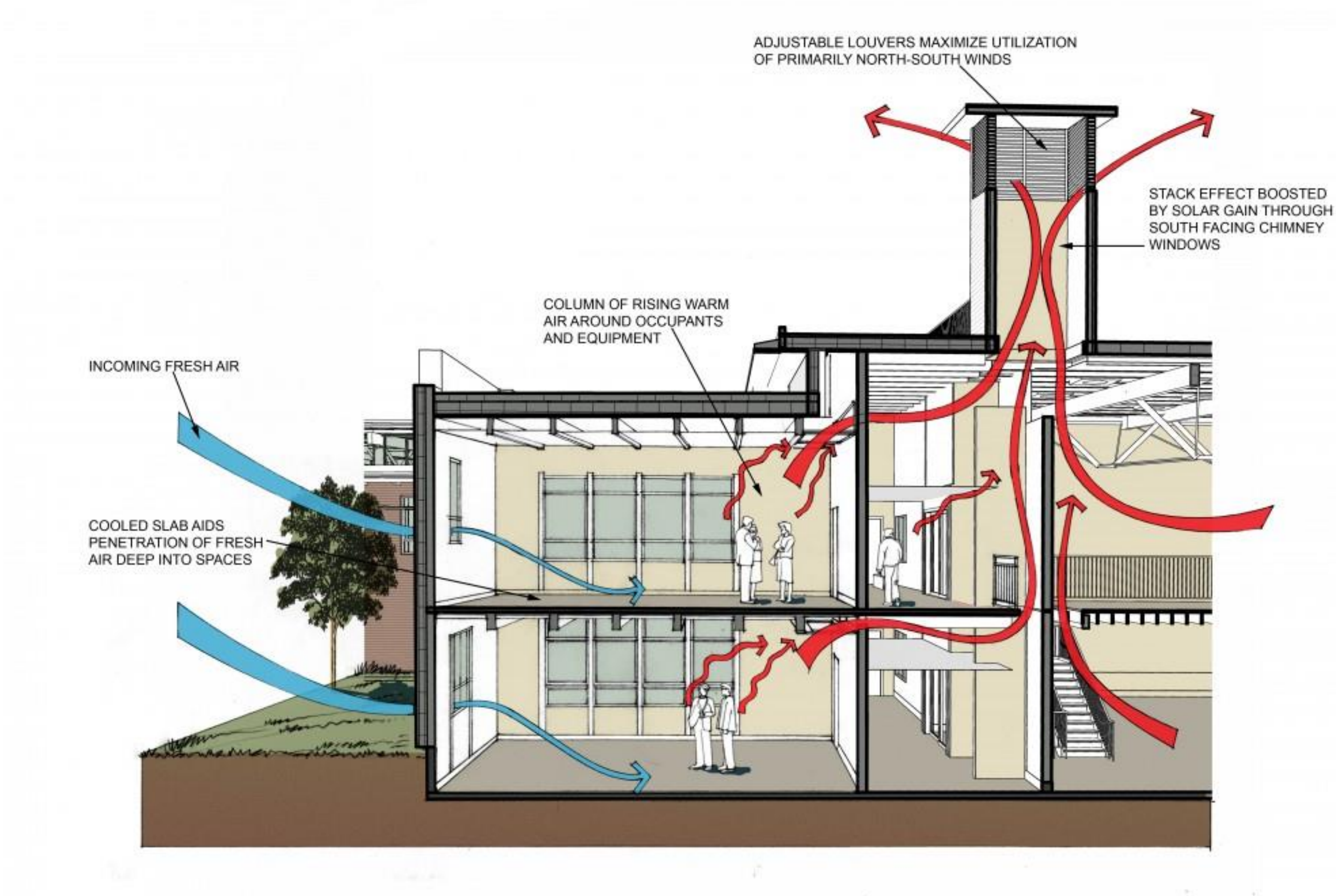


Figure 2-43: Stack ventilation model for hospital

The stack driven ventilation in fig 2-35 relies on ait temperature differences to generate air movement. In a hospital setting the heat generated by equipment and machinery within the hospital

2.8.5 Atria and courtyards

A courtyard is a space within a building, that is open to the sky. An atrium has a similar configuration to a courtyard, with a roof covering that allows day light into the space. This architectural feature is widely used to create cross ventilation and stack effect. Cross ventilation is achieved when air is admitted through the perimeter fenestrations and let out through openings facing the courtyard. An atrium supports stack effect when air flows towards the atrium from different openings in the building, and is expelled through the outlets at the top of the atrium. In this case, to improve stack effect upper floors, the atrium should be extended above the roof.

Figure 2-45: Aga Khan University hospital Courtyard

Figure 2-44: Aga Khan University hospital access to maternity hospital pavilion

The atrium functions as a powerful ventilation strategy especially when it is used for public gatherings and circulation. A study of the flow of air of 16 various forms of cavities in courtyards, proved that natural ventilation would be improved by including cavities in the surrounding walls. Furthermore, air velocity is increased significantly by locating 2 cavities in opposite locations, while the lowest velocity of airflow occurs in closed courtyards. Figures 2-32 and 2-33 illustrate an atrium and a courtyard at the Aga Khan university hospital in Nairobi. The courtyards and atria are used to control the source of outdoor air ensuring that it is clean, to admit fresh air into the facility. These create wind pressure that effects cross-ventilation and distribution of fresh air, while ensuring the air is from a controlled source.

2.9 Assessment of indoor air quality in maternity spaces

Assessment of indoor air quality in maternity hospitals entails gathering information from building walk-throughs, interviews of facility personnel, and observations of the built environment and the natural environment surrounding the building. The observations on building blueprints and schematics were summarized. The specific rooms that were studied are illustrated for clarity. mechanical and architectural floor plans blueprint are used to provide actual measurements and existing building features. An outline of the building conditions along with occupant activities is drawn from information gathered during a walk-through of the facility that includes the duration of occupancy on a daily basis and the regular building operations. Notes on the schematic layouts give clarity and direction when evaluating pollutant pathways. (Hessa-Kosa, Indoor Air Quality, 2019)

2.9.1 Assessment criteria for indoor air quality

Assessment of the quality of indoor air in a space entail gathering information from the building, facility personnel and observation of surrounding areas. During the investigation carried out for assessing the indoor air quality, certain markers were used as indicators of the composition and state of indoor air to help make conclusions on the indoor conditions. The observations and information collected are summarized using the buildings schematic drawings, the available mechanical schematics, photographs and sketches. The observation exercise is guided by the following parameters which help to make architectural critique for indoor air quality in a space:

a) Condition of supply air handling units
b) Plumbing inconsistencies
c) Ventilation inconsistencies such as closed air supply vents or redirected air flow channels
d) Implicit responses to perceived air quality such as air purifiers and pedestal fans)
e) Chemical storage
f) Position and type of appliance that may contribute to air contamination (e.g., copy machine)
g) water-damaged ceilings, soffits or tiles
h) Lifting or poorly adhered floor tiles and sheet vinyl
i) Flaking paint
j) Rust on metal structural components such as window frames)
k) Stains on flooring
l) Location of lifts and staircases that may influence air movement

(Hessa-Kosa, Indoor Air Quality, 2019)

Identification and observation of these factors guides the selection of research methodologies and informs the observer on evident signs of poor indoor air quality and their mitigation measures.

2.10 Summary of literature review

The literature review set out achieve the objective of outlining the factors that affect indoor air quality in maternity hospitals and to establish passive ventilation approaches of provision of fresh air as outlined in chapter one.

1. Establish the factors affecting indoor air quality in maternity hospital facilities.

The factors that influence the quality of air in a maternity facility include design features, human activities, facility management features and activities such as ventilation systems, cleaning and disinfecting activities, and outdoor air and microclimatic factors. Human activities generate heat and odours which accumulate within spaces. The review of self-reported symptoms from patients showed that higher volumes of oxygen are required to be admitted into the spaces to curb the need for more oxygen due to an increase in tidal volume in patients. Maternal hyperventilation therefore necessitates a higher air change rate to avert discomfort. A higher air change rate would translate into frequent replacement of old air with fresh out door air. Using passive ventilation strategies, the old and used air is diluted and expunged from the indoor spaces using mixing ventilation and displacement ventilation. It is recommended to apply assisted stack ventilation to occasion movement of air using ventilation cowls based on buoyancy of warm air.

2. To establish approaches of provision of fresh air using passive ventilation in maternal hospital in the Nairobi tropical Upland climate.

From the literature, displacement ventilation and mixing ventilation are recommended as methods of providing fresh air. These are achieved through stack ventilation, orientation of buildings in the direction of prevailing winds, courtyards and atria and use of vegetation to condition outdoor air for freshness. It is also hypothesised that natural personalised ventilation would assist to curb symptoms of discomfort for pregnant women. To achieve this both mechanical and passive ventilation are used to occasion air movement and determine the flow pattern when outlets are located in designated positions to favour the desired flow direction and distribution. Extract only mechanical system can be used together with wind scoops and stack ventilation to create an upward motion of warm air for extraction at the top of a building. Orientation, window position, opening features and atriums and courtyards aid in cross-ventilation.

Wind towers and vegetation are applied when prevailing winds

2.10.1 Parameters for optimal provision of fresh air through passive ventilation

Table 2-7: Building level parameters for provision of fresh air using passive ventilation

PARAMETER	CONSIDERATIONS
Position of opening	Room level configuration; low level inlets and high level
Window opening components	Louvres or shading devises that can affect flow of wind into the space.
Orientation of openings or building	Towards prevailing winds at acceptable admission angles. Suction and channelling of wind.
Configuration of passive ventilation system	Wind scoop, wind catcher, atria, courtyards, stack ventilation, use of ducted natural ventilation through supply and extract systems
Source control	Using vegetation at low level or high-level wind catchers

2.11 Theoretical framework

The struggle for natural ventilation in hospital environments is ever increasing, with major contradistinctions arising when deep plan layouts and supplemented with highly mechanized air conditioning systems for provision of fresh air. Provision of fresh air as a factor affecting indoor air quality has been identified in literature as a feature that can be attributed to natural ventilation. Common parameters are highlighted in the literature, that can be attributed to provision of fresh air through natural ventilation for optimal indoor air quality.

Table 2-8: parameters associated with features of natural ventilation systems

	Factor	**Parameters**
1.	**Natural ventilation**	Position of opening, size of opening, window components, orientation of openings, conditions of air handling units
2.	**Fresh Air contribution to indoor air quality**	Clean source, air velocity, exhaust of used air, air changes per unit time.

The characteristics of a ventilation system can be attributed to there being fresh air at all times within a space. By considering these parameters, the factors affecting natural ventilation for the provision of fresh air are identified as follows:

1. **Window opening components** – these include size, shape and physical characteristics of the window
2. **Assisted natural ventilation** – the use of ducted natural ventilation and air handling units
3. **Source control** – addresses the possible control of the source of outdoor air to ensure that outdoor air admitted into a building is clean

Selection of methodologies are then guided by considering these variables. The study of each is assigned an appropriate methodology to capture the phenomenon under study and to draw out information to be used in answering the research questions.

2.12 Conceptual Framework

It is generally accepted that the freshness if indoor air has a direct impact on the health and wellbeing of users. The maternity hospital is one such building where fresh air is of paramount importance for patients and hospital staff. Exposure to poor quality indoor air triggers several health issues, which if not addressed can lead to catastrophic consequences. The varying physiological conditions of pregnant mothers exhibit symptoms of discomfort that can be alleviated by fresh air. Outdoor air being generally cleaner than indoor air is the primary source of fresh air for hospital environments. The design of fenestrations is expected to address the issue of provision of fresh air and exhaust of used air for optimal indoor air quality. Ventilation design has significant influence on the air admittance, direction of flow, distribution, indoor air velocity and exhaust of used air. These theories provide the basis for both development of new practices that can be collated to design ventilation systems that perform optimally towards indoor air environment as well as evaluation of existing ventilation systems with the objectives of recommending improvements. The literature on hospital environments forms the underpinning theories for determining the features of building fenestrations and air inlets that facilitate comfortable indoor air quality and how they can be applied in maternity hospital design.

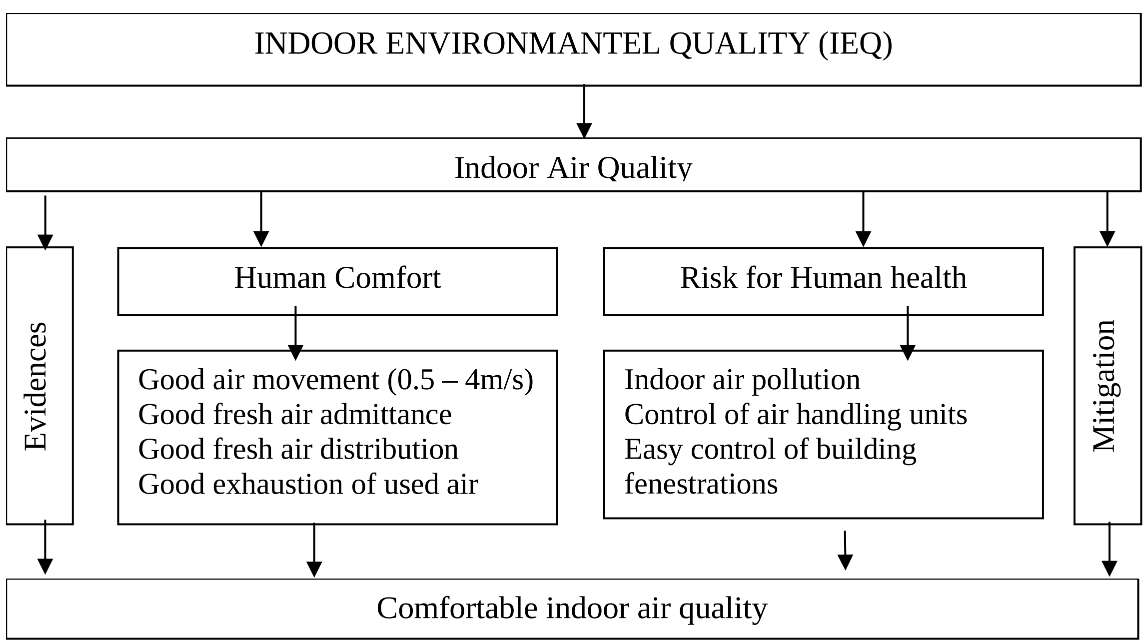


Figure 2-46: Conceptual framework of the potential of ventilation design for indoor air quality in maternity hospitals.

