UNIVERSITY OF NAIROBI

AN INVESTIGATION INTO THE OPTIMAL COMBINATION OF HYBRID VENTILATION DESIGN

(CASE STUDY: CONTEMPORARY OFFICE BUILDINGS IN NAIROBI)

BY

OMOLO PAUL SAGI

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DECLARATION

I declare that this is my original work and has not been presented to any other university or institute of higher learning for examination or academic purposes.

Signature___________________________ __________________

OMOLO PAUL SAGI (Author) **DATE**

REG. NO B53/80520/2012

This research proposal has been presented for examination with my approval as the University supervisor.

Signature___________________________ __________________

ARCH. PETER NJERU **DATE**

DEPARTMENT OF REAL ESTATE AND CONSTRUCTION MANAGEMENT

UNIVERSITY OF NAIROBI

DEDICATION

I dedicate this project to my late dad Mr. Joseph Omolo and my mum Mrs. Margaret Atieno , without whose encouragement I would not have undertaken or completed this endeavor.

To my lovely wife Bridget Ntinyari Sagi, for her support.

ACKNOWLEDEMENTS

I thank God for through Him all things are possible, for his faithfulness in ensuring completion of the good work that He begun in me.

Thank you to my supervisor Arch. Peter Njeru, for his dedication without which this work would not been possible.

I thank all that participated in the study, and my colleagues for their motivation and camaraderie.

Finally, to the entire staff of The Department of Real Estate and Construction, thank you.

I take full responsibility for this study. Any errors or a shortcoming herein do not reflect the contribution of the aforementioned.

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LIST OF ABBREVIATIONS

CBD: Central Business District

IAQ: Indoor Air Quality

UNEP: United Nations Environment Program

AHU: Air Handling Units

HVAC: Heating Ventilation and Air Conditioning

ASHRAE: American Society of Heating, Refrigeration, Air Conditioning Engineers

CIBSE: Chartered Institute of Building Services Engineers

VAV: Variable Air volume

AAK: Architectural Association of Kenya

BRE: Building Research Establishment

ABSTRACT

Passive and active ventilation modes have long been used to ventilate office buildings. However, active ventilation strategies have taken over, with many designers choosing to design fully glazed office towers to match those in the Western countries, whose aesthetics are associated with power and dominance. With current focus on the environment today, these active strategies have come under scrutiny and passive means of ventilation have come back into focus for many designers especially when designing for Nairobi's climate. However, natural ventilation is not always adequate to fulfil a buildings ventilaton requirements. This research project therefore aims to investigate the optimum use of hybrid ventilation as an alternative ventilation strategy.

The literature review gives information on the various types of ventilation strategies and their merits and demerits. The author then uses the case study method to conduct the research. Three case studies confined to Nairob's central busines district (CBD) are selected, namely ICEA building, Lonrho House and I&M towers. Data for the study was obtained through observations, questionnaires and interviews with the office building occupants purposively sampled.

Findings from literature review are compared against data from the case studies so as to gauge the performance of the study parameters. Based on the research findings, the author draws recommendations that can be adopted to advance the existing ventilaton systems used in office buildings in Nairobi's CBD. Recommendations for imminent research are also outlined, opening doors for expansion of the study subject in future research undertakings.

CHAPTER ONE: INTRODUCTION TO THE STUDY

1.0 Introduction

According to Randall, N. (2006), ventilation is the process of changing the air in a room or other internal space. This process should be continuous with fresh air taken from a clean source. There are various types of ventilation: passive ventilation as provided for through fenestrations, active ventilation as provided through mechanical means and hybrid ventilation which utilizes both active and passive means.

For many centuries, buildings relied on natural ventilation strategies alone. However, after World War II, active ventilation systems emerged. These afforded designers the freedom from the T, H, or L-shaped floor plans that were then mostly used. Designers could now design however they wanted without trying to give the maximum number of operable windows to adequately provide natural ventilation. This led to the construction of the modern glass-walled high rise buildings reckoned to be the icon of freedom from ancient construction systems as well as heating and cooling techniques. The traditional footprint, interior layout and exterior appearance of buildings therefore changed.

Over the last few years, there has been a large focus on the environmental impacts of energy production and consumption. This has led to an increased awareness of the energy used by equipment in ventilation and air conditioning system (Heiselberg, P. 2006). Natural ventilation technologies have therefore made a comeback. However, these systems are not always able to deliver a desired airflow rate all the time, despite their energy efficiency (Kleiven, T. 2003).

This therefore led to the development of hybrid ventilation systems that combine both natural and mechanical ventilation technologies and are driven by the expectation that annual energy costs should reduce (Heiselberg, P. 2006).

This study therefore investigates the various ventilation systems intended for high-rise office buildings within the Nairobi Central Business District, with a focus on finding out the optimum combination of hybrid ventilation systems.

1.1 Background

The population influx across urban areas and the demand for workspace has influenced the emergence of commercial buildings, under which office buildings can be categorized as they house various business premises that economies are dependent on. Defined as places of business where professional, administrative or clerical obligations are executed, office buildings are an important building type in the modern age, where trade keeps economies running (Daniels, K. 1997).

According to AAK Survey that was conducted on iconic Buildings in Kenya; defines a modern building as one with great architecture and aesthetics, distinctively Kenyan or African design, high quality construction, use of innovative technology, ecologically responsive or “green” design.The environment provided within these buildings is crucial as most office users spend up to fifty per cent of their time in the office, necessitating the creation of healthy and vibrant environments (Allard,F.2005).

During the long history of commercial building architecture, passive ventilation and daylighting have been influential in shaping buildings for commercial use. However, passive ventilation in enormous office spaces in Nairobi has become less fashionable. Most modern buildings use active ventilation strategies with a few relying on natural air flow a fact occasioned by relying on imported architecture (fully glazed buildings) considered to be fashionable.

The past two decades has seen many contemporary high-rise office buildings in the interior of the (CBD) in Nairobi, adopt mechanical air conditioning systems as their main form of ventilation (Swinborne, H. 2005).

Despite the budgets and ecological impacts incurred in installation and use of active systems, current design practices do not seem to take these into consideration enough to cause a change in design practices in Kenya.

In light of this, it is first important that different environments be evaluated for their climatic appropriateness for various ventilation types for example, some climatic environments enjoy good air circulation for lengthier phases of the year and may lend better to passive ventilation systems. Therefore, in each environment, it is useful to know what ventilation modes are justifiable.

1.2 Problem statement.

Both Passive and active ventilation modes have advantages and disadvantages. Natural ventilation systems tends to minimise both initial and operational costs compared to active ventilation systems while maintaining ventilation rates that are consistent with tolerable interior air quality. Also, certain studies have shown that tenants reported fewer symptoms in buildings with passive ventilation as compared to buildings with active ventilation [Mendell, 2005]. Active ventilation strategies allow freedom in building design and more so provide control of building internal conditions.