3 CHAPTER 3: RESEARCH METHODOLOGY

3.0 Introduction

This chapter outlines the methods used answer the research questions and achieve the research objectives. Ranjit Kumar defines research as a technique used to find answers to questions. Using research to find answers to questions implies that the process being applied is being undertaken within a framework of a set of philosophies; uses procedures, methods and techniques that have been tested for their validity and reliability; and is designed to be unbiased and objective. (Kumar, 2011). The philosophical orientation of this research is from an architecture background, seeking to find answers applicable in the built environment. The concept of 'validity' is applied to any aspect of the research process. It ensures that correct procedure have been applied in a research study to find answers to an interrogation. 'Reliability' refers to the quality of a measurement procedure that provides replicability and accuracy. 'Unbiased and objective' means that you have taken each step in an impartial manner. (Kumar, 2011). The basis on which the problem was identified and how the objectives were defined to find solutions is outlined in this section. Table 3-1 highlights the approach taken to achieve the specific objectives outlined.

Table 3-1: A summary of the research methodology approaches used to achieve the outlined research objectives.

Research Objectives	Methodology objectives	Specific research approach
1 Establish the existing architectural natural ventilation strategies in maternity facilities	Document the existing passive ventilation methods applied in various maternity facilities. Explain the techniques that will exhibit the types of windows, opening features and ducted ventilation inputs identified in the case study.	Observation Note taking Interviews Photographs, drawings and sketches.

2 To investigate how effective the natural ventilation strategies are in selected maternity healthcare facilities	Determine comparative techniques that will evaluate the existing ventilation strategies. Explain how the data collected showing the effectiveness of existing strategies on indoor air quality is documented.	Observation, measurements and tests Explanatory data analysis
3 Propose passive ventilation strategies for supply of fresh air in maternity hospitals in the Nairobi tropical climate.	Explain the application of predicting expected air change rates for specific indoor spaces, from the conceptual and theoretical framework in optimizing indoor air quality in maternity spaces.	Structured calculations based on room volume and volume of outdoor air admitted per unit time.

2.1 Research Design

This study is designed to include quantitative and qualitative research of indoor air quality in maternity hospitals and an explanatory case study research for the same. According to Ranjit Kumar 2001, explanatory research attempts to clarify why and how there is a relationship between two aspects of a situation or phenomenon. (Kumar, 2011). It also includes case study research approach which represents a much broader view. It means conducting an empirical investigation of a contemporary phenomenon within its natural context using multiple sources of evidence (Yin, 2003). The research identified its importance, established operational definitions for clarity within the study, and exemplifies discovery and understanding of ideas and responses.

This research identifies indoor air quality parameters, ventilation parameters relating to fresh air in maternity spaces with a view to compare the performance of existing ventilation conditions with optimal indoor air quality for human comfort in these spaces. It examines the self-reported symptoms of discomfort associated with inadequate fresh air, obtained from interviews of users in the selected facilities.

2.2 Research Strategy

The research strategy defines the method used to find answers to the research questions validly, objectively, accurately and economically. (Kumar, 2011). Hancock and Algozzine propose an organizing framework that classifies research as qualitative or quantitative stating that quantitative research use numbers, normally in the form of statistics, to explain phenomena. Qualitative researchers, however, use words to describe trends or patterns in research settings. (Hancock & Algozzine, 2006). The research will adopt three steps as follows:

a) finding out what is existing

   finding out the characteristics of fenestrations used to admit fresh air into the selected maternity hospitals; Kenyatta National Hospital and Nairobi hospital. Finding out the existing immediate external environmental that may affect the quality of outdoor air admitted into the building. These will be documented and classified according to shape, size, opening components and external environment. The existing windows and internal conditions will be critiqued to find out the performance towards indoor air comfort.

b) finding out what is lacking

   determine the architectural interventions of opening orientation, size, geometry, components and location that can be made to improve indoor air quality. The variable of indoor air change rate and velocity will be read against the variables of window properties.

c) making recommendations to mitigate the effects of poor indoor air quality

   following the results obtained, appropriate recommendations will be made to offer design guidelines for professionals in the building industry and facility stakeholders on what would be optimal method of provision of fresh air in a maternity hospital.

The data collected in this research is both qualitative and quantitative data. Qualitative data will be obtained from interviews with facility personnel and observation of the case study areas in question. Quantitative data will be obtained through measurements of existing building features and from the building's blue prints and mechanical layouts of the facilities. Primary data will be obtained from local case studies and secondary data from desktop studies of international case studies.

The study will examine selected maternity facilities in Nairobi and take measurements of factors affecting indoor air quality. It will compare and contrast the existing conditions with the established recommendation for indoor air quality. It will then determine methods of improving the indoor air quality by considering the air flow rate vis a vis prevailing wind speeds, indoor air velocity, source control, filtration and exhaust.

2.3 Unit of analysis

The unit of analysis in architectural research is the element that is being studied (Rukwaro, 2016). For this study the unit of analysis is the maternity hospital. It is defined as a hospital facility for maternal healthcare with a maximum capacity of 120 beds. The study examined maternity facilities as a separate entity exclusive for maternity care or as a wing within a larger hospital scheme. The case studies will study the window design and orientation and its effect on admittance of fresh air and exhaust of used air. The study took a hospital unit with similar defined spatial requirements, and studied the source of fresh air, supply of fresh air, distribution within the various rooms, the flow pattern of air from the inlet through to the outlet and mechanical and ducted ventilation. An analysis of the internal spatial configuration and partition details that allow or obstruct infiltration of air from one space to the next.

2.4 Case study selection criteria

Ventilation standards provide a guide for room ventilation rates for indoor spaces which satisfy comfort and health requirements by creating suitable indoor air quality. Standards define acceptable indoor air quality and necessitate that air is free from hazardous levels of contaminants and be judged as satisfactory by most occupants (Hedge, 1996). The case studies recorded in this research were selected based on the availability of building data, access to the building premises, and time within which the research was carried out.

In this research, a cross-sectional survey of the built environment of maternity facilities and their ventilation as case studies are documented. They are examined in a descriptive research design to facilitate measurement and descriptions of findings. The selected case studies provide reliable information on existing natural ventilation methods. The information obtained can be analysed to give an indication on how the desired specific indoor air quality can be achieved through natural ventilation. The case studies include multiple sources of evidence which makes it possible to examine different approaches to natural ventilation in similar tropical climates. The case study method in this research allows causal links between natural ventilation and alleviating some of the identified specific challenges experienced by expectant mothers, to be identified and explained. The different case studies give insight on further challenges experienced by pregnant mothers that can be addressed by the built environment indoor air quality. The case studies are selected through purposeful sampling and therefore exemplify the problem under study.

2.5 Data collection methods

According to (Bluyssen, et al., 1996), for purposes of assessing indoor air quality, the assessment of the ventilation performance of a building, can be defined in terms of the following parameters: total rate of supply achieved by the ventilation system; total exhaust rate of the ventilation system; recirculation fraction of supply air; exfiltration and infiltration rates. In investigation of physical and chemical measurements in spaces includes measurement of CO, CO2 and TVOC (total volatile organic compounds and assessment of perceived air quality by users. For evaluating retrospective and immediate symptoms and perceptions were evaluated using a questionnaire given to the occupants of the buildings (Bluyssen, et al., 1996). Following this method, the airflow parameters to be considered for each selected room include the following: air supplied by the ventilation system; infiltration through the building envelope; and air coming from adjacent rooms. The following checklist was consequently developed to capture ventilation measurements for the local case study investigations

1. ventilation rate — the amount of fresh air that is admitted into a space per unit time; air changes per hour (ACH)
2. airflow direction — the overall direction of air flow in the building; and
3. air distribution or airflow pattern — the distribution of fresh air from the clean outdoors source, through to other interior rooms or out through opposite outlets. Observance of the position of openings and outlets to see their effect on the air flow pattern

The research examines how these aspects of indoor air quality are affected by window Orientation, number of openings, size of openings and position of openings.

2.5.1 Observation

This method was used to record visual data on the aspects of ventilation in the built environment of hospital buildings. A predetermined checklist was used to identify the relevant architectural elements required for this study. Unobtrusive observation technique was used to identify and record, the use and response to ventilation in the space. The data collected was recorded in written notes, sketches and photographs. Observation helped to determine the application of natural ventilation in the existing spaces, the means of controlling admittance of outdoor air and the effectiveness of structural non-energized means as a ventilation strategy. Observation was carried out on two levels: observing the building orientation according to prevailing wind direction and the fenestrations and duct systems installed to effect ventilation within the spaces. In the first level of observation the building layout and orientation is examined. The response of the building configuration to the wind directions given for its specific region is observed and recorded.

In the second level the location, size, features and number of air inlets and outlets is observed and recorded. The second level of observation takes into account further natural ventilation strategies that may include mechanical fittings, ducting systems or retrofitted installations.

Observation findings are recorded in terms of orientation, number, size and position of opening. These features of the building used to admit air into the building are examined to establish their influence on the ventilation rate, the direction of air flow the distribution of air and the effects of

2.5.2 Note taking

Descriptive notes were taken to document qualitative information on the qualities and building characteristics observed. They were used to provide qualitative description and understanding of the features observed and described by respondents. Written record of building ventilation characteristics, responses from interviewees, measurements,

2.5.3 Photographic recording

Photographs were taken to substantiate the verbal responses of the respondents and findings of this study. They were taken at the time the respondents were taking the interviews. The photo graphs focus on building fenestrations, mechanical ventilation inlets and outlets and interior spaces where access was granted.

2.5.4 Actual measurements

This method involves wind speed logging. Zephyrus digital windmeter application was used to log the prevailing external wind speed vis a vis the internal air velocity at a given time to investigate the effect of the fenestration components, orientation and positioning at room level on indoor air velocity. Measurements of window sizes and sill heights were taken using measuring tape. Separate measurement for the ward spaces, nurses' station, consultation room and waiting rooms were taking.

Figure 3-1 A tape measure used to measure sizes of indoor spaces, windows sill heights and window opening dimensions.

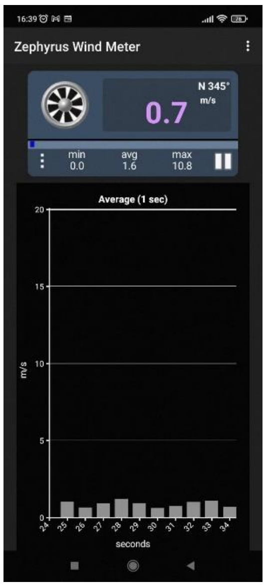
Figure 3-2 Zephyrus Pro Anemometer

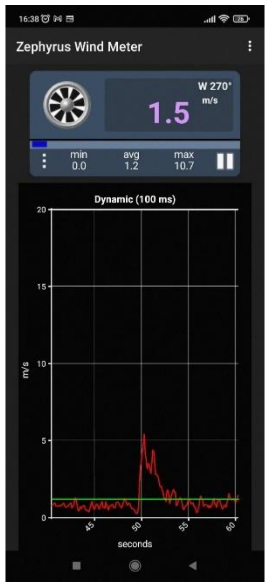
An anemometer was used to record internal and external wind speeds in selected spaces. The results obtained are compared and rated against the Chartered Institute of Building Services Engineers and European norms on ventilation design for hospitals established in chapter two.

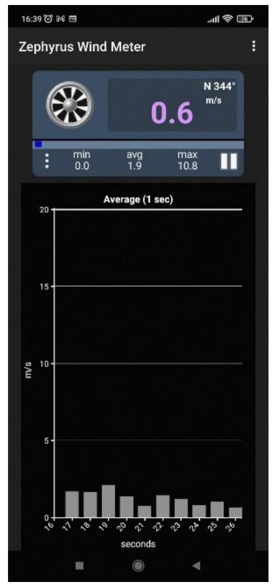
The wind meter is used to record dynamic winds speeds per second, as well as average wind speeds.

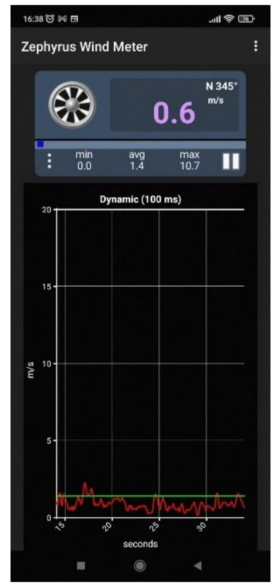
Table 3-2: (Below) Indoor air velocity measurements and corresponding outdoor air velocity measurements. (Source: Author using Zephyrus Wind meter digital wind meter, at Aga Khan University Hospital (AKUH). The record taken include gushes of wind that occur when the window is opened or when internal doors are opened.

Consultation room

<table>
<tr><td colspan="2">Indoor air velocity</td><td colspan="2">Corresponding outdoor air velocity</td></tr>
<tr>
<td>

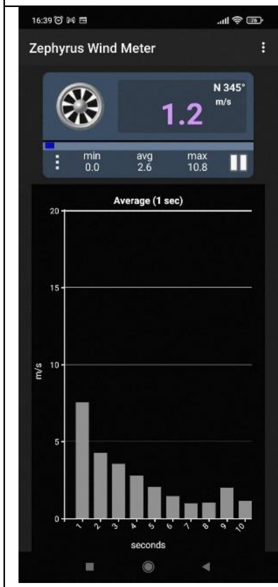
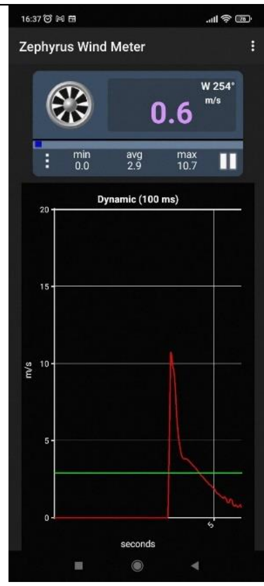
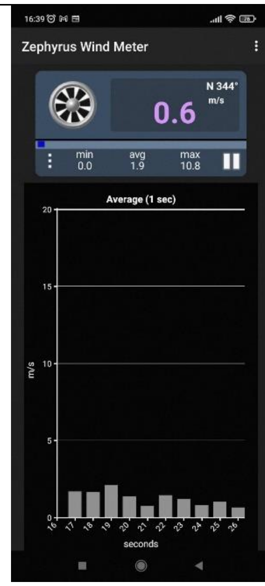
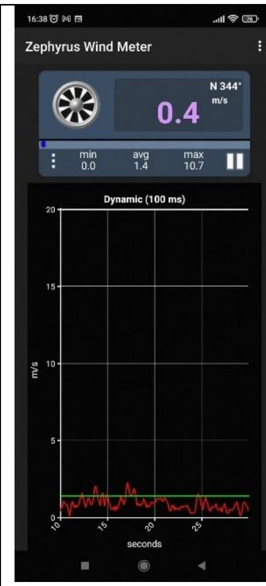
Average air velocity</td>
<td>

Dynamic air velocity</td>
<td>

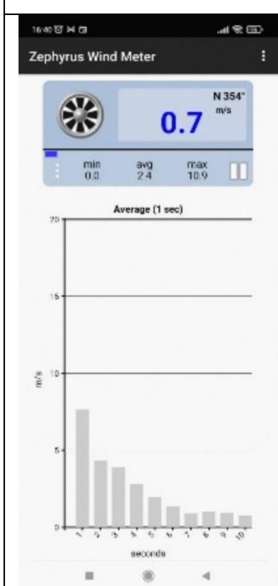
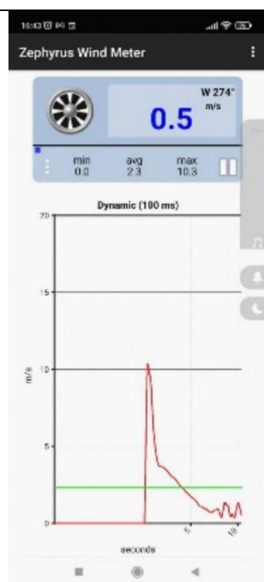
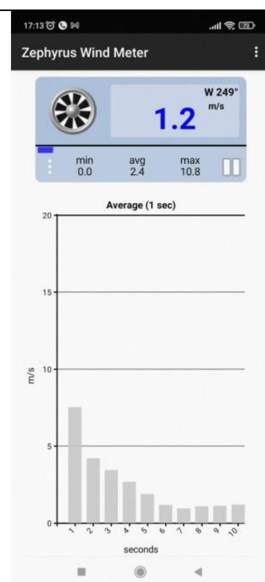
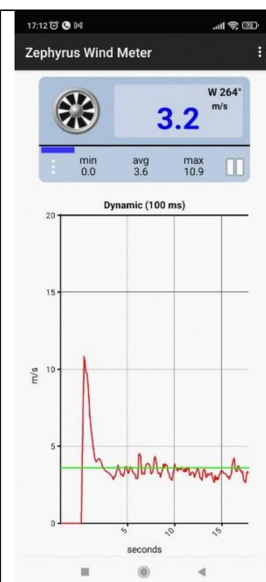
Average air velocity</td>
<td>

Dynamic air velocity</td>
</tr>
</table>

Ward rooms (Shared)

Indoor air velocity		Corresponding outdoor air velocity	
			
Average air velocity	Dynamic air velocity	Average air velocity	Dynamic air velocity

Single ward room

Indoor air velocity		Corresponding outdoor air velocity	
			
Average air velocity	Dynamic air velocity	Average air velocity	Dynamic air velocity

Nurses station

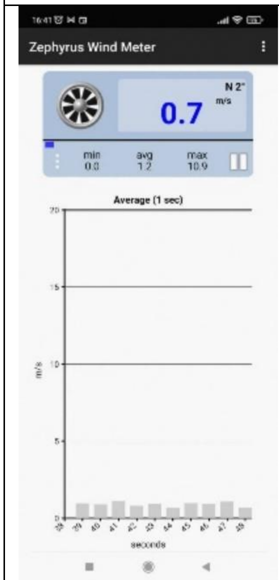
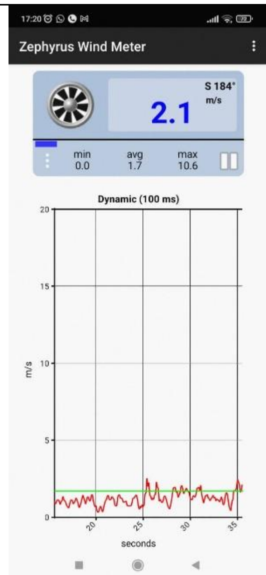
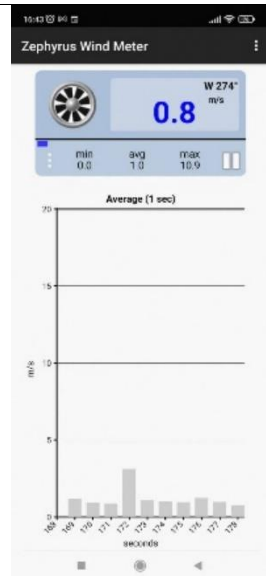
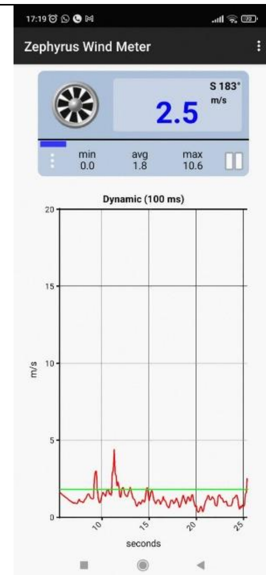
Indoor air velocity		Corresponding outdoor air velocity	
			
Average air velocity	Dynamic air velocity	Average air velocity	Dynamic air velocity

Table 3-3 Distribution of direction of prevailing winds

N **Northern**	**NE** **North Eastern**	**E** **Eastern**	**SE** **South Eastern**	**S** **Southern**	**S** **Southwestern**	**W** **Western**	**NW** **North Western**
4.8%	33%	35%	14.4%	9.1%	2.5%	0.8%	0.4%

Figure 1-6 shows the established wind rose for the Nairobi tropic climate. This was used to gauge the significance of room orientation on how much wind could be used for admittances of fresh air.

The City of Nairobi is located at longitude 36 50' E mid 1 18' S. The mean altitude is around 1,700 meters above the mean sea level but as the city has a highly variable topography, this height ranges from l,600m (to the East) to over 1,800 (to the West and Northwest of the Central Business District

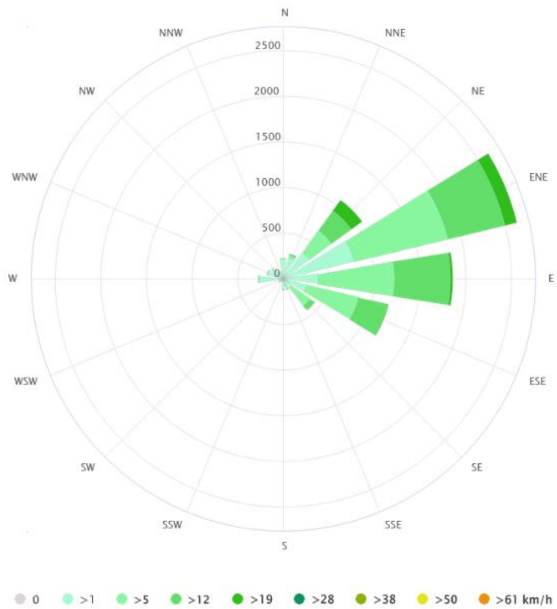


Figure 3-3 Nairobi Wind rose. Source: (Meteoblue, 2006-2022)

(CBD). The prevailing winds have a strong Easterly component. The North easterly winds prevail during the northern winter while the southeasterlies are dominant during the southern winter. Computed frequency wind roses show that the surface winds at the city of Nairobi have a high frequency of easterly flow for all months of the year. However, some westerlies are observed during the period June, July and August which are associated with the high-pressure ridge that prevails over East Africa during the period. During this period, the winds are also observed to be more variable both in speed and direction. There is also large diurnal variability with the day-time winds being highly constant in direction than is the case with night-time conditions. (Department of Meteorology, University of Nairobi, 1992)

2.5.5 Structured interviews

From the exploration of selected existing maternity facilities in Nairobi there seems to be far less attention given to indoor air quality in maternity hospitals in the City of Nairobi. Extensive use of mechanical ventilation is observed to mitigate the symptoms of discomfort experienced due to lack of fresh air. Evidences of absence of fresh air are clear indicators that much still require to be done to address the issue of poor indoor air quality. Despite the average wind velocities of 12kph in Nairobi at an altitude of 1700-1800m above sea level, minimal fresh air finds its way into the various spaces that comprise a maternity. In a study on Comfort and health of patients and staff, linked to the physical environment of various departments in hospitals, Bluyssen and Eijekelenboom postulate that occurrence of headaches was associated with room layout, visual aspects (presence of a window to the façade and corridor, presence of a window to the facade, control of the view) and the thermal environment. The strongest association (p value <0.001, OR >2.0) was the presence of a window to the façade and corridor (in comparison to no window). (Eijekelnboom & Bluyssen, 2019).

During the pilot study carried out for this research, the established indoor environment quality markers and building related features were observed against the prevailing winds, with a view of harnessing wind for admittance of fresh air into the building. Health and comfort complaints were recorded to indicate user dissatisfaction. These are recorded in table (Figure 1-7) which relates stuffiness and presence of odours with the fenestrations allowing fresh outdoor air into the building. Ventilation measurements were taken to correspond with the period of time during which the health and comfort complaints were recorded. This consisted of ventilation flow rates for each of the rooms selected, examined under the headings of supply of air by the existing ventilation system, air supply through the building envelope and air distribution within the rooms and from room to room. (Figure 1-8). To achieve more accurate outcomes, basic principles of ventilation were held constant as far as possible. Lastly, physical measurements and characteristics of the rooms were taken to produce high quality outcomes that could be used to draw conclusions and recommendations for further study. The physical measurements and characteristics include room dimensions, room orientation and spatial relationships of the different rooms that constitute the maternity hospital or department.

(Figure 1-9).

Freshness sensation: [Stuffy 0 – 1 – 2 – 3 – 4 – 5 – 6 Fresh]

Stuffiness index: [Stuffy 0 – 1 – 2 – 3 – 4 – 5 – 6 Fresh]

Prescence of odours: [Unwanted odour 0 – 1 – 2 – 3 – 4 – 5 – 6 Odour free]

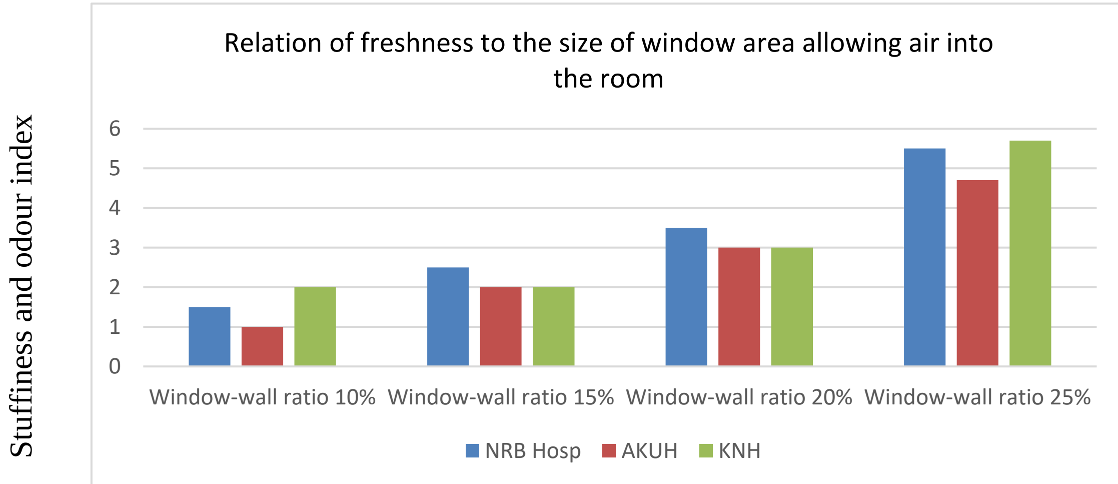


Figure 3-3-4 Relation of freshness to the size of window area allowing air into the room

Structured interviews were carried out with different respondents including, doctors, nurses, and technical staff. The respondents were requested to make judgements according to their experience in the subject spaces. The Likert scale was used by the respondents to express their responses. The responses were collected and used to quantify the results. The application of each method of data collection is determined by the respondents to be interviewed for instance some respondents preferred to fill in the questionnaire while others preferred to discuss in an in-depth interview so as to give more of their sentiments.

3 CHAPTER 4: DATA COLLECTION AND ANALYSIS

This chapter presents the existing ventilation strategies of the selected cases. The effectiveness of these strategies is measured based on indoor air velocity measured and the air change rates. Prevailing winds at the time of measurement are recorded and compared with internal air velocity using wind admitted by fenestrations in the perimeter of the buildings. The recordings are linked to physical architectural characteristics of the buildings with a view of finding the effectiveness of the buildings external/façade openings in providing adequate fresh air and its contribution to indoor air quality and comfort. Calculations for air change rates of selected rooms were carried out and compared to the established and recommended air changes for maternity hospitals. Interviews carried out during this study recorded accounts of interviewees who expressed discomfort from having experienced a stuffy warm room. The case studies were selected based on the availability of building data, access to the building premises, and time within which the research was carried out. The research objectives were used to guide the data collection and analysis as follows:

Objective 1: Establish the existing natural ventilation strategies in maternity hospitals.