However, these two ventilation systems have demerits as well. One of the major demerits of passive ventilation is the uncertainty in performance, which results in issues such as: high risk of draught glitches, poor indoor air quality and unacceptable thermal comfort conditions. Similarly, HVAC systems often lead to criticisms from the tenants who claim to experience acute health and comfort effects that appear to be interconnected to time spent in a buildings technically denoted to as Sick Building Syndrome, particularly in circumstances where individual control is not possible (Heiselberg,P. 2006).Therefore, hybrid ventilation systems have been technologically advanced as they have access to both ventilation modes hence allows the best ventilation mode to be chosen based on the circumstances.

Makachia, P. [2001], observes that despite Nairobi's climatic appropriateness for passive ventilation designs; active ventilation design is freeing designers from conventional systems of positioning office buildings in relation to the sun or ventilating them with operable windows. Hybrid ventilation therefore comes in and seeks to offer equilibrium among the two systems. Consequently, this research intends to examine the optimal combination of hybrid ventilation systems in modern office buildings in Nairobi.

1.3 Research Questions

- What types of ventilation systems are currently used in modern office buildings in Nairobi?
- What are the aids of natural and mechanical ventilation in modern office buildings in Nairobi?
- What are the aids of the use of hybrid ventilation in modern office buildings in Nairobi?
- How effective is Hybrid ventilation compared to mechanical and natural ventilation strategies?

1.4 Research Objectives

1. To examine the existing state of ventilation design in office buildings in Nairobi.
2. To establish the aids of both natural and mechanical ventilation methods in modern office buildings within Nairobi.
3. To investigate the aids of integrating hybrid ventilation in office buildings in Nairobi.
4. To compare the efficiency of hybrid ventilation to mechanical and natural ventilation strategies.

1.5 Scope and Limitations

Due to envisaged time limitations, the research was subject to the hereunder manageable scope:

The study focused on high-rise buildings in the interior of the Nairobi Central Business District. This area was chosen because of its climatic appropriateness for natural ventilation systems in modern office buildings as was established by UNEP (2007). It mainly involved a reasonable examination of various selected modern high-rise office buildings within this region based on their style of their architecture. This entailed the examination of various ventilation strategies used in the office buildings to establish their effectiveness and their impact on users and the environment.

1.6 Justification of the Study

The study will assist modern office building designers, regulatory bodies and authorities to adjust and integrate policies and procedure to ensure office buildings are not only designed and approved to meet the high spatial demand as experienced within Nairobi, but also to consider Nairobi's climatic appropriateness for passive ventilation design and its related advantages i.e. reduction of operating costs to improve building affordability and value, energy efficiency and reduced maintenance.

The study will also provide an insight on how existing contemporary office building which are facing a cost implication based on operating active ventilation, could be made to adjust to minimise the cost without compromising the ventilation requirements, through incorporation of an optimal combination of natural and mechanical ventilation systems.

1.7 Assumptions of the study

Physical scope (geographical)- Office buildings sandwiched within the frontiers of Uhuru Highway, Harambee Avenue, Moi Avenue and University way will be studied; a sample of this population will be a fair representation.

Conceptual scope - There is so many application and types of active ventilation systems used differently in various buildings i.e. hospitals, processing industry et al; for the purpose of this research, the researcher will limit ourselves to the reason behind there adoption in contemporary office buildings within Nairobi C.B.D.

1.8 Definition of Terms

Passive/Natural Ventilation: - is the process of bringing in and extracting air through an indoor space by natural means.

Active/Mechanical Ventilation: - refers to the exchange of outdoor air provided by mechanically powered equipment, such as a fan.

Hybrid ventilation: - systems that offer a relaxed internal environment using both passive ventilation and active systems, but using different features of these systems at various times of the day or season of the year by incorporating intelligent controls.

1.9 organization and arrangement of the study

The research comprises of five sections as follows:

Chapter One is introductory. It contains the problem statement, objectives, research methodology, scope and the significance of the study.

Chapter Two discusses the literature reviewed and the theoretical framework, which acts as a foundation for the research. It includes: review of natural, mechanical and hybrid ventilation techniques. The section also contains an overview of these techniques and strategies in office buildings and their potential merits and demerits.

Lastly the section discusses opportunities and matters explicit to the use of hybrid ventilation systems in office buildings in the interior of the CBD by describing a plan to enable the realization of the potential benefits of this system in Kenya particularly Nairobi CBD.

Chapter Three is the research methodology section. It gives a background of the region as well as the people being studied. It shows how the sample sizes are obtained and the sampling techniques that are used. The data collection tools and procedures are also discussed.

Chapter Four is the data presentation and analysis section. In this sector, the information that was collected from the field is analyzed and presented in the form, tables, and plates among other methods.

The responses of various population to whom questionnaires were directed together with oral interviews conducted are presented and analyzed. A summary of the findings is given and the problems encountered in the field are also mentioned.

Chapter Five gives the deductions and recommendations made grounded on the outcomes of the findings. Suggested areas of further research are also mentioned.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter gives an overview of mechanical and natural ventilation strategies and to further elaborate on hybrid ventilation strategies. It explores the various factors deliberated in the application of natural ventilation modes in modern office buildings in Nairobi.

2.0.1 Overview of Ventilation Strategies

Ventilation is the deliberate introduction of outdoor air into a space and the process by which clean air is moved around the building. Ventilation is essential in buildings to ensure delivery of a comfortable thermal environment and adequate interior air quality. Traditionally, ventilation has been provided in buildings to uphold tolerable interior air quality (IAQ) by fulfilling the following functions (BRE, 1994):

- providing sufficient oxygen;
- diluting body odours;
- diluting to tolerable levels the intensity of carbon dioxide produced by occupants and combustion, together with other internally and externally produced pollutants.

Moreover, ventilation can be used to provide internal thermal comfort in buildings by controlling temperature inside buildings and avoiding overheating (Santamouris,M. 2007). The three methods that can be used to ventilate a building are: natural (passive), mechanical (active) and hybrid (mixed-mode) ventilation.

To create a healthy working environment, a minimum standard of clean air is required. Natural ventilation is generally not entirely controllable while mechanical ventilation can be controlled. This research examines the optimal combination of the two to produce a healthy internal work environment.

2.1 Natural Ventilation

Also referred to as passive ventilation, is the mechanism of bringing in and extracting air through an interior space by natural means. This mainly occurs by tapping into either the wind pressure or using the stack effect. Passive ventilation has two main purposes: to ensure indoor air quality; and to offer thermal comfort in exception of energy usage or regular maintenance. Moreover, it helps to eliminate noise and health problems such as sick building syndrome that are characteristic of active ventilation (Allard, F.2002).

Natural ventilation helps to maintain good IAQ by replacing polluted interior air with clean exterior air. This ensures that indoor air contains sufficient oxygen, dilutes body odours, dilutes carbon IV oxide concentration and removes internally and externally produced pollutants such as those from materials that off-gas, dust, from office equipment and from automobile exhaust fumes. Fresh air also prevents symptoms of poor IAQ such as fatigue, coughs, headaches, sneezing and irritation (Givoni, 1976; Santamouris, 2007). It also improves user thermal comfort, by helping to increase heat loss from the body and inhibits moist skin discomfort (Allard, 2002; Givoni, 1976).

In order for passive ventilation to be effective (i.e by ensuring good IAQ and passive cooling in a building), its essential be considered during the design process. A building and its constituents are elements that can reduce or increase air movement as well as impact the air content and therefore should be taken into consideration. Active ventilation systems can be designed independently from the design of the building or installed in current buildings after a few adjustments however design for passive ventilation must be intentional (Heiselberg, 2006).

Some predominant outdoor conditions that determine the usefulness of passive ventilation include: microclimate (wind speed, temperature, humidity and surrounding topography), and the building itself (orientation, number of windows or openings, size and location) (Heiselberg, 2006).

There are two types of passive ventilation made possible by the use of a natural driving force. These are:

Wind driven ventilation (due to pressure differences)

Stack driven ventilation (due to temperature differences)

Both types of passive ventilation use air pressure variances due to height to pull air through the building. Lower pressures higher in the building help jerk air upward. The only difference between stack ventilation and wind driven ventilation is where the pressure variance comes from. These pressure differences occur at the inlets and outlets of buildings and can be attained by infiltration or by allowing air to flow in and out of a building by opening windows and doors (Heiselberg, 2006).

More often than not, both wind and thermal buoyancy are relied on as driving forces in passive ventilation systems, though one of them is usually predominant. The building and the ventilation system are then designed for ideal utilisation of this driving force. The dominating force also affects the shape and plan of the building, the selection of ventilation elements to be utilised (e.g. a wind scoop or an atrium), and the air paths into, out of and through the building (ventilation principle) (Heiselberg, 2006).

Apart from the usual driving forces behind natural ventilation, two other features can be used to define and characterize various concepts to do with natural ventilation. These are: ventilation principle and the characteristic ventilation element which shall be looked at further (Kleiven, T.2003).

2.1.1 Stack driven ventilation/Thermal buoyancy

This technique of ventilation occurs owing to temperature differences which cause a density difference between internal and external air. This difference in density generates pressure variances that pull air in and out of a building via appropriately positioned openings in the building envelope (Kleiven, 2003).

It occurs when interior air temperature exceeds outdoor temperature, causing pressure to be built up in the upper portion of the building while lower pressure remains in the lower part. At a definite height, the indoor and outdoor pressure equals each other, and this level is called the neutral plane. Higher pressure beyond the neutral plane drives air out through openings in the building envelope, and lower pressure under the neutral plane pulls air in through openings in the building envelope. Thermal buoyancy is sometimes called the stack effect or the chimney effect (Kleiven, 2003).

According to Koenisberger.E.A (1974), the stack pressure can be calculated from the equation:

$Ps = 0.042 \times h \times \Delta T$, where Ps = stack pressure in N/m2, h = height of stack in m, ΔT temperature difference in degC (the constant is N/m3 degC) .

This method is highly dependent on the interior and exterior temperature differences and is limited to lower magnitude than wind driven ventilation. This method can achieve acceptable ventilation rates but is not considered an effective means of cooling. Therefore, combined wind plus buoyancy driven stack ventilation ought to be looked into instead (Atkinson,J. 2009).

2.1.2 Wind driven ventilation

This is the most familiar approach to natural ventilation. According to Daniels, K. (1997): “Wind driven ventilation happens as a result of various pressure created on the building envelope by wind. These pressure variances drive air into the building via openings in the building envelope’s windward side, and drive air out of the building via openings in the building envelope’s leeward side.”

When wind flows over a building, it creates positive inward acting pressures on the windward side and negative outward acting pressures on the leeward side. This creates a net pressure difference across the building that drives cross ventilation (Atkinson, 2009). In this system of ventilation, the wind pressure is proportionate to the air velocity. This is expressed in the following equation**: Pw = 0-612 × v2**, where Pw = wind pressure in N/m2

v = wind velocity in m/s (the constant is Ns2/m4) (Koenisberger, 1974).

The major shortcoming of this system is that when wind direction changes, so does wind pressure coefficients. Therefore, when wind pressure drops to low values, passive ventilation airflow rates also drop. However, it can mitigated by self-regulating inlet vents.

2.1.3 Combined Wind and Buoyancy Driven Stack Ventilation

Stack ventilation systems when properly designed can make use of both wind and buoyancy driven pressure differences (Atkinson, 2009).

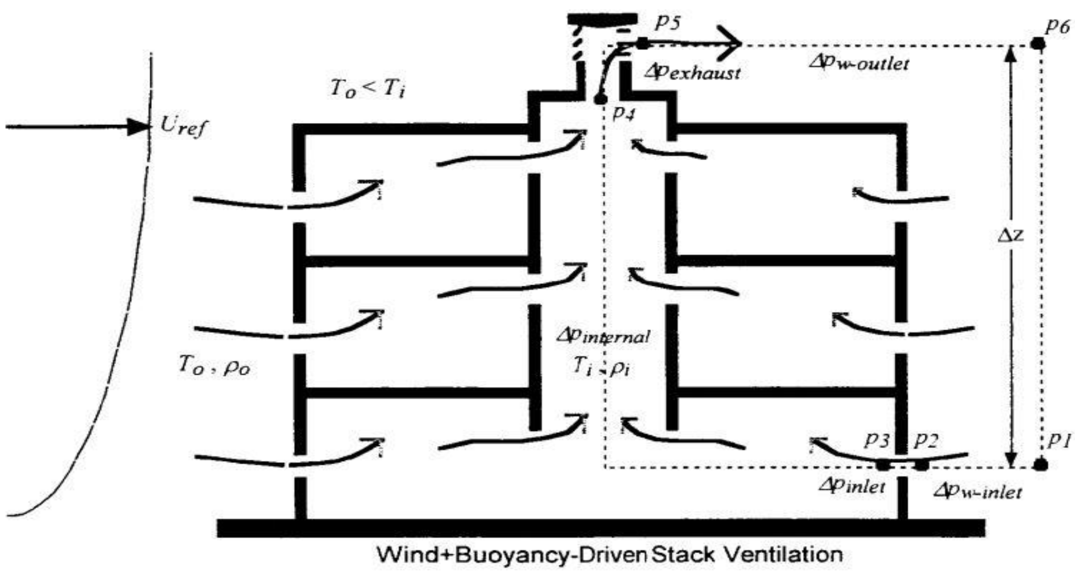

Plate. 2.01: Wind and buoyancy driven stack ventilation. (Source: Axley, 2001)