Objective 2: Investigate the efficiency of passive ventilation strategies in selected maternity hospitals.

Objective 3: Propose passive ventilation strategies for supply of fresh air in maternity hospitals.

The respective data analysis objectives derived from the above are as follows:

Objective 1: identify and document the existing architectural natural ventilation strategies in the selected maternity facilities.

Objective 2: record measured external wind speeds and corresponding indoor air velocity to gauge the supply of fresh air and exhaust of used air with a view to establish the effectiveness of existing ventilation strategies and attribute it to the characteristics of the air inlets and outlets. Calculating air change rates for selected patient rooms to check whether they fall within the recommended

Objective 3: describe workable ventilation strategies from review of existing methods with a view to propose design standards that can be adopted by building practitioners for maternity hospital ventilation design.

4.1 CASE STUDIES

4.1.1 Case study 1: Kenyatta National Hospital Maternity Wing

Data and measurements taken for this study addressed source of fresh air, Admission of fresh air into the building, distribution of air within the various rooms, comfort described by users and expulsion of used air from the interior. The measurements taken give the sizes of openings, position of openings, indoor air speed vis a vis outdoor air speed. The photographs taken are limited to spaces with permission granted by the administration.

Calculation of air changes per hour were done for the shared ward room to establish whether they meet the required standard. These were guided by ASHRAE Standard 170-2013 and the CIBSE Guidelines which indicate that patient rooms must have a minimum of 6 air changes/hr (ACH) of fresh air ventilation and 4 ACH of total air movement. Class B operating rooms must have 6 or 9 ACH, depending on room type, of fresh air ventilation, and 20 ACH of total air movement. (Stipe, 2016).

Table 4-1: Record of internal wind speeds, area of window opening and cross ventilation.at the Kenyatta National Hospital

Room designation	**Room volume (m^3)**	**Internal wind speed average (m/s)**	**Surface area of window opening (m^2)**	**Cross ventilation**
Nurse's station	35.7	4		No
Shared ward with 6 beds	72.45	3	6.0	Yes
Doctors' consultation room	45	1	1.0	No
Matrons' office	31.5	1	1.6	Yes
Hallway	145.8	3	1	Yes

Assessment of Natural Ventilation at Kenyatta National Hospital (KNH)

Figure 3-2: Kenyatta National Hospital Atrium adjacent to Maternity Wing (Source Author)

Figure 3-1: Kenyatta National Hospital Walkway adjacent to Maternity Wing (Source Author)

- Sliding windows at shared ward section. Operable area is 1m x 1m.
- Window sill height is 1100mm from internal floor finish level.
- Vegetation cover is observed right outside fenestrations.
- Courtyards with narrow plan floor plates
- Sliding windows, louver windows and pivot hung windows

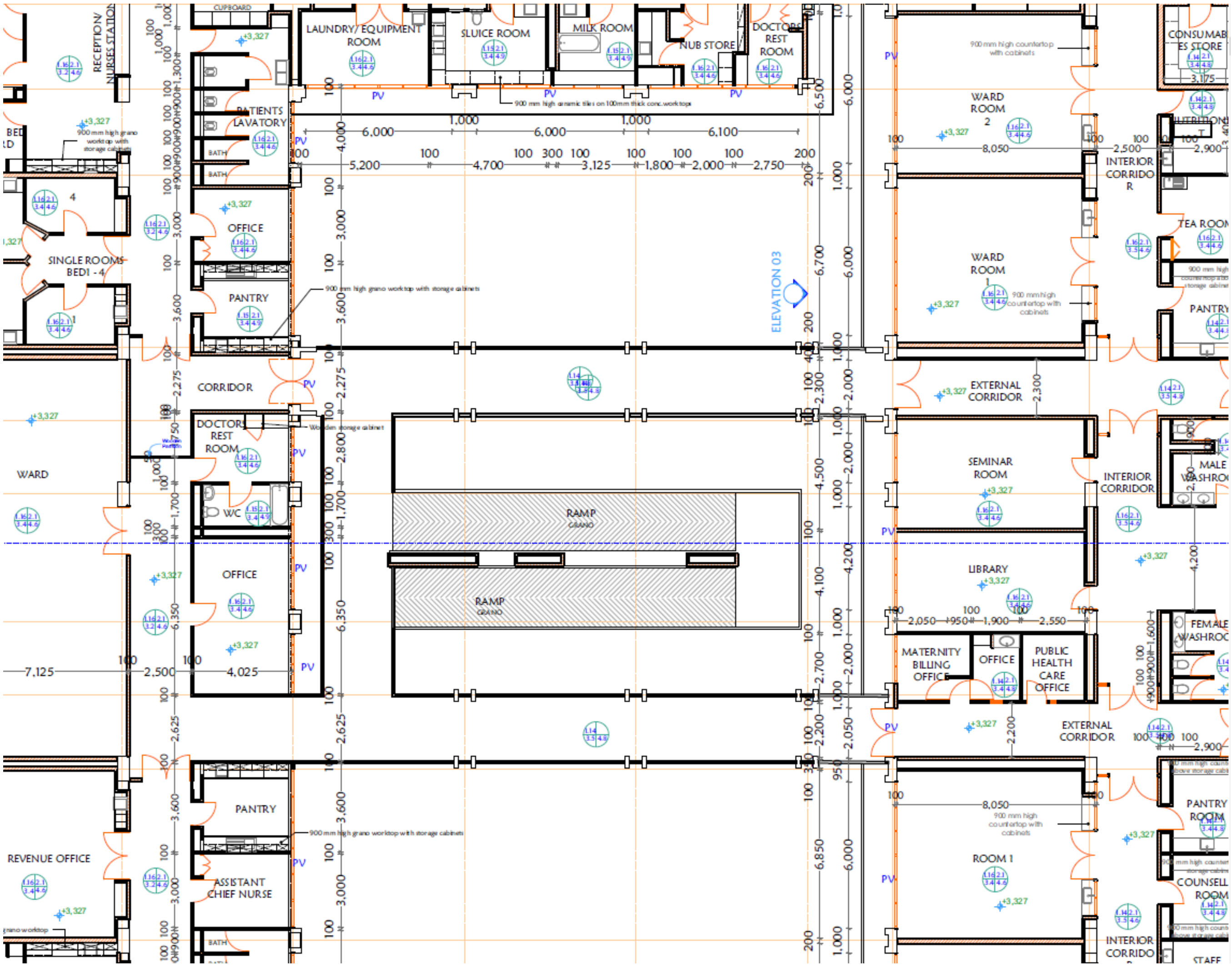


Figure 3-3: Maternity wing architectural layout. (Source: Architectural drawings given by KHN property manager's office.)

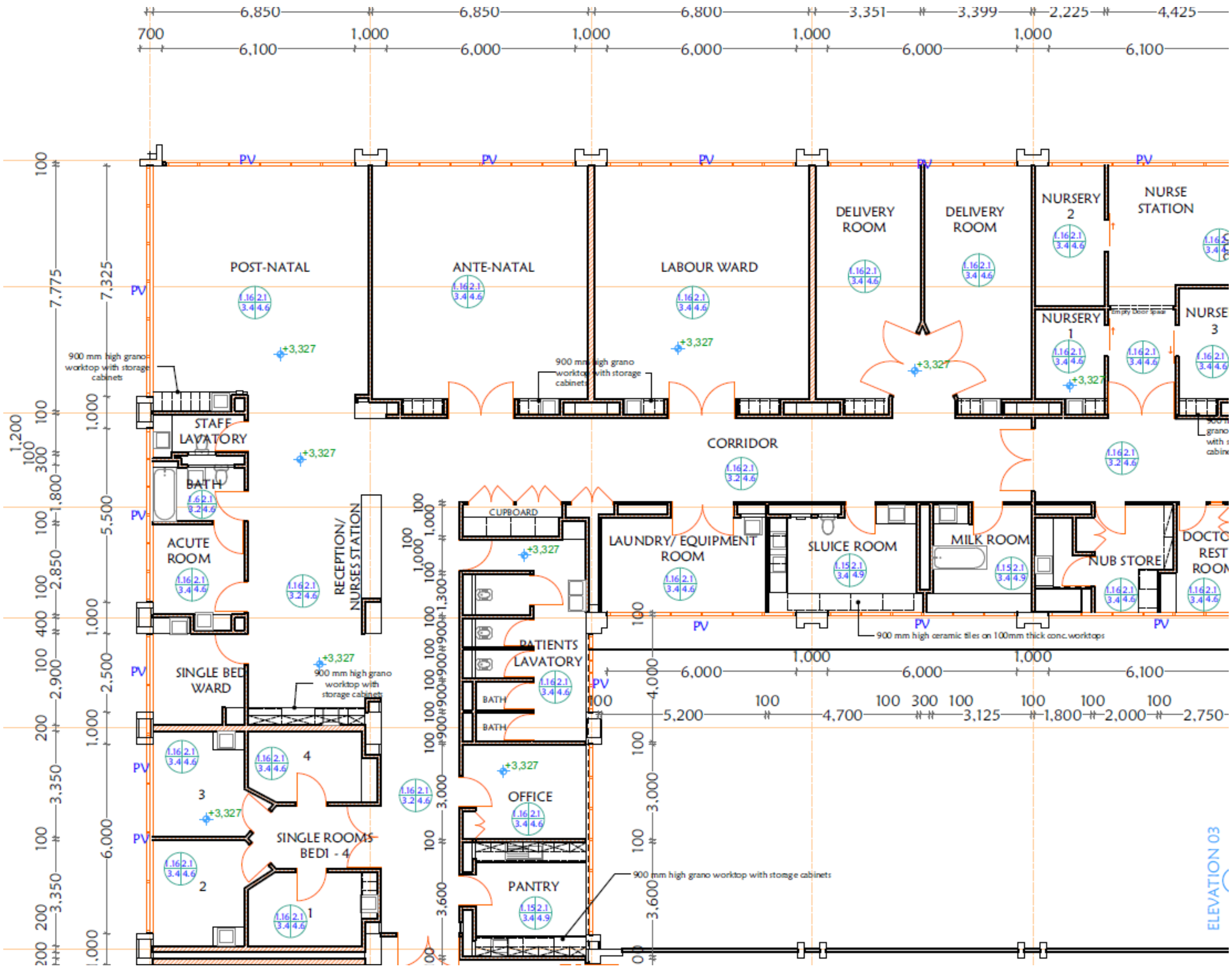


Figure 3-4: Maternity wing architectural layout. (Source: Architectural drawings given by KHN property manager's office.)

Figure 3-8: Kenyatta National Hospital Internal hallway within Maternity Wing. (Source Author)

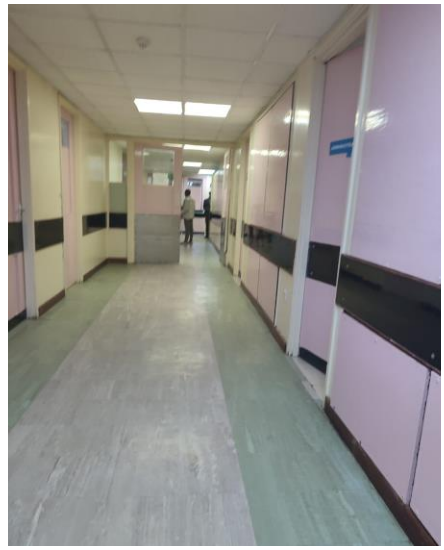


Figure 3-7: Kenyatta National Hospital Internal hallway within Maternity Wing. (Source Author)

Figure 3-5: Kenyatta National Hospital Internal hallway within Maternity Wing. (Source Author)

Figure 3-6: Kenyatta National Hospital Internal hallway within Maternity Wing. (Source Author)

Figure 3-12: KNH Multibed antenatal maternity ward

Figure 3-11: Varied size and positioning of windows in antenatal clinic, KNH (Source: Author)

Figure 3-10:KNH Doctors antenatal consultation room (Source: Author)

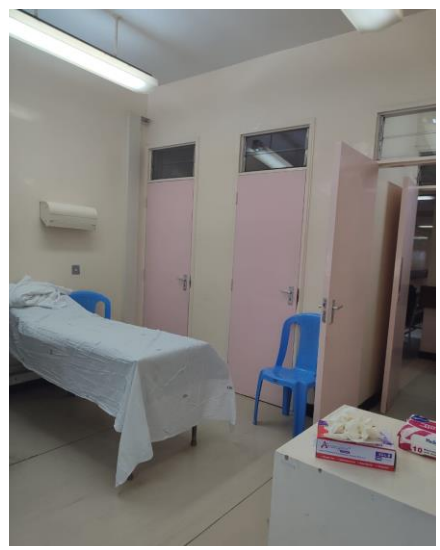


Figure 3-9: KNH Antenatal care room

Table 4-2: Notes taken for measurement features of indoor air parameters

Measurement feature for indoor air parameters	**Comments**
Admission	The prevailing wind in the microclimate at KNH flows from the west
Source control	The immediate environment is covered in vegetation. This creates a microclimate which freshens the outdoor air before it is admitted into the spaces. There is evidence of wind tunnel effects within the courtyards and atriums adjacent to the maternity wards, nurses' offices and matron's offices.
Distribution/circulation	When air is admitted into the rooms it takes the general direction of other openings such as doors and vents within the interior partitions. From the responses obtained, the users described instances of air freshness whenever wind was admitted at speeds of more than 4m/s or more. However, when wind speeds are lower than 4/s, the general flow of air is inadequate to reach all the internal spaces, since it is attenuated due to internal partitions. Mechanical fans are in place to mitigate this issue. These have inbuilt controls which are operated at the nurses' station.
Exhaust	Air moves towards internal courtyards and is exhausted. Air admitted through the windows shown in figure 4-2 infiltrated into the corridors, creating temporary cross ventilation. When the doors are closed (figure 4-3) air is admitted and exhausted through the same window in the room.
User comfort	The respondents stated that there is often stale air in the spaces. They built in mechanical system is still inadequate and does not provide the much-needed fresh air.