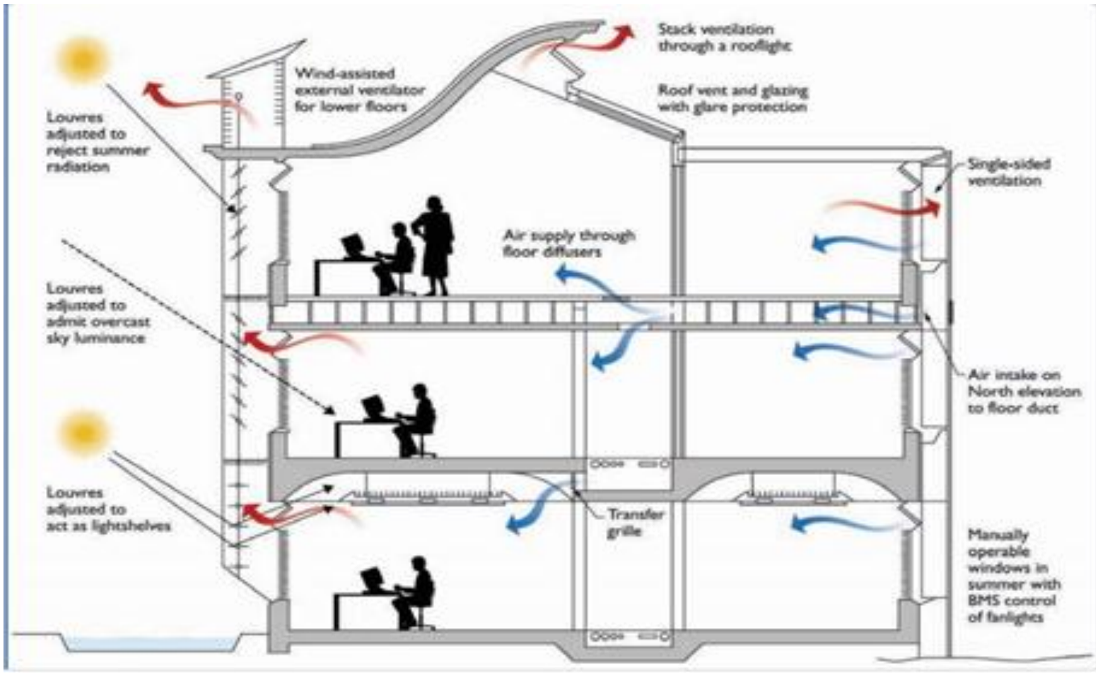

Plate. 2.02: A schematic showing the various natural ventilation strategies. (Source: www.bsria.co.uk, 2009)

2.1.4 Natural Ventilation Principles

Ventilation principles for passive ventilation are the methods used to fully utilise the natural driving forces to ventilate a space. They indicate how natural driving forces are utilised to ventilate a building by linking exterior and interior airflows. Furthermore, the ventilation principle gives an indication on how the air is introduced into the building, and how it is exhausted out of it. This is usually subject to the shape of a building together with the position of the ventilation openings. This is done using three ventilation principles namely: single-sided ventilation, cross ventilation, or stack ventilation (Kleiven, 2003).

Accoridng to Allard and Ghiaus (2005): "single-sided ventilation, the most localized of all strategies, may be used when ventilation is needed for individual rooms. Cross-ventilation allows clean air to reach the floor of the building and depends upon building form and the urban environment. Stack ventilation systems circulate air through the whole building and depend upon building form and internal layout. Combinations of all of these approaches exploit their individual advantages."

Single Sided Ventilation

This relies on openings on only one side of the ventilated enclosure. Clean air goes in the room through similar side as used air is exhausted. An example of this is in the rooms of a cellular building with openable windows on one side and closed internal doors on the other side. The core driving principle behind this principle is wind turbulence (Kleiven, 2003).

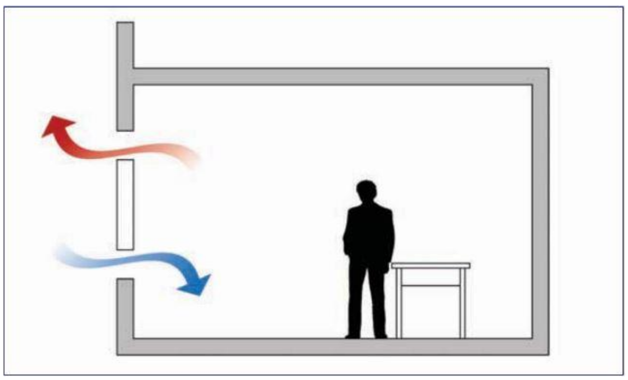

Plate. 2.03: Single sided ventilation.
(Source: www.bsria.co.uk, 2009)

Where ventilation openings are provided at different heights within the façade, the ventilation rate can be improved by the buoyancy effect. The contribution from thermal buoyancy depends on the temperature variance between the interior and the exterior, the vertical distance between the openings, and the area of the openings. The more the vertical distance between the openings, and the more temperature variance between the inside and the outside, the stronger is the effect of the buoyancy. If windows are designed with this in mind, a room depth of up to six – seven metres can be satisfactorily ventilated in this way. This strategy however generates lower ventilation rates than others, and the ventilation air does not penetrate so far into the space (Kleiven, 2003).

Cross Ventilation

This occurs when air flows between two sides of a building envelope due to pressure variances triggered by wind. The air enters and leaves through windows, hatches or grills integrated in the façades. The ventilation air moves from the windward side to the leeward side. An example of this is in an open-plan office landscape where the space stretches through the whole depth of the building. The airflow also passes through several rooms through open doors or overflow grills.

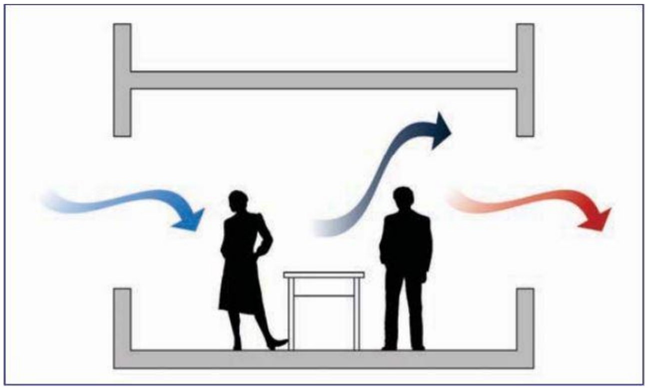

Plate. 2.04: Cross ventilation. (Source: www.bsria.co.uk, 2009)

Cross ventilation is also mentioned when considering a single space where air goes into one side of the space and leaves from the opposite side. In this situation the ventilation principle on the system level can be either cross- or stack ventilation. As the air circulates across a fully occupied space, it picks up heat and pollutants. Consequently, this limits the depth of a space that can be effectively cross-ventilated (Kleiven, 2003). Cross ventilation can achieve high air change rate, and ventilate a deeper floor plate (five times the floor-ceiling height) than single-sided ventilation.

Stack Ventilation

This is experienced where the driving forces encourage an outflow from the building, thereby drawing clean air in via ventilation openings at a lower level. Fresh air typically enters through ventilation openings at a low level, while used and polluted air is exhausted through high level ventilation openings (a reversed flow can occur during certain conditions). Designing the outlet to a region of wind-induced under pressure can improve the efficiency of stack ventilation. An example of this is a building with a raised central part, where warm and polluted air from the nearby surrounding spaces rises to be exhausted through wind towers positioned on the roof.

Owing to its physical nature, the stack effect requires a definite height between the inlet and the outlet. This is possible to achieve by e.g. adjusting the floor to ceiling height, changing the orientation of the roof profile, or using a chimney or an atrium. By its nature, stack ventilation is homogenous to cross ventilation as far as some specific spaces are concerned, since air enters one side of the space and leaves from the opposite side (CIBSE Application Manual AM10, 1997). The air might flow through the whole width of the building and be extracted via a chimney, or it may flow from the edges to the middle to be exhausted via a central chimney or atrium (Kleiven, 2003)

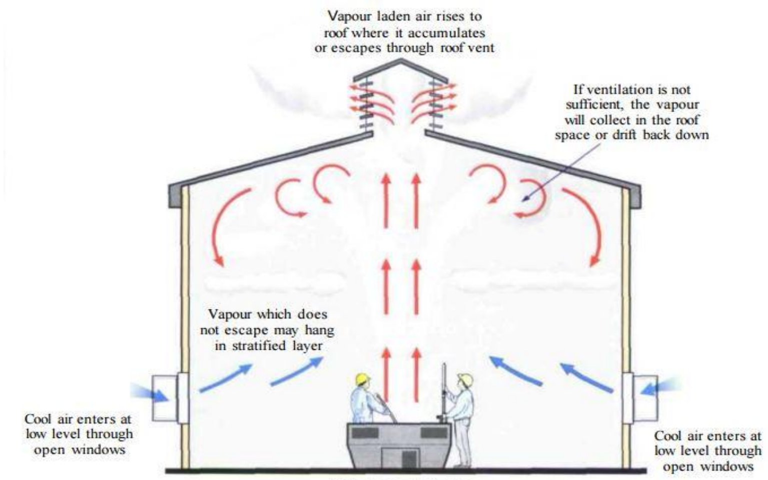

Plate. 2.05: An example of stack ventilation to remove vapours through roof ventilators.

(Source: www.ucu.org.uk, 2000)

2.1.5 Natural Ventilation Devices

The most common device for passive ventilation is the operable window. The mechanism behind it is mostly wind-driven ventilation, although buoyancy driven ventilation could have a non-negligible effect. The operable window could also be mechanically actuated for automatic control of the airflow (Allard and Ghiaus, 2005).

The principle forces of passive ventilation vary in amplitude with time. Therefore, the passive ventilation rate should be restricted with appropriate devices. Apart from operable windows examples of other devices used include: louvers, which provide large ventilation rates with protection against rain; vents, which ensure a good control of ventilation degrees and provide good protection; wind catchers; and chimneys, which increase airflow rate (Allard and Ghiaus, 2005).

A number of these devices let in not only air but also rain, insects, noise and dust. Double-skin façades are well suited to noisy or polluted areas, and protect against driving rain. Furthermore, stacks and chimneys which are used for buoyancy-driven ventilation can be constructed to take benefit from the wind and become wind catchers (Allard and Ghiaus, 2005).

2.2 Application of natural ventilation systems in office buildings in Nairobi.

This section explores various factors considered in the application of natural ventilation systems to modern office buildings in Nairobi. The main factors discussed are: climate suitability, ambient air quality, and codes and standards.

2.2.1 Climatic Suitability

The most important issue in determining the potential of passive ventilation systems is the suitability of the climate. UNEP assessed Nairobi climatic appropriateness grounded on a single-zone model of passive ventilation heat transfer in office buildings and via application of Bioclimatic Chart shown by **figure 2A below**; their findings are presented herein.

According to U.N.E.P research inferences (2007) though climate change is global concern for major world cities, the climatic change trend as experienced in Nairobi County is so gradual to warrant incorporation of active ventilation designs as recently observed in modern office building.

According to UNEP[2007], direct ventilative cooling was well-thought-out to be useful (although perhaps not sufficient) when outdoor conditions fall below both the cooling set point and the dew point limit yet above the outdoor heating balance point temperature determined grounded on the indoor heating set point temperature limit above.

For night ventilative cooling, no lower limit need be placed on outdoor air temperatures and while the air humidity limit is not likely to be immediately significant for thermal comfort reasons, it will be sustained to avoid moisture-related problems in building materials and furnishings. From the above UNEP findings it's evident that Nairobi region is endowed with opportunities to engage meaningful passive ventilation designs towards construction of office buildings, especially with reference to ventilation.

2.2.2 Ambient Air Quality

A second significant issue in defining the potential for natural ventilation systems in Nairobi CBD modern office buildings and elsewhere is the influence of ambient air quality. While poor ambient air quality affects both active and passive ventilated buildings, there are two reasons for greater concern with passive ventilation.

Typical natural ventilation modes do not incorporate filtration. Although the filtration in mechanical ventilation modes does not eliminate all pollutants from the outdoor air, it largely incorporates some form of particle filtration. Second, in order to achieve ventilative cooling, natural ventilation modes may present far greater quantities of outdoor air into the building.

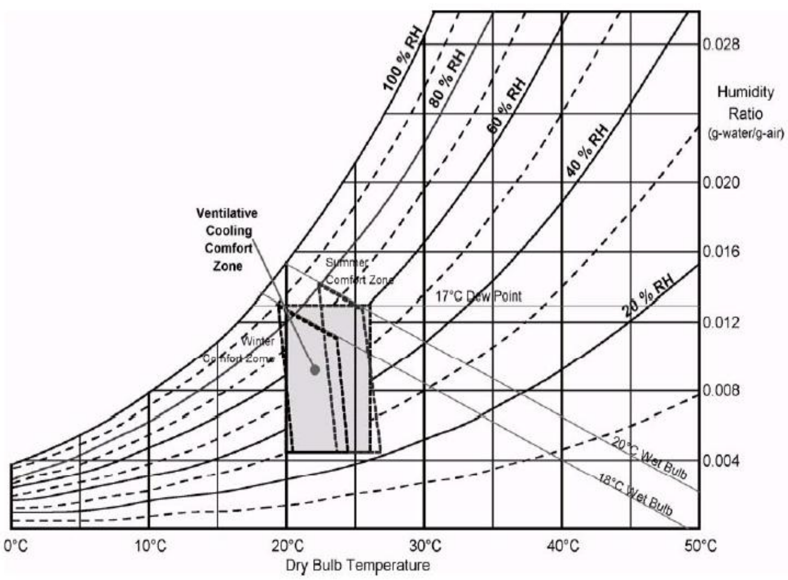

Plate. 2.06: Bioclimatic Chart indicating the ventilative cooling comfort zone used by UNEP to establish Nairobi area is within passive ventilation comfort zones [UNEP, 2007].

According to UNEP, (2007) Nairobi has undertaken many emission control measures for the previous two decades and, as an outcome, significant improvements have been made in ambient air quality. Opportunity still lies within Nairobi CBD in the information that pollutant concentrations that violate the air quality standards may be local and/or seasonal phenomena even within non-attainment regions, the local variation within Nairobi CBD indicates that passive ventilation may still be a viable option for modern office buildings.

Perhaps less obvious is the possibility that an area with a seasonal ambient air quality problem may be able to take gain from some type of hybrid HVAC system that reduces outdoor air intake and/or treats outdoor air during the problem seasons. Even if ambient concentrations of some contaminants exceed suggested limits, the indoor levels may be suitable due to deposition or other elimination mechanisms.

2.2.3 Standards and Regulatory Context

Passive ventilation has long been accepted by ventilation standards and building codes, though not ever in terms of stipulating engineering-based design methods. This segment deliberates on the standards and regulatory context relevant to natural ventilation, specifically the building code Standards.