Figure 3-13: Multibed antenatal ward walkway, KNH

Figure 3-14: Multibed Antenatal ward KNH

Air change rate for a multibed maternity ward at the Kenyatta Hospital

A projected approach to establish an average air change rate was applied to one of the labour wards studied, taken from The Nairobi Hospital maternity wards drawings. The results are as follows:

ACH = 60Q/Room Volume = 3600 x Volumetric flow rate of air per second

Wind speed (Nairobi average of 4m/s)

Recommended ACH for hospital ward = 6 TO 10

CALCULATION

Factors affecting ventilation:

1. Opening size
2. Location
3. Orientation

Air changes per hour (ACH)

$$ACH = \frac{60Q}{Vol.\ of\ room}$$

Where, Q is the volumetric flow rate of air per minute.

Figure 3-15: Colonnade walkway adjacent to multibed ward, KNH (Source Author)

$$Q \ = average\ flow\ velocity\ (m^3)\ \times cross\ sectional\ area\ of\ opening$$

Where, $Volumetric\ flow\ rate\ = volume\ of\ air\ flowing\ per\ unit\ time$

= m^3/s (cubic metres per second)

So, the area of a room is $48.75m^2$ with a height of $3m$ thus giving a volume of:

$$volume\ of\ room\ = 7.5\ x\ 6.5\ \times 3\ = 146.25m^3$$

The air flow per second through the window is $4m/s$, so the average air flow is:

$$average\ air\ flow\ = \frac{wind\ speed\ at\ window}{room\ area}$$

= $^4/_{48.75}$ = 0.082

Air flows through the windows of a total area of 4.8m^2

Thus, ACH = $\mathbf{4.8 \times 3600 \times 0.082} / \mathbf{146.25} = \mathbf{9.68}$

The air change per hour in this specific room is 9.68

Air change rate for a delivery room at the Kenyatta National Hospital

ACH = 60Q/Room Volume = 3600 x Volumetric flow rate of air per second

Recommended ACH for hospital ward = 20

CALCULATION

Air changes per hour (ACH)

$$ACH = \frac{60Q}{Vol.\ of\ room}$$

Where, Q is the volumetric flow rate of air per minute.

$$Q = average\ flow\ velocity\ (m^3) \times cross\ sectional\ area\ of\ opening$$

Where, $Volumetric\ flow\ rate = volume\ of\ air\ flowing\ per\ unit\ time$

= m^3/s (cubic metres per second)

So, the area of a room is 6.0 x 4.025m^2 with a height of 3m thus giving a volume of:

$$volume\ of\ room = 24.15 \times 3 = 72.45m^3$$

The air flow per second through the door is 0.02m/s so the average air flow is:

$$average\ air\ flow = \frac{wind\ speed\ at\ window}{room\ area}$$

= $0.02 / 24.15$

Air flows through the door of a total area of 3.78m^2

Thus, ACH = $\mathbf{3.78} \times \mathbf{3600} \times \mathbf{0.02} / \mathbf{24.15} = \mathbf{11.26}$

The air change per hour delivery room at the Kenyatta Hospital is 3.75

4.1.2 Case study 2: The Nairobi Hospital Maternity Wing

Data and measurements taken for this study addressed source of fresh air, Admission of fresh air into the building, distribution of air within the various rooms, comfort described by users and expulsion of used air from the interior. The measurements taken give the sizes of openings, position of openings, indoor air speed vis a vis outdoor air speed.

Table 4-3: Record of internal wind speeds, area of window opening and cross ventilation.at the Nairobi Hospital

Room designation	Room volume	Internal wind speed average (m/s)	Surface area of window opening (m^2)	Cross ventilation
Nurse's station	50	0.5	2	No
Shared ward with 6 beds	56	1	3	Yes
Doctors' consultation room	20	0.4	1.2	No
Matrons' office	10.5	0.3	1.0	No
Hallway		2	1	Yes

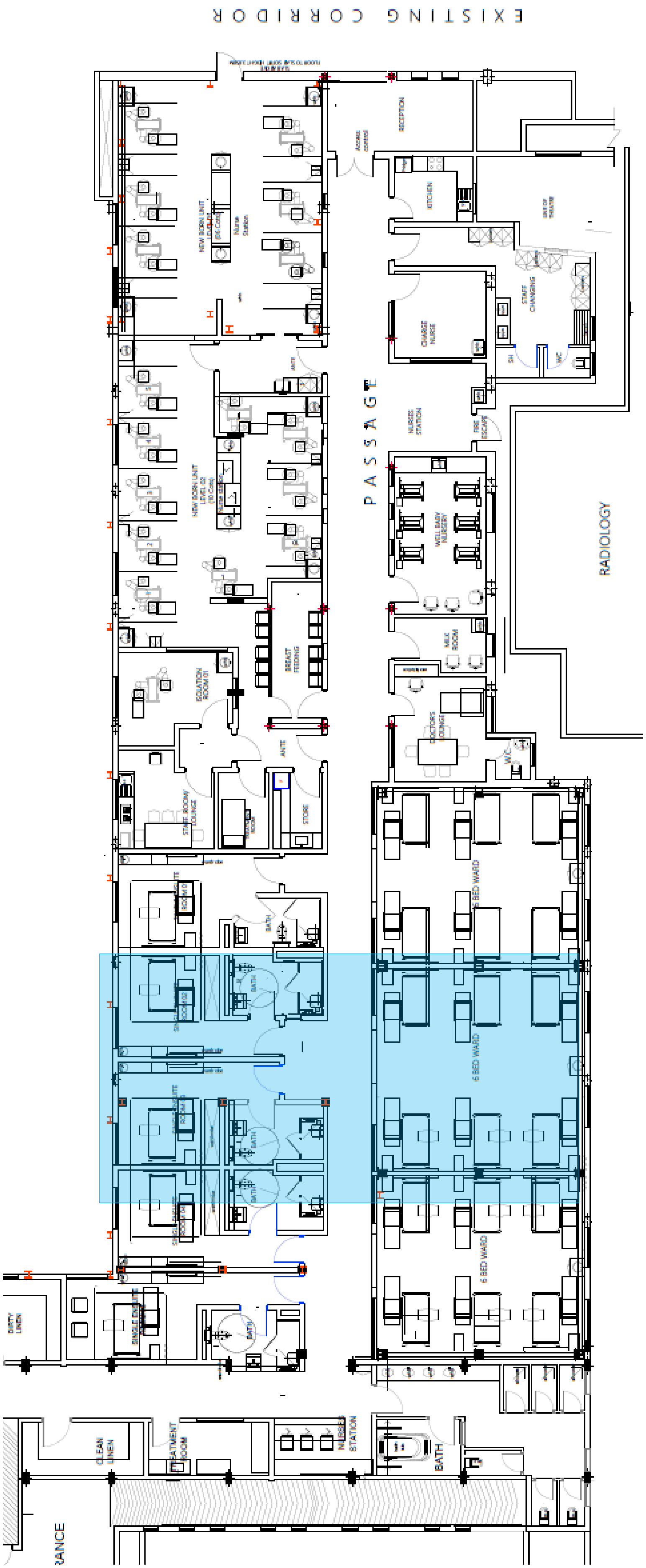


Figure 3-16: The Nairobi hospital, multi-bed ward floor plan (Source: Nairobi Hospital property management office)

Legend:

Multi-bed ward Space studied

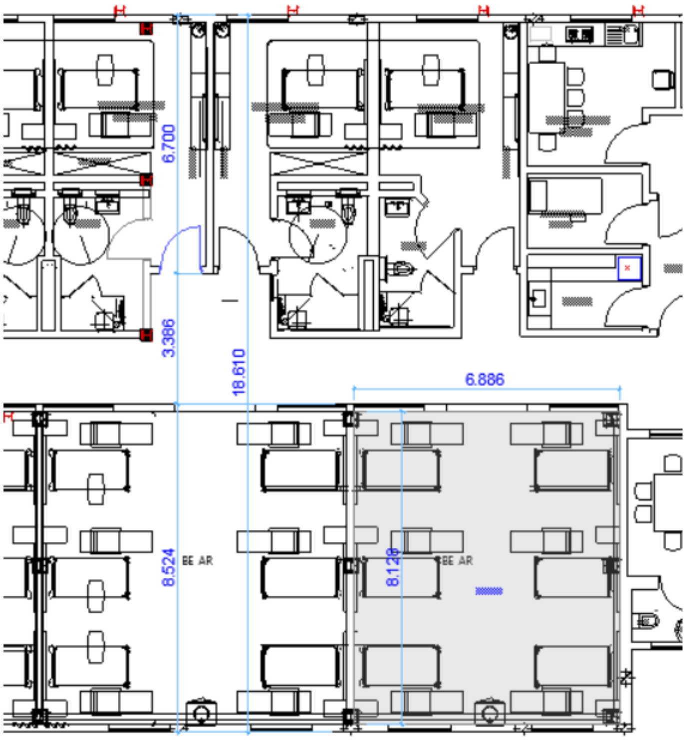


Figure 3-17: Part plan of multibed ward at the Nairobi Hospital

- The floor plate has a depth of 18.6m with double banked sections.

- There are mechanical ventilation extractors in all wet rooms, staff meeting rooms and isolation rooms.
- Cross ventilation is allowed for with operable windows on one end of the ward and vents incorporated within the doors along the walkways.

- Respondents noted that there is constant need for air to flow, due to accumulated old air. Fresh air moves in and out of rooms when doors are opened.

- One doctor remarked that they'd prefer more fresh air to be admitted more frequently in the wards and consultation rooms than it is at the moment.

Table 3-4: Measurement features for indoor air

Measurement feature for indoor air parameters (The Nairobi Hospital)	**Comments**
Admission	The prevailing wind in the microclimate at The Nairobi hospital flows from the west. The wind speed average is 11.6m/s
Source control	There is minimal vegetation cover adjacent to the maternity department. There are no perimeter fenestrations for the labour wards, delivery room and nurses' station. High reliance on ducted mechanical ventilation and air conditioning. the multibed maternity wards have fenestrations at the periphery, which are located on the first-floor level.
Distribution/circulation	When air is admitted into the rooms it takes the general direction of other openings such as doors and vents within the interior partitions. From the responses obtained, the users described stuffiness and constant use air-conditioning. Mechanical fans are in place to mitigate this issue. These have inbuilt controls which are operated at the nurses' station.
Exhaust	Air is exhausted using mechanical exhaust air handling systems. Air admitted through the windows flows into the corridors, creating temporary cross ventilation. When the doors are closed air is admitted and exhausted through the same window in the room.
User comfort	The respondents stated that there is often stale air in the spaces. The built-in mechanical system is still inadequate and does not provide the much-needed fresh air.

Air change rate for a multibed maternity ward at the Nairobi Hospital

A projected approach to establish an average air change rate was applied to one of the labour wards studied, taken from The Nairobi Hospital maternity wards drawings. The results are as follows:

ACH = 60Q/Room Volume = 3600 x Volumetric flow rate of air per second

Wind speed (Nairobi average of 4m/s)

Recommended ACH for hospital ward = 6 TO 10

CALCULATION

Factors affecting ventilation:

1. Opening size
2. Location
3. Orientation

Air changes per hour (ACH)

$$ACH = \frac{60Q}{Vol.\ of\ room}$$

Where, Q is the volumetric flow rate of air per minute.

$$Q = average\ flow\ velocity\ (m^3) \times cross\ sectional\ area\ of\ opening$$

Where, $Volumetric\ flow\ rate = volume\ of\ air\ flowing\ per\ unit\ time$

= m^3/s (cubic metres per second)

So, the area of a room is $56m^2$ with a height of $3m$ thus giving a volume of:

$$volume\ of\ room = 56 \times 3 = 168m^3$$

The air flow per second through the window is $4m/s$ though the average air flow is:

$$average\ air\ flow = \frac{speed}{area}$$

= $^4/_{56}$ = 0.071

Air flows through the windows of a total area of $4.8m^2$

Thus, ACH = $\mathbf{4.8} \times \mathbf{3600} \times \mathbf{0.071}/_{\mathbf{168}} = \mathbf{7.3}$

The air change per hour in multibed maternity ward at the Nairobi Hospital is 7.3

Air change rate for a delivery room at the Nairobi Hospital
ACH = 60Q/Room Volume = 3600 x Volumetric flow rate of air per second
Recommended ACH for delivery room = 15 to 20 ACH

CALCULATION
Air changes per hour (ACH)

$$ACH = \frac{60Q}{Vol.\ of\ room}$$

Where, Q is the volumetric flow rate of air per minute.

$$Q = average\ flow\ velocity\ (m^3) \times cross\ sectional\ area\ of\ opening$$

Where, $Volumetric\ flow\ rate = volume\ of\ air\ flowing\ per\ unit\ time$

= m^3/s (cubic metres per second)

So, the area of a room is $22.8m^2$ with a height of $3m$ thus giving a volume of:

$$volume\ of\ room = 22.8 \times 3 = 75.504m^3$$

The air flow per second through the window is $4m/s$ though the average air flow is:

$$average\ air\ flow = \frac{speed}{area}$$

= $^{0.2}/_{22.8}$ = 0.008

Air flows through the door and vent of a total area of $3.7836m^2$

Thus, ACH = $\mathbf{3.7836} \times \mathbf{3600} \times \mathbf{0.008}/_{\mathbf{75.504}} = \mathbf{1.44}$
The air change per hour in delivery room at the Nairobi Hospital is 1.44

4.1.3 Case study 3: Aga Khan University Hospital

Data and measurements taken for this study addressed source of fresh air, Admission of fresh air into the building, distribution of air within the various rooms, comfort described by users and expulsion of used air from the interior. The measurements taken give the sizes of openings, position of openings, indoor air speed. The CDC Guidelines for Ventilation requirements for areas affecting patient care in

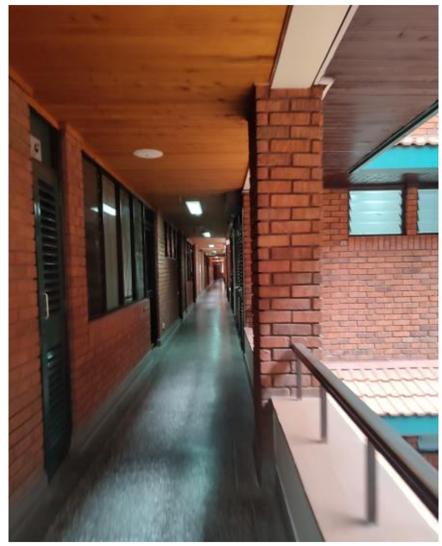


Figure 3-19: AKUH Doctors plaza atrium and corridor (Source Author)

Figure 3-18: Doctors consultation room (Source: Author)

hospitals and outpatient facilities recommend 10 – 15 ACH and internal air velocity of 0.2 – 0.5m/s (CDC 2019.)