The Local Government Adoptive By-Laws (1968) where ventilation standards are stipulated currently allows passive ventilation of buildings via a short statement which asserts that:

"Ventilating systems could be active or natural. When passive ventilation and infiltration are relied upon, adequate ventilation shall be evident. When infiltration and passive ventilation are insufficient to meet ventilation air requirements, mechanical ventilation shall be provided."

The standard is not exact as to the meaning of "demonstrable" or "sufficient ventilation." Therefore, it is not specific whether natural ventilation systems need to allow for the same ventilation rates as those required by the standard for mechanical systems. The noted interpretation implies that natural ventilation systems need not provide these rates, but the standard is not very clear about this exception.

The current versions of the Local Government Adoptive By-Laws and its addenda, allow the use of natural ventilation. All of the requirements are in terms of accessible openings that are sized based on 4 % to 5 % of the floor area of the ventilated space. The article does not consider climatic conditions or ambient air quality in their requirements.

2.3 Mechanical/active ventilation

Mechanical ventilation is the exchange of outdoor air provided by mechanically powered equipment e.g. fans (Alspach, P. Brager, G., and Hall, D.H (2011).Mechanical ventilation and air conditioning technologies are continuing to play a dominant role in many office buildings today. These techniques have a growing number of components, require more space and use a substantial amount of electricity. These modes however, have not succeeded to deliver the anticipated indoor climate. The sick building syndrome (SBS) is still more common in mechanically ventilated buildings than in passively ventilated ones (Kleiven, T. 2003).

Active ventilation is frequently considered when a building is located in a noisy area or in areas where the local air quality is poor, hence the use of openable windows for passive ventilation is not a concrete solution. Security contemplations may also lead to the practice of mechanically assisted ventilation in many buildings as it allows the units to be securely locked.

According to Atkinson J, Chartier Y, Pessoa-Silva CL, (2009). "The type of active ventilation used depends on climate. For example, in warm and humid climates, infiltration may be reduced or prohibited to decrease interstitial condensation (which occurs when warm, moist air from inside a building enters through a wall, roof or floor and encounters a cold surface). In these scenarios, an affirmative pressure active ventilation system is frequently used. Conversely, in cold climates, exfiltration should be prohibited to decrease interstitial condensation, and negative pressure ventilation is used. Locally generated pollutant's rooms; such as a bathroom, toilet or kitchen, the negative pressure system is often used."

2.3.1 Types of active ventilation

Ventilation systems work in three main ways:

- Active extract/natural supply
- Mechanical supply/Natural supply
- Combined mechanical extract and supply

According to Koenisberger (1974), the installation of these systems can take the following forms:

- **An exhaust system:** removing the used air and letting fresh air find its way in through grilles and openings (room under reduced pressure)
- **A plenum system:** supplying air into the space and forcing out used air through grilles.
- **A balanced system:** both providing and extracting air. The most dependable, but most expensive system used when combined with warm air heating, as it permits partial recirculation.

They work by using:

- **A circulation system** e.g. a ceiling fan, which creates internal air movement, but does not introduce ‘fresh’ air.
- **A pressure system**, where ‘clean’ exterior air is blown into the building by inlet fans, generating a higher internal pressure than the outside air.
- **A vacuum system**, where ‘stale’ interior air is removed from the building by an exhaust fan, generating a lower pressure inside the building than the outside air.
- **A balanced system** that uses both supply and extract fans, sustaining the internal air pressure at a similar level to the external air and so decreasing air infiltration and draughts.
- **A local exhaust system** that removes local sources of heat or pollutants at their source, such as cooker hoods, fume cupboards etc. (Designing Building Ltd, 2016).

In commercial buildings, active ventilation is mainly driven by air handling units (AHU) linked to duct within the building that supplies air to and extracts air from the interior. They usually encompass an insulated box that forms the housing for; filter racks or chambers, a fan (or blower), and sometimes heating elements, cooling elements, sound attenuators and dampers (Designing Buildings Ltd, 2016)

Heating Ventilation and Air Conditioning (HVAC) refers to a system where mechanical ventilation includes heating, cooling and humidity control. The main components involved in active ventilation include: fans, filters, ductwork, fire dampers and diffusers.

2.3.2 Merits and Demerits of Active Ventilation Systems

The following information is sourced from Atkinson et al, (2009), and Technical Note AIVC 59, (2005).

Merits:

Active ventilation strategies are deliberated to be efficient in providing the designed flow rate, regardless of the impacts of variable wind and ambient temperature. As active ventilation can be incorporated easily into air-conditioning, the indoor air temperature and humidity can also be controlled.

Filtration systems can be fixed in active ventilation such that harmful microorganisms, particulates, gases, odours and vapours can be omitted. Therefore, the quality of ventilation can be controlled. The airflow path in mechanical ventilation systems can be controlled.

Demerits:

Active ventilation strategies regularly do not work as projected and normal working may be intermittent for several reasons, including equipment failure, utility service interruption, poor design, poor maintenance or incorrect management.

Installation and maintenance costs for the operation of a active ventilation system may be very high. If an active system cannot be correctly fixed or sustained due to scarcity of funds, its performance will be compromised.

Air conditioning systems often lead to complaints from the occupants, especially in cases where individual control is not possible. Mechanical systems contribute expressively to energy consumption in a building.

2.4 Reasons behind Adoption of Mechanical Ventilation in Nairobi

Mechanical ventilation strategies are included in the total building design for a number of motives that ranges from industrial necessity to aesthetic appeal to be gained from marketing the building or its use.

The overall technical and aesthetic resolution embraces the use of natural design features to minimize the use of active plant. Good design is visually acceptable as well as being technically competent [Heikkinen and Helmonem, 2005].

2.4.1 Aesthetics and Availability in the Market

Makachia (2001) stresses that, in a tropical context like Kenya, architects are often confronted with briefs requiring utilization of modern materials in high-rise buildings like offices.

This often means attempting to import and implement materials tested elsewhere but whose indigenous environmental viability has hardly been proven.

Nairobi is one such city whose diverse nature and future positioning finds itself in such an uncertain position. Thus aspiration for use of contemporary building materials like glass often may conflict with environmental deliberations of human comfort at the micro level in the spaces created and as well as the urban macro climate.

2.4.2 Affordability and Acceptability

According to Lee (2003) active ventilation design effects on lifestyles and discernments of the environment have been profound: the home, the office, the school have all been sealed off from the outdoors.

It’s remarkable how energy and effort is expended to provide climatic comfort indoors, while at the same time maintaining such unrewarding environments outdoors, at one time it was even proposed that whole cities should be covered by geodesic domes as asserted by Buckminster Fuller (1928): a suggestion that was seriously discussed for some cities, and which takes the problem a step further to the ultimate technological solution.

2.4.3 Marketing Advantage over Competitors

According to Swinborne, H. (2005) building are fully glazed and air-conditioned as a marketing strategy to captivate more tenants, a fact underscored by Makachia (2001) who observes that the 1990's was characterized by an obsession for glass as curtain walling and in windowpanes to most facades.

This trend is set to remain unabated if recent examples like View Park Towers along the Uhuru Highway and University Way Roundabout are anything to go by.