Figures 4-18 and 4-19 illustrate the doctors' clinics at Aga Khan University Hospital. Large sliding windows characterise these offices. There is minimal reliance on air condition on indoor spaces. There is adequate natural ventilation supported by the large windows, single banked corridors and the courtyard, which allow for cross ventilation. The Maternity unit located at the third-floor level at the Aga Khan University Hospital has a deep plan as illustrated in Figure 4-21.

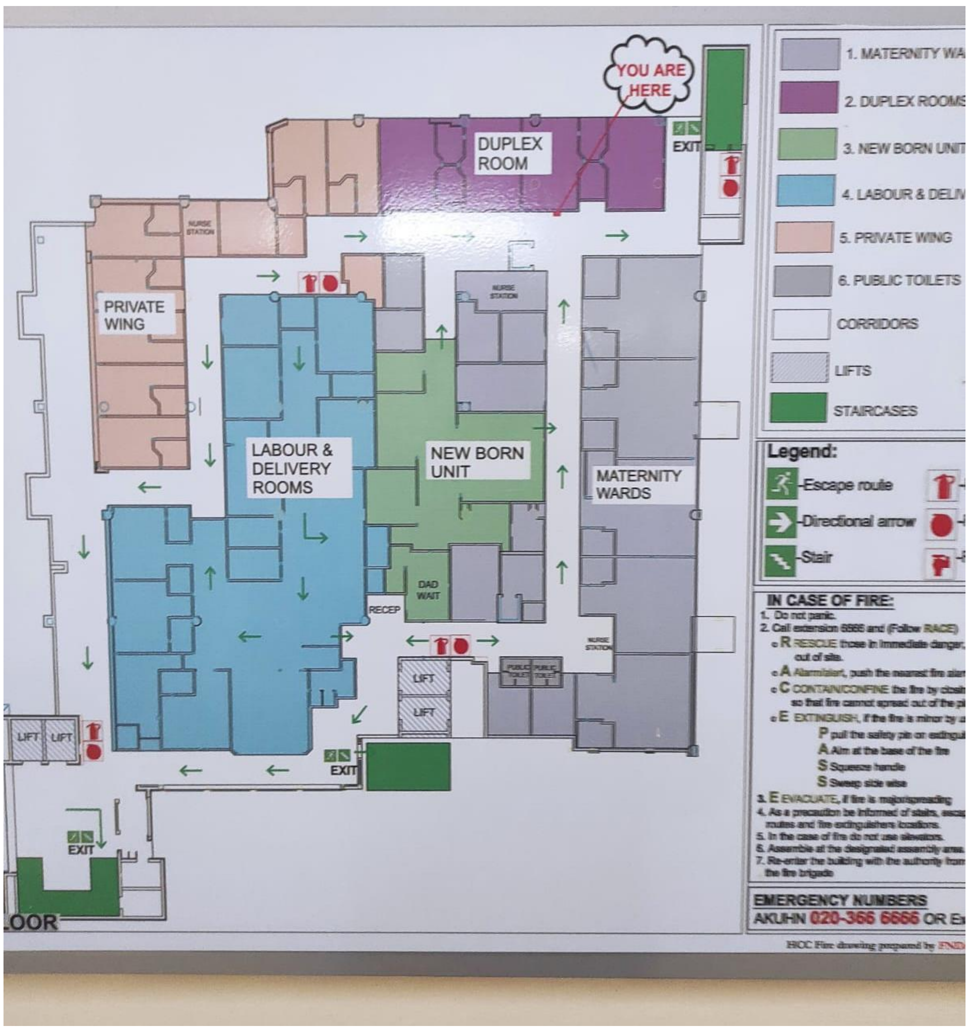


Figure 3-20: AKUH Maternity unit Map

Figure 3-22: AKUH Delivery room (Source Author)

Figure 3-21: AKUH Delivery room; fully reliant on mechanical ventilation (Source Author)

Room designation	Room volume	Internal wind speed average (m/s)	Area of window opening (m^2)	Cross ventilation
Nurse's station	30	0.15	0	No
Shared ward with 6 beds	25	1	2	Yes
Doctors' consultation room	40	0.2	3	Yes
Private room single bed	36	0.3	0.5	No
Hallway		2	1	Yes

Table 3-5: Case study observation record for cross ventilation, internal wind speeds and area of window opening

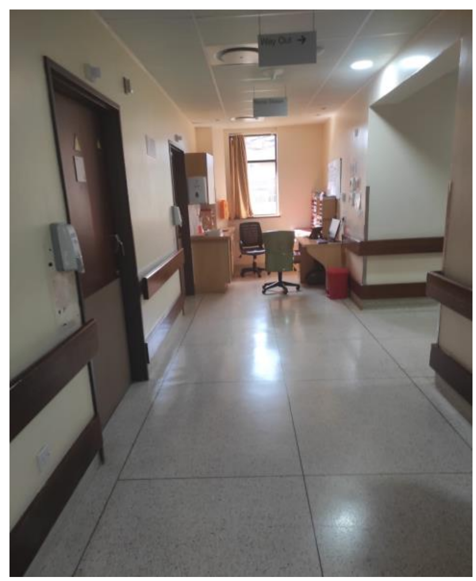


Figure 3-23: Doorway Access to the delivery room (AKUH) (Source Author)

Figure 3-24: Maternity unit Hall way (Source Author)

Table 3-6: Comments on parameters for gauging indoor air quality.

Measurement feature for indoor air parameters (The Aga Khan Hospital)	**Comments**
Admission	The prevailing wind in the microclimate at the aga Khan university hospital flows from the west. The wind speed average is approximately 6.0m/s
Source control	The maternity facilities are located on the third floor. There are no perimeter fenestrations for the labour wards, delivery room and nurses' station. Perimeter fenestrations are found in the multi bed ward spaces. High reliance mechanical ventilation and air conditioning. The layout has a deep plan format necessitating the need for air conditioning at all times.
Distribution/circulation	When air is admitted into the rooms it takes the general direction of other openings such as doors and vents within the interior partitions. It is quickly mitigated due to curtains and adjoining rooms, causing air flow to be very minimal. From the responses obtained, the users described stuffiness, heat and constant use air-conditioning. Mechanical fans are in place to mitigate this issue. These have inbuilt controls which are operated at the nurses' station.
Exhaust	Air is exhausted using mechanical exhaust air handling systems. Air admitted through the windows flows into the corridors, creating temporary cross ventilation when doors are open. When the doors are closed air is admitted and exhausted through the same window in the room. For fully mechanically ventilated rooms, exhaust of used air is through air handling vents and doors spilling into the corridors.
User comfort	The respondents stated that there is often stale air in the nurses' station due to patients and visitors at the payment office adjacent to the nurse's station. The built-in mechanical system is still inadequate and does not provide the much-needed fresh air. Air conditioning units are installed in all patient rooms.

Air change rate for a multibed maternity ward at the Aga Khan University Hospital

A projected approach to establish an average air change rate was applied to one of the labour wards studied, taken from The Nairobi Hospital maternity wards drawings. The results are as follows:

ACH = 60Q/Room Volume = 3600 x Volumetric flow rate of air per second

Wind speed (Nairobi average of 4m/s)

Recommended ACH for hospital ward = 6 TO 10 (CIBSE 2016).

CALCULATION

Air changes per hour (ACH)

$$ACH = \frac{60Q}{Vol.\ of\ room}$$

Where, Q is the volumetric flow rate of air per minute.

$$Q = average\ flow\ velocity\ (m^3) \times cross\ sectional\ area\ of\ opening$$

Where, $Volumetric\ flow\ rate = volume\ of\ air\ flowing\ per\ unit\ time$

= m^3/s (cubic metres per second)

So, the area of a room is $25m^2$ with a height of $3m$ thus giving a volume of:

$$volume\ of\ room = 25 \times 3 = 75m^3$$

The air flow per second through the window is $1.5m/s$ so the average air flow is:

$$average\ air\ flow = \frac{wind\ speed\ at\ window}{room\ area}$$

= $1.5/25$ = 0.06

Air flows through the windows of a total area of $1.8m^2$

Thus, ACH = $\mathbf{1.8 \times 3600 \times 0.06/75 = 5.18}$

Air change rate for a delivery room at the Aga Khan University Hospital

A projected approach to establish an average air change rate was applied to one of the delivery rooms studied, taken from The Aga Khan university Hospital maternity wards drawings. The results are as follows:

ACH = 60Q/Room Volume = 3600 x Volumetric flow rate of air per second

Wind speed (Nairobi average of 4m/s)

Recommended ACH for delivery room = 20 (CIBSE 2016).

CALCULATION

Air changes per hour (ACH)

$$ACH = \frac{60Q}{Vol.\ of\ room}$$

Where, Q is the volumetric flow rate of air per minute.

$$Q = average\ flow\ velocity\ (m^3) \times cross\ sectional\ area\ of\ opening$$

Where, $Volumetric\ flow\ rate = volume\ of\ air\ flowing\ per\ unit\ time$

= m^3/s (cubic metres per second)

So, the area of a room is m^2 with a height of 3m thus giving a volume of:

$$volume\ of\ room = 4.5\ x\ 4.5 \times 3 = 75m^3$$

The air flow per second through the door is $0.2m/s$ so the average air flow is:

$$average\ air\ flow = \frac{wind\ speed\ at\ window}{room\ area}$$

= ${}^{0.2}/_{20.25}$ = 0.009

Air flows through the door of a total area of $2.1m^2$

Thus, ACH = $\mathbf{2.1 \times 3600 \times 0.009/_{60.75} = 1.23}$

The air change per hour in AKUH Delivery room is 1.23

4.2 DATA COLLECTED

The features of fresh air presented to the respondents include air freshness sensation, stuffiness and unwanted odours. Respondents were asked to rate, on a scale of 1 to 6, their description of the freshness of air, and their perceived relation to the inlets and outlets of air in the building. Feature Checklist based on the indicated scale:

Air freshness sensation: [Stuffy 0 – 1 – 2 – 3 – 4 – 5 – 6 Fresh]

Stuffiness index: [Stuffy 0 – 1 – 2 – 3 – 4 – 5 – 6 Fresh]

Prescence of odours: [Unwanted odour 0 – 1 – 2 – 3 – 4 – 5 – 6 Odour free]

Table 3-7: Features of perceived freshness of indoor air from the case studies

Room designation: **Ward**	**Air freshness sensation**	**Stuffiness rating**	**Prescence /absence of unwanted odours**
	1 to 6	1 to 6	1 to 6
Orientation			
Kenyatta Hospital	6	5	5
Nairobi Hospital	4	4	3
AKUH	5	4	2
Number of Openings			
Kenyatta Hospital	4	4	4
Nairobi Hospital	2	2	2
AKUH	3	4-6	4-6
Size of Openings			
Kenyatta Hospital	4	4	5
Nairobi Hospital	3	3	3
AKUH	2	4	5
Position of openings			
Kenyatta Hospital	4	2	5
Nairobi Hospital	3	3	3
AKUH	6	5	6

Room designation: **Consultation rooms**	**Air freshness sensation**	**Occurrence of Stuffiness rating**	**Prescence /absence of unwanted odours**
	1 to 6	1 to 6	1 to 6
Orientation			
Kenyatta Hospital	4	5	4
Nairobi Hospital	4	3	3
AKUH	6	6	6
Number of Openings			
Kenyatta Hospital	4	3	3
Nairobi Hospital	4	4	4
AKUH	6	6	6
Size of Openings			
Kenyatta Hospital	3	3	3
Nairobi Hospital	2	2	2
AKUH	5	6	6
Position			
Kenyatta Hospital	4	4	4
Nairobi Hospital	3	3	3
AKUH	6	6	6
Room designation: **Nurse's station**	**Air freshness sensation**	**Stuffiness rating**	**Prescence /absence of unwanted odours**
	1 to 6	1 to 6	1 to 6
Orientation			
Kenyatta Hospital	4	5	4
Nairobi Hospital	4	3	3
AKUH	2	1	2
Number of Openings			

Kenyatta Hospital	3	4	4
Nairobi Hospital	4	4	3
AKUH	2	1	2
Size of Openings			
Kenyatta Hospital	4	4	4
Nairobi Hospital	3	3	3
AKUH	2	1	2
Position			
Kenyatta Hospital	4.5	4.5	4.5
Nairobi Hospital	2	2	2
AKUH	2	1	2

4.3 Summary

The fieldwork, data collection and case studies set out to identify the natural ventilation strategies in the selected hospitals and measure their effectiveness.

The dominant natural ventilation strategies applied are displacement ventilation and mixing ventilation. The building elements in places are windows oriented in the direction of prevailing wind, use of atria a courtyard. Mechanical equipment such as fans are in place to occasion air movement in some wards. Cross ventilation is used fresh air in the antenatal and maternity sections. Air is admitted through façade windows, but finds its way out through internal doors into internal corridors and halls such as the waiting areas. When window opening area is reduced (in the case of fewer operable window panels, warm air accumulated occasioning the need to expel it. The air changes per hour are low to average according to the documented ASHRAE standards. This is because of greatly varying wind speeds and temperatures during different times of the year. In order to curb the problem of lack of fresh air, higher air change rates are proposed. The current air change rates were calculated and an increase air change rates is recommended. This can be achieved using displacement ventilation by increasing the area of air outlets to reduce the distribution time within the space, faster exhaust of indoor air is achieved using introduction of high-level outlets creating a secondary air flow directions alongside the prevailing air flow direction which is towards internal doorways. displacement ventilation method is applied to achieve an air change rate of 10 – 15 ACH as recommended by the CDC Guidelines for Ventilation requirements for areas affecting patient care in hospitals and outpatient facilities (CDC 2019.)

In cases of deep plan layout, the use of wind catchers can be applied to reduce reliance on air conditioning units. Positioning and orientation of the wind catcher should be based on direction of prevailing wind. Since the average wind velocities in Nairobi range from 0 – 17km/h, the inlet of the wind catchers can have operable panels for ease us use by patients and staff.

Table 3-8: Air change rates for multi-bed delivery and ward rooms for the three Case studies.

Delivery rooms		
Location	**ACH**	**Recommended air changes per hour**
Kenyatta National Hospital (KNH)	**11.26**	**10-20**
Aga Khan University Hospital (AKUH)	**1.23**	
The Nairobi Hospital	**1.44**	
Multi-bed ward rooms		
Location	**ACH**	**Recommended air changes per hour**
Kenyatta National Hospital (KNH)	**9.68**	**6-10**
Aga Khan University Hospital (AKUH)	**5.18**	
The Nairobi Hospital	**7.3**	

CHAPTER 5: CONCLUSIONS AND RECOMMENDANTIONS

5.1 Introduction

The conclusions and recommendations outline the outcomes of the research study following the research objectives that underpin the study. The author outlines the passive ventilation strategies applicable to hospital environments. The section proposes recommendations that should be adopted in designing natural ventilation for maternity hospital in the built environment. The research draws the following recommendations for natural ventilation strategies for provision of fresh air in maternity hospitals.

5.2 Responses to research objectives

The research objectives that are pursued in this research report are:

I. Establish the factors affecting indoor air quality in maternity hospitals.
II. Investigate the effectiveness of natural ventilation strategies in selected maternity hospitals
III. Propose passive ventilation strategies for supply of fresh air in maternity hospitals.

Objective I: To establish the factors affecting indoor air quality in maternity hospitals.

The quality of indoor air serves the purposes of convective cooling, physiological cooling, and provision of fresh air. Indoor air is at risk of accommodating pollutants brought about by metabolism, the activities of occupants and emissions from materials used in construction and furnishing, that require to be removed in order to maintain optimal indoor air quality. The qualities of indoor air that are mainly affected by these factors are temperature and freshness. In a maternity hospital the effects of these undesirable qualities of indoor air are magnified by the physiological state of pregnant women, as highlighted in the literature review. Indoor air pollutants in a maternity hospital emitted inside buildings, derived from metabolism, the activities of occupants and emissions from materials used in construction and furnishing include CO2 from metabolism and gas appliances, carbon monoxide from poorly maintained gas and other combustion, formaldehyde from fibre boards and foam insulation, moisture, odour (generated as part of metabolism and emitted from furnishings and fabrics), ozone (from electrical appliances normally associated with poor maintenance), particulates, including dust, organic fragments, fibres and smoke particles, volatile organic compounds (VOCs) from furnishing fabrics and household chemical products and, laboratory contaminants (chemicals, biohazards, radioactive products).

These pollutants, coupled with the established symptoms of discomfort occasioned by pregnancy creates an acutely uncomfortable indoor environment especially in a maternity hospital. Indoor Air Quality (IAQ) addresses the content of interior air that could affect health and comfort of occupants. The quality of indoor air should can be reliably assessed based on the occupants' symptoms and measure taken to restore the balance composition of air required for human comfort. The design and maintenance of a maternity hospital should ensure that the content of indoor air is preserved at the chemical composition of clean dry air, that is: clean dry air with the following approximate chemical composition Nitrogen (N_2) 78%, Oxygen (O_2) 21%, Argon (Ar) 1%, Carbon dioxide (CO_2) 0.03%. The factors of indoor air in a hospital that affect the quality of indoor air at a given time include: outside air and local climatic factors (temperature, relative humidity, air velocity, air change, etc.); building management (running and upkeep activities, ventilation systems, HVAC, cleaning and disinfecting etc.); design features (room dimensions and spatial organisation, etc.); and human occupancy and medical procedures.

Design recommendations based on factors of indoor air in a hospital:

i. Installation of wind catchers for deep plan hospitals to trap wind from a clean source at a high level above the building to enhance indoor air quality.
ii. Use of landscaping to create fresh air zones around the building where perimeter fenestrations admit outdoor air
iii. The designer should indicate the location of air inlets and air out lets including thermal chimneys and wind catchers where applicable, to guide the installation of ducted and filtered ventilation systems.
iv. Calculating the anticipated air changes in the specific patient care rooms to fall within the recommended air changes per hour for patient rooms in a maternity hospital: Maternity wards (6-10 ACH), Delivery room (15-20 ACH). All practitioners should ensure that the

recommended ACH are achieved in refurbishment of patient rooms as well as in new construction of maternity hospitals.

II. Objective II: To investigate the efficiency of natural ventilation strategies in selected maternity hospitals

Natural ventilation strategies in the selected maternity hospitals include cross ventilation, use of atria and courtyards, and ducted mechanical ventilation. Air changes per hour for patient care rooms was analysed to find out whether the ventilation strategies applied are providing the recommended air changes. In the course of the study, it was revealed by several respondents, that the existing indoor air conditions in maternity facilities still leave a lot to be desired. They expressed a desire for better indoor air quality stating that they often apply user defined comfort measures such as portable fans, when permanent and retrofitted ventilation systems fail.

For naturally ventilated buildings, the air changes per hour is calculated as follows:

$$ACH = \frac{60Q}{Vol.\ of\ room}$$

Where, Q is the volumetric flow rate of air per minute.

$$Q = average\ flow\ velocity\ (m^3) \times cross\ sectional\ area\ of\ opening$$

Where, $Volumetric\ flow\ rate = volume\ of\ air\ flowing\ per\ unit\ time$

= m^3/s (cubic metres per second)

For mechanically ventilated rooms, the air changes per hour are determined by the rate of Cubic Feet Per minute (CFM rate) of the air conditioning system: **ACH = (CFM X 60) / V**

Where; ACH = Cubic feet per minute x 60 / Volume of room in cubic ft (ft^3)

Use of large windows, high level louvre windows and timber louvers positioned in interior doors, provided the required admittance and distribution of fresh air at the Kenyatta National Hospital (KNH). The air changes per hour (ACH) obtained for the multi bed wards in the selected case studies are as follows:

Table 5-1: Existing air change rates vis a vis recommended air changes per hour for multi-bed maternity wards

MULTIBED MATERNITY WARDS	Existing features	Recommended air changes per hour (CIBSE 2016	Existing Air change rates
Kenyatta National Hospital	i. Courtyards, large windows, cross ventilation, louvres high-level windows ii. Ducted natural and mechanical ventilation	**6-10**	9.68
Aga Khan hospital	i. Ducted natural ventilation, air conditioning units ii. Courtyards, perimeter windows, cross ventilation, louvres high-level windows		5.18
Nairobi Hospital	i. Ducted natural and mechanical ventilation		7.3

Design recommendations based on effectiveness of natural ventilation strategies:

i. Calculating the anticipated air changes in the specific patient care rooms to fall within the recommended air changes per hour for patient rooms in a maternity hospital: Maternity wards (6-10 ACH), Delivery room (15-20 ACH). Increase the anticipated air change rate to cater for low wind speed due to varying weather conditions when using passive ventilation

ii. Include operable window features to respond to the changing needs for pregnant women

iii. Installation of ducted and filtered ventilation systems; for both mechanical and passive ventilation systems to ensure privacy gradients are maintained in the maternity hospital

III. Objective III: To establish approaches of provision of fresh air using passive ventilation in maternity hospitals in Nairobi tropical upland climate

The literature review highlighted various passive ventilation strategies. These strategies are used in anticipation of the indoor air quality in a maternity hospital. The following are classifications and their corresponding recommendations

1. **Outside air and local climatic factors (temperature, relative humidity, air velocity, air change, etc.);** source control measures such as vegetation or high-level wind catchers to trap cleaner air
2. **Building management (running and upkeep activities, ventilation systems, HVAC, cleaning and disinfecting etc.);** the use of ducted air from the external environment in the case of deep plan hospital layouts.
3. **Design features (room dimensions and spatial organisation, etc.);** the window position, size, and opening features, position of vertical circulation such as lifts and stairwells, position of interior openings to direct air flow within the facility.
4. **Human occupancy and medical procedures. (The health status, and medical activities carried out in inpatient and out-patient rooms).** (Settimo & Capolongo, 2019)**.** – the expected capacity of the wards, nurses' station, waiting rooms and consultation offices can give an indication of the volume of fresh air needed per hour in order to inform the passive ventilation design. Inclusion of hybrid ventilation systems that apply both displacement and mixing ventilation.

5.3 Conclusions from Literature review

Natural ventilation plays a significant role in provision of fresh air for the health and wellbeing of mothers during the period of pregnancy. To ensure proper admission, distribution and exhaust of air in a maternity facility passive and operable design strategies should be installed for use by patients and nurses. This study, which focuses on hospitals in the city of Nairobi shows that fresh air is of particular importance for pregnant mothers and directly impacts physiological comfort of the mothers. The literature review has highlighted that pregnant woman have particular ventilation needs based on anecdotal reports and questionnaire studies that record consistent evidence that the sense of smell of women changes during pregnancy. In addition, the literature review draws a connection between provision of fresh air in indoor environments and the ventilation needs of pregnant women to curb self-reported increased olfactory sensitivity, higher body temperature and pain management during labour. It was established that almost all pregnant women experience a stronger sense of smell, necessitating targeted design solutions for supply of fresh air particularly in maternity hospitals. Further, the literature review proposes that provision of fresh air should receive more attention in maternity hospitals because fresh air alleviates the symptoms of discomfort experienced as a result of increased olfactory sensitivity experienced during this period, eliminates suboptimal indoor air conditions which have far reaching consequences on the mother and the baby, reduces the sensation of fatigue due to inhaling adequate quantities of oxygen found in fresh air from uncontaminated sources and ensures physiological cooling (when outdoor air is cooler than indoor air) in the event of increased temperature due to increased blood volume.

The literature review has identified various methods of natural ventilation involving methods of harnessing winds and channelling them into indoor spaces. The behaviour of wind around buildings is highlighted to understand pressure differences created by building shapes, distribution and orientation. These form the basis of observation and judgement of case studies undertaken and aids in proposing techniques that can be applied in a maternity hospital setting. With the knowledge of wind direction and speed in Nairobi upland climate, design parameters for optimal provision of fresh air through passive ventilation strategies are proposed.

It would therefore behove building construction professionals to include structure interventions for natural ventilation in maternity hospitals. Emphasis should be given to spaces where pregnant mothers are accommodated during their visits and stays at maternity facility. Atria, courtyards, wind towers and orientation towards prevailing winds were found to be the most efficient methods of passive ventilation in the Nairobi tropical upland climate. The use of stack effect would be effective when coupled with ventilation cowls to aid in upward air movement of warm old air. Positioning of openings, size of opening and opening features also greatly influences the admission, distribution and exhaust of air into and out of a space. These features should be designed to achieve the recommended air change rates for the rooms. The need for fresh air in a maternity hospital range from the nominal amounts needed for breathing ($2\ l\ s^{-1}$) to the much higher ventilation rates necessary to control odours, including odours which are only particularly perceptible by the patients.

Passive ventilation strategies should be applied according to the following classification of indoor air in maternity hospital:

1. **Outside air and local climatic factors (temperature, relative humidity, air velocity, air change, etc.);** source control measures such as vegetation or high-level wind catchers to trap cleaner air

2. **Building management (running and upkeep activities, ventilation systems, HVAC, cleaning and disinfecting etc.);** the use of ducted air from the external environment in the case of deep plan hospital layouts.
3. **Design features (room dimensions and spatial organisation, etc.);** the window position, size, and opening features, position of vertical circulation such as lifts and stairwells, position of interior openings to direct air flow within the facility.
4. **Human occupancy and medical procedures. (The health status, and medical activities carried out in inpatient and out-patient rooms).** (Settimo & Capolongo, 2019). – the expected capacity of the wards, nurses' station, waiting rooms and consultation offices can give an indication of the volume of fresh air needed per hour in order to inform the passive ventilation design. Inclusion of hybrid ventilation systems that apply both displacement and mixing ventilation.

Table 5-2: Recommended air changes per hour (CIBSE 2016)

ROOM DESIGNATION	ROOM VOLUME	AIR CHANGES PER HOUR (ACH)
Single room ensuite	75	6-10
6 bed capacity wards	108	6-10
Patients' washrooms	45	10
Nurses' station	90	8-12
Doctor's office	60	8-12
Theatre	90	10-20
Visitor's lounge	75	4-6
Delivery room	75	15-20
Father's lounge	60	4-6

The literature review highlights the recommended air changes per hour with a view of gauging how effective old indoor air is replaced by fresh air. These guidelines are important in designing for ventilation. By following these values and considering the anticipated room capacities, correct sizing and positioning of fenestrations and choice of natural or assisted passive ventilation can be specified. The selection of mechanical ventilation equipment is also guided by these air changes per hour, since they usually specify the volume of air provide in their cubic feet per minute (CFM) values. These air change rates are compared with those obtained from the case studies to gauge the effectiveness of the existing ventilation strategies in the selected case studies.

5.4 Conclusions from case studies:

The case studies seek to respond to the second research objective; To investigate how effective the natural ventilation strategies are in selected maternity hospitals. The parameters that were observed to measure the effectiveness of passive ventilation strategies include identification of existing strategies, measurement of indoor air velocity, and calculation of air change rates.