Given that aesthetics is more of a subjective matter than objective no convincing arguments can be offered to dissuade clientele and professionals from opting for it. However, with reference to him, we do have a say regarding objective issues as environmental comfort (ibid).

2.4.4 Internal Comfort

Use of these active systems became a popular vogue as a way of redressing comfort difficulties experienced in glass clad office buildings esteemed to aesthetic appeal though facing overheating problem (Makachia, 2001). The view is underpinned by Heiselberg, (2004): the currently accepted methods of controlling the interior environment of the work place i.e. use of universal air conditioning; are largely wasteful and bear no reference to the precise requirements of individual.

2.4.5 An Abundance of Energy

Makachia (2001) asserts that with regards to building design, cheap and abundant energy has permitted building to evolve, whose climate, form and style are not based on natural constraints. He continues by pointing out that the external containing envelope of buildings becomes the consequence of their internal organization and material structure, in contrast to traditional architecture, where the building façade design is as a result of heat and cold.

2.4.6 Air Pollution

(Randal,2006) Air contamination is a socio-technological disease born out of the Industrial Revolution. It is an adverse change in the physical, chemical and biological features of the atmosphere, caused mainly by compounds which are present in the wrong place. The pollutants have a disastrous effect on life and materials.

2.4.7 Presence of Equipment in the Building

Chadderton, D.(2003) articulates that active ventilation is included in the total building design for a variety of reasons that ranges from industrial necessity to aesthetic appeal to be gained from marketing the building or its use.

The overall technical and aesthetical resolution includes the use of natural design features to minimize the use of active plant. For instance:-

- Heat gains occurring within the building, from people, lights, electrical, catering and mechanical equipment, produce uncomfortable air-temperature for the occupants.
- Vehicles within or close to the high-rise building would cause either internal or external noise. The building has to be air-sealed from the outdoor environment to limit noise penetration and consequently requires active ventilation and possibly refrigeration.
- Close monitoring of the indoor atmosphere is required for manufacturing process such as pharmaceuticals, electronic, nuclear components, and paper and cotton production.

Secure containment of radioactive processes and materials that all possible leakages of contaminated air and dust are eliminated. Full mechanical control of the indoor environment becomes necessary both for the process and for the personnel.

The consistent operation of most microprocessors and electric motors depends upon maintaining a maximum surrounding ambient air temperature of up to 40 degrees Celsius and the plant room requires to be actively ventilated.

2.5 Merits and Demerits of Passive versus Active Ventilation

Various issues should reasonably be considered when comparing passive ventilation strategies to active ventilation alternatives. Here, sets of these issues that are inseparably linked will be considered including:

2.5.1 Cooling Energy Savings and Limits of Applicability

When applicable, passive ventilation can offset cooling energy usage and the associated energy costs and carbon dioxide discharges thought to be related to global climate changes.

The potential cooling energy that may be saved depends, of course, on both the climate in which a high-rise building is located and the relative level of internal and other gains that impact the high-rise building's thermal performance. Clearly, when passive ventilation is not applicable due either to outdoor temperatures or, in some instances, outdoor humidity's that are too high, then these energy savings cannot be realized.

2.5.2 Control and Reliability

At face value, the control and reliability offered by active ventilation systems would seem to be an important advantage when compared to natural ventilation systems. Indeed, this is often cited as the primary reason active ventilation should be preferred to passive. However, in practice, active ventilation strategies are often regulated to control temperature rather than air quality and, thus, may not offer satisfactory ventilation for air quality control. For example, VAV systems, which are frequently used in office buildings, may fail to maintain acceptable air quality for this reason [Leyten and Kurvers 2004].

2.5.3 Building Users Health, Comfort & Productivity

According to Fisk and Rosenfeld (2005), air conditioning aggravates the effects of arthritis and neuritis. It also affects those with sinus disorder. In addition to these obvious reactions to a HVAC controlled environment there are other subtler reactions that can harmfully affect a person's health. Studies between those who have worked for lengthy periods in HVAC controlled offices and those who work outdoors have constantly shown that the people subjected to air conditioning are more prone to colds, flu and other minor ailments. It has also been established that the body experiences a definite amount of stress when it is forced to go from a boiling hot environment into an HVAC controlled one. Over time this, too can cause problems.

2.5.4 Active Ventilation Equipment Cost & Space Requirements

Active ventilation equipment often accounts for a large portion of the cost of construction of new high-rise buildings and the renovation of existing buildings. In larger high-rise office buildings, these costs may be expected to range from 35 % to 45 % of construction costs. Consequently, the original cost savings that may be realized by replacing, or at least reducing, active ventilation systems and cooling by natural ventilation systems is, potentially, quite large.

2.5.5 Duct Cleanliness & Filtration

The spatial, day lighting, air quality, and construction savings benefits that may result from the removal of active air handling systems could, conceivably, exceed the original cost savings offered by replacement of these active systems with passive alternatives.

Consequently, mechanical ventilation systems offer the important benefit of air filtration but with possible cost and health penalties of unclean ducts while natural ventilation systems, as generally configured, prevents the duct cleaning problem altogether yet offer little or no filtration of ventilation airflows.

Passive ventilation proposes the ways to control air quality in buildings, to directly condition indoor air with cooler outdoor air, to indirectly condition indoor air by night cooling of building thermal mass, and to provide refreshing airflow past occupants when desired. While active ventilation systems may also accomplish these goals, passive ventilation systems:

- Can offset cooling energy consumption when climate and operational conditions are suitable,
- Can offset the fan power required to provide ventilation mechanically,
- Potentially provide quantitative health, comfort, and productivity advantages that may, in part, be due to the greater robustness of natural ventilation systems,
- Offers qualitative merits of ‘fresh air’ in the minds of most occupants,
- May offer users greater direct control of their environments and, as a result, may benefit from less limiting comfort criteria that results from occupants’ capability to adapt their environment to their immediate discernment of comfort,
- Can offset a substantial portion of the relatively large original costs linked with conventional mechanical ventilation systems in commercial buildings by simply substituting them with lower cost natural ventilation systems,

- Can recover the large spatial requirements that conventional mechanical systems demand and return them to serve formal architectural, day lighting, and air quality objectives or to reduce non-mechanical construction costs.

2.6 Hybrid Ventilation Strategies

For many centuries, buildings relied on passive ventilation strategies alone. The end of World War II, saw the appearance of "cheap" energy, which brought about the sealed, air-conditioned Modernist box. Architecture was now freed from its connection with the natural surroundings. This type of high-rise building design then spread around the world. Before that period, all buildings were naturally ventilated as active ventilation systems were not advanced enough to sufficiently condition spaces in buildings (Wood and Salib, 2012).

For many years' mechanical ventilation was then, the norm. However, over the past few years, the environment has become more of an issue and passive ventilation technologies have been introduced. Despite their energy efficiency, many ventilation systems relying solely on passive driving forces are normally not able to provide a desired airflow rate all the time. (Kleiven, 2003).

According to Wood and Salib (2012): "In tall office buildings, HVAC (heating, ventilation and air-conditioning) systems account for about thirty three percent or more of overall high-rise building energy consumption. Additionally, half of that percentage is due to incapacitating the heat gains due to lighting, occupants, miscellaneous power and solar and thermal gains and losses. It is rare for a significant high-rise office building to rely one Hundred percent on passive ventilation.