Table 5-3: Indoor air velocity and air changes per hour for multibed maternity wards from local case studies

MULTIBED MATERNITY WARDS	Existing features	Indoor air velocity	Air change rates
Kenyatta National Hospital	Courtyards, large windows, cross ventilation, louvres high-level windows	0.5m/s	9.68
Aga Khan hospital	- Ducted natural ventilation, air conditioning units - Courtyards, large windows, cross ventilation, louvres high-level windows	0.2m/s	5.18
Nairobi Hospital	Ducted natural and mechanical ventilation	0.07m/s	7.3

Table 5-4: Indoor air velocity and air changes per hour for delivery rooms from local case studies

DELIVERY ROOMS	Existing features	Indoor air velocity	Air change rates
Kenyatta National Hospital	Courtyards, large windows, cross ventilation, louvres high-level windows	0.5m/s	11.26
Aga Khan hospital	- Ducted natural ventilation, air conditioning units - Courtyards, large windows, cross ventilation, louvres high-level windows	0.05m/s	1.36
Nairobi Hospital	Ducted natural and mechanical ventilation	0.05m/s	1.44

Table 5-5: Recommended air changes per hour for patient and non-patient rooms in a maternity hospital (CIBSE, 2016)

The spaces with windows to the outdoor or to courtyards recorded the highest indoor air velocity averages. The deep plan ward rooms fully reliant on air-conditioning recorded the lowest indoor air velocity averages. From the interviews, measurements taken and observations, the rooms with an air change rate lower than 9 required increased air change rate; of 10-12 ACH.

PARAMETER	CONSIDERATIONS	Recommendations
Position and size of opening	Room level configuration; low level inlets and high level	Openings configuration can be design geared towards achieving the recommended air change rate for the specified room
Window opening components	Louvres or shading devises that can affect flow of wind into the space.	Opening components should allow adequate volumes of fresh air into

		space or used to mitigate drafts and strong wind should be operable
Orientation of openings or building	Towards prevailing winds at acceptable admission angles. Suction and channelling of wind.	When spaces are in the perimeter careful consideration should be taken to position maternity facility rooms to take advantage of prevailing winds, or use of wind catcher to channel fresh outdoor air deeper into the plan.
Configuration of passive ventilation system	Wind scoop, wind catcher, atria, courtyards, stack ventilation, use of ducted natural ventilation through supply and extract systems	For maternity spaces the configurations should include easily operable panels, and acoustic treatment, if need be, to ensure a tranquil environment in the wards and the general facility.
Source control	Using vegetation at low level or high-level wind catchers	In the event that courtyards and atria are applied vegetation should be used to create a clean source of fresh air for admittance into a building. For opening located in the perimeter close range vegetation can be used to provide a clean source of fresh outdoor air.
Distribution of fresh air into multiple rooms within a facility	Perimeter openings, use of louvres within internal partitions, depth of rooms from the perimeter.	Use of fan assisted mechanical ventilation when air paths are mitigated by internal partitions. Ducted mechanical ventilation has the opportunity of filtering out

		pollutants that may be obtained from the external air. Other forms of mechanical ventilation should be applied including: stack ventilation, wind catchers should be applied to bring in fresh air to deep plan spaces.

The admittance, flow direction, distribution, exhaust of air within a maternity hospital is determined by microclimatic factors, building design features, human occupancy and activities, as well as facility management activities. The expected load of air required to support these activities can be calculated in cubic meters of air per hour. The local climate should be manipulated to include vegetation to effect temperature driven air exchange as well as freshen incoming air. Building design features should include structural passive ventilation systems, to reduce reliance on high tech air conditioning.

From the established standards the air changes per hour for maternity wars and delivery rooms ranges form 6-20 ACH; where it is recommended to have 6-10 ACH for the wards and 10-20 for delivery rooms. These air change rates respond to the need for increased frequency for oxygen supply for the mothers during labour, delivery and postnatal care. However, from the data collection and analysis, some of the air changes per hour for the wards and delivery rooms differ from the established standard. The ACH for the multibed ward at KNH is within the international standard. Base on the established standard; CDC Guidelines for Ventilation requirements for areas affecting patient care in hospitals and outpatient facilities recommend 10 – 15 ACH and internal air velocity of 0.2 – 0.5m/s (CDC 2019.) The average internal air velocities for the three case studies measured during the same period of time were approximately 0.005-0.4 m/s. The author was able to generate average and dynamic air velocity values, using an anemometer, and determine whether the indoor air velocity is acceptable.

Figure 5-2: KNH, outdoor micro-climate configuration

Figure 5-1: KNH, antenatal clinic waiting area; deep plan section; air is distributed from perimeter fenestrations through internal partitions.

Figure 5-3: KNH, private wing ward double banked corridor

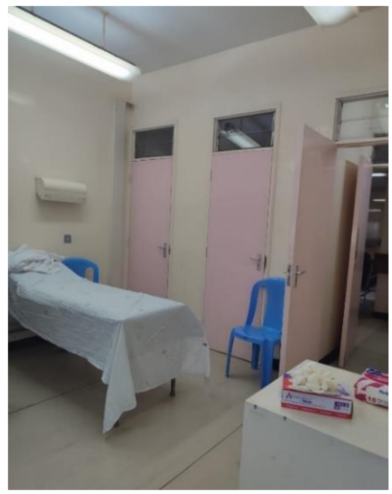


Figure 5-4: KNH, antenatal clinic: note the high-level louvre windows and larger window panels at sill height of 1000mm

Figures 5-5 and 5-6 : KNH, maternity department; use of large windows and high-level operable louvre window. To maintain the recommended privacy gradient, further interior partitions are in place which do not mitigate against the flow and distribution of air.

The values obtained for ACH at the Kenyatta National hospital wards fell within the recommended standards. However, due to varying wind speeds that may occasion stuffiness, and from the responses obtained in the questionnaire air velocity should be increased using operable passive ventilation strategies or ducted mechanical ventilation strategies. The existing mechanical ventilation operated from the nurses' station should be in full functioning capacity at all times.

The values obtained for ACH and internal wind speeds at the Nairobi hospital wards and delivery room fell below the recommended standards. The air velocity should be increased using operable passive ventilation strategies or ducted mechanical ventilation strategies. The existing mechanical ventilation operated from the nurses' station should be in full working capacity at all times. The values obtained for ACH and internal wind speeds at the Aga Khan university hospital multibed wards and delivery room fell below the recommended standards. Reported heat sensation by both patients and staff points to the need for improved indoor air quality. The air velocity should be increased using operable passive ventilation strategies or ducted mechanical ventilation strategies. Ducted and operable passive ventilation strategies such as wind catcher can be applied for the existing single rooms that are fully reliant on air-conditioning. This should cater for the deep plan layouts.

Therefore, when designing for maternity hospital patient care spaces consideration for indoor air velocity, air changes per hour as parameters for the design of ventilation should be made. Using prevailing winds, the expected indoor air velocities and air changes per hour should be calculated at the design stage to fall within 0.3m/s and 0.7m/s for wards; and 7-10ACH for wards and 15-20 ACH for delivery rooms. To achieve this the use of hybrid ventilation systems should be applied. Where possible Natural personalised ventilation may also be considered. For instance, in the case of a maternity village where patients spend months in the facility due to accessibility to healthcare, the specific need of each patient may vary. Therefore, operable natural personalised ventilation should be an option for providing dilution or mixing ventilation. A hybrid ventilation system would combine both passive and mechanical ventilation systems. In each case operability is required for ease of use by patients and staff, adjustments for changing weather conditions and adjustment for varied needs of different patients.

5.5 RECOMMENDATIONS

i. Building practitioners should factor in periods of low wind speeds by including air flow enhancing features such as win catchers, thermal chimneys and larger operable windows.
ii. Practitioners to ensure the desired privacy gradient is achieved in installation of ducted and filtered ventilation systems.
iii. Periods of high wind speeds should also be factored in by including operable mechanisms for air flow enhancing features such as wind catchers, thermal chimneys and larger operable windows.
iv. The relevant ventilation parameter for comfort is the air speed over the body, whereas the ventilation parameter for olfaction is air exchange for optimal indoor fresh air. An average ventilation rate of about 6 air changes per hour (ACH) can be suggested as the minimum health ventilation rate in maternity hospital buildings and an ACH of 10-20 for clinical/delivery rooms.

5.5.1 VENTILATION DESIGN STANDARDS FOR MATERNITY HOSPITALS

1 All maternity wards should be cross-ventilated with openings on opposite sides.
2 Ensure the ventilation inlet is lower that the ventilation outlets. Air outlets can be positioned through the roof or on opposite walls.
3 Maximise Wind induced ventilation by orienting the entire building or fenestrations with reference to the prevailing winds.
4 Allow for adequate internal airflow to encourage natural ventilation throughout the whole building.

5.6 AREAS FOR FURTHER RESEARCH

This research studies the fresh air needs of pregnant women and how architecture can contribute to making indoor air comfortable for them. Considering the complex nature of pregnancy, building design could also be adapted to address other identified sources of discomfort in maternity hospital identified in this study including higher body temperature than normal. This could also be addressed using passive ventilation and further research could also be carried to establish thermal comfort design standards for maternity hospitals. Supply of fresh air in other building types for pregnant women would be beneficial to this area of study. For instance, in break out rooms for pregnant mothers and nursing rooms nestled in modern workplaces.

Considering the recommendations for ducted ventilation further research is required to analyse the effect of ducted ventilation on noise levels in maternity hospitals. Further this research did not investigate the economic implications of structural and mechanical passive ventilation strategies. Further investigation is required to provide guidance on economic viability of these passive ventilation strategies in maternity hospitals.

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7.0 APPENDICES

Interviews

The following is a record of the interviews carried out for the purpose of this study. The respondents gave their views from their experiences of the facilities at different time of the year.

INTERVIEW 1

Interview – 24th February 2021

Source: Author

Respondent: Deputy Director Facilities and Services Richard Binga

1. Describe the Ventilation system at the retrofitted Maternity section at Kenyatta national Hospital

It is comprised of windows and a mechanical system that connects to ceiling vents positioned at designated spots in the maternity unit. It takes advantage of the wind regime in some instances.

2. Are there any mechanical HVAC systems installed?

For the maternity wards, offices, and other facilities in the maternity wing, there is natural ventilation and an extraction system for air movement and extraction of foul odour. There is air conditioning system in the new-born unit

3. If any, what are the complaints you have received from the patients and staff about the air quality in the rooms?

Occasionally the rooms get stuffy. They propose that it is due to crowding and an ever-increasing volume of users. Air circulation need to be occasioned more often as air does not move out as fast as they would like.

A system is installed that allow the nurse to switch on the fan when needed. A switch is located at the nurse's station for ease of access and control.

4. **What would you recommend that building professionals consider for optimal indoor air quality when designing a maternity hospital?**

Consider designing for ventilation using a safety factor that provides for more than the standard requirements for that rooms size. Since a maternity unit serves users who are not necessarily there for medical attention, but rather for specialized attention during child birth the air quality expected would be for healthy people. However, due to the strenuous nature of the pre-natal, perinatal and post-natal processes, enhanced air movement is a vital component towards provision of comfort for the users. They can also design for redundancy, where by the additional cost would be of much value during instances of large volumes of patients. Allow for adequate back up and larger fans than is recommended for the sizes for the rooms.

5. **Do you think the various users are adequately utilising the available ventilation strategies out in place?**

Yes. However more can be done to educate the staff on ensuring constant fresh air using the non-automated strategies already in place.

Observations

1. Design for air changes using a factor of 1.5 – 2.0
2. Increase head rooms to cater for the increasing number of users. Increased headroom allows for flexibility in addressing the following:
    1. Larger volumes of fresh air to be accommodated thereby reducing instances of draughts.
    2. Constantly changing cooling needs of expectant mothers
    3. Occasion the use of stack effect, allowing natural freshening of air.
    4. Heat generated by machinery in various spaces in a maternity wing requires to be dissipated
    5. Allow for both natural and mechanical ventilation.
6. Include a visitor's lounge. This will impact on movement and formation of small crowds in the shared spaces such as the maternity wards.
7. Orient the building such that the prevailing winds are used to occasion air movement and provision of fresh air.
8. Use courtyards to create cooling islands that allow for fresh air.

Ensure cross-ventilation at all times. A control mechanism can be installed for the specific users to control the cross ventilation during different seasons, or in the event of varied individual needs.

INTERVIEW TWO– 22nd March, 2021

SOURCE: AUTHOR

RESPONDENT: DR. WANJOHI (NAIROBI HOSPITAL)

HOW WOULD YOU DESCRIBE THE MATERNITY WARD VENTILATION?

We need more air flowing through the room. Let the flow of air be non-stop, sufficient and adequate enough. We do not face extreme winters or summers; the weather conditions are favourable all year long. Proper ventilation would make a difference to not only the mothers but also the doctors and nurses. Though we are a developing nation we should go a step further and do more than just the bare minimum of having a window in the room. We need to ensure that the air is flowing through the room, and ensure that the air exchange is sufficient enough to reduce exhaustion and stuffiness?

As a developing nation, we should take advantage of our conditions and find ways of how to use our environment to our greatest advantage that suit us.

WHAT EFFECT HAS THE RENOVATIO OF THE MATERNITY WING HAD ON THE INDOOR AIR QUALITY?

The shift from 6 beds to 8 beds in a maternity ward, while still maintaining the same size of the room, moved the current situation from bad to worse. Less space, more congestion, air flow and exchange are low, this would result to fatigue and stress on the expectant mother. It could be better. We should not just accept it but do something about it to make it better.

Make the windows a bit bigger and incorporate cross ventilation in the rooms, even though we may be operating on a tight budget we can still do better than just the bare minimum.

HOW WOULD YOU DESCRIBE THE INDOOR AIR QUALITY IN THE MATERNITY WING?

I would say that ventilation is limited. The window sizes are of inadequate size since the users often desire for more fresh air to be admitted into the space. In addition, the waiting rooms within the office space should also be well ventilated in order to avoid exhaustion and fatigue while waiting to be assisted. We should take note of these minor nuances which in the long run will have a positive impact on the patients and the medical practitioners.

CONCLUSION

The interviewees stated that all spaces that comprise maternity hospitals should be of adequate size to avoid congestion, have sizeable windows for sufficient and consistent air flow and light. These minor adjustments would be beneficial to patients, staff and visitors.

Due to differences in microclimate, building designs and varying room functions, 15 or 20 air changes per hour (ACH) may be the minimum required. However, in practice, most hospitals operate at 20 to 25 ACH with some using up to 40 ACH. These rates are all up from 12 ACH, which was the requirement for many years.