Tall high-rise office buildings tend to have greater floor area sizes, higher population density and higher internal heat gains through equipment. They therefore tend to be more difficult for passive ventilation to be achieved than in residential or hotel buildings which have smaller floor plate depths, cellular layouts, and greater contact with the outside envelope."

In recent years, the large focus on the environmental impacts of energy production and consumption has provided an improved responsiveness of the energy used by fans, heating and cooling coils and other equipment in ventilation and air conditioning systems. Thus, ventilation systems that combine both passive and active ventilation technologies have developed. These hybrid ventilation systems have been driven by the expectation that annual energy costs should reduce (Heiselberg, 2006).

Data from case studies conducted in the international project IEA ECBCS-Annex 35 (Heiselberg, 2002), show that substantial energy savings have been made in a number of buildings, mainly because of a very substantial decrease in energy use for fans and a reduced energy use for cooling.

In buildings today, the outdoor surroundings should be utilized to create tolerable indoor surroundings. Sustainable policies such as natural cooling, day lighting and passive ventilation should be optimized. Ideally, these strategies should fulfil the demands for heat, light and fresh air. They are also well accepted by occupants if optimally controlled and be encouraged where possible. However, in most cases supplementary active systems are needed. In spite of that, mechanical ventilation systems have been under scrutiny. This has been due to improved responsiveness of the energy used by fans, heating and cooling coils and other equipment in ventilation and air conditioning systems (Heiselberg, 2002).

Unfortunately, in the nature of ventilation systems in many office and educational buildings today, the choice has become that of choosing either natural or mechanical ventilation. This has prevented the widespread use of sustainable technologies because with passive ventilation alone, a definite level of performance cannot be guaranteed under all conditions.

Therefore, this has led to a blend of the best composition of each system to create what is known as a hybrid ventilation system (Heiselberg, 2002).

Heiselberg, (2002), defines hybrid ventilation as: “strategies that offer a relaxed internal surrounding using both passive ventilation and active systems, but using various features of these systems at altered times of the day or season of the year. In hybrid ventilation active and passive forces are united in a two-mode system where the operating mode differs according to the season, and within individual days. Thus the active mode reflects the external surroundings and takes maximum benefit of ambient conditions at any point in time. The main difference between a conventional ventilation system and a hybrid system is that; the latter has an intelligent control system that can switch automatically between natural and mechanical modes to purposefully minimize energy consumption.”

Hybrid ventilation strategies include two operating modes, which vary in operation depending on the season. As this system is in a position to get access to both ventilation modes, it permits the best ventilation mode to be chosen according to the current circumstance.

The major difference between regular ventilation systems and a hybrid system is that the latter has an intelligent control system that can switch automatically between natural and mechanical modes in order to minimize energy consumption (Heiselberg, 2006).

A hybrid system varies from a conventional ventilation system in that the former can switch automatically between passive and active modes in order to minimize energy consumption through the use of an intelligent control system (Heiselberg, 2006). Hybrid ventilation depends highly on the outdoor climate and microclimate around the building, and the thermal behaviour of the building. It is therefore necessary to take these factors into consideration at the early stages of design.

When designing a hybrid ventilation system is it is often required that ventilation design for interior air quality control is separated from ventilation design for natural cooling. This is mainly because devices for indoor air quality control and thermal comfort control are quite different, therefore have different challenges to be solved (Heiselberg, 2002).

Users of a space should have the maximum possibility of controlling their own environment. However, automatic control is still needed to support the users in achieving a comfortable indoor climate and to take over during non-occupied hours.According to Meinhold and Rösler (2002), in some cases users strongly appreciated the manual control and refused a fully automatic system, but measurements showed that the active system was seldom applied and that the air quality in some periods was very low. Automatic control is also needed during non-occupied hours to decrease energy use and to precondition rooms for occupation, i.e. to provide and control night cooling.

For hybrid ventilation, it is important that the ventilation system and the control system are designed together in one process. Many of the hybrid ventilation components are also integral parts of the building (Heiselberg, 2006).

Hybrid ventilation is applicable in the following circumstances, (ASHRAE Green Guide, 2006):

- When the owner and design team are willing to explore employing a nonconventional high-rise building ventilation technique that has the ability of minimising on-going operating costs as well as providing a healthier, stimulating surrounding.
- When it is determined that the building users would accept the notion of using the outdoor surrounding to determine (at least, in part) the indoor environment, which may mean greater variation in conditions than with a strictly controlled environment;
- When the design team has the proficiency and willingness, and has the charge from the owner, to devote the additional effort to generate the integrated design needed to make such a technique work successfully;
- Where extreme outside conditions, or a specialized type of high-rise building use, do not preclude the likelihood of the successful application of such a technique; buildings with atriums are particularly good candidates."

Hybrid ventilation is mainly described by: hybrid ventilation principles, the control strategy for IAQ, the specific boundary conditions and components as well as the level of building integration (Heiselberg, 2006).

Hybrid ventilation should be accompanied with appropriately developed and implemented control strategies. To achieve this, sensors are required in the high-rise building in order to measure temperature, IAQ and occupancy, as well as actual weather conditions (Santamouris, 2007).

2.6.1 Hybrid Ventilation Strategies

The Chartered Institute of Building Services Engineering (CIBSE AM13, 2000) categorizes physical hybrid strategies as follows:

Contingency designs: these are usually passively ventilated buildings that have been carefully planned to permit the selective additions of active ventilation and cooling systems, when this is needed.

Complementary designs: passive and active systems are both present and are designed for combined operation.

Zoned designs: these allow for differing servicing strategies in different parts of the building.

The ASHRAE Green Guide, (2006) however categorizes the strategies into two main variants:

The changeover (or complementary) type: spaces are ventilated either mechanically or passively, but not both simultaneously. The controls for this type are able to switch between active and natural ventilation seasonally, diurnally, or on a measured parameter.

The concurrent (or zoned) type: both methods offer ventilation simultaneously, though usually to zones discrete from one another. In this case controls are needed to prevent “fighting” between the two ventilation methods.

2.6.2 Hybrid Ventilation Principles

The International Energy Agency–Energy Conservation in high-rise Buildings and Community Systems (IEA-ECSBC) Annex 35 (Heiselberg, 2002), defines the following hybrid ventilation principles:

• **Passive and active ventilation:** This principle relies on two fully autonomous strategies where the control strategy either switches between the two systems, or uses one system for some tasks and the other system for other tasks. For example, it can use systems with active ventilation during occupied hours and passive ventilation for night cooling.

• **Fan-assisted natural ventilation**: this principle is based on a passive ventilation system combined with an extract or supply fan. It covers natural ventilation systems that, during periods of weak natural driving forces or periods of increased demands, can enhance pressure differences by mechanical (low-pressure) fan assistance.

• **Stack and wind-assisted active ventilation:** this principle is based on an active ventilation system that makes optimal use of natural driving forces. It covers mechanical ventilation systems with very small pressure losses, where natural driving forces can account for a considerable part of the necessary pressure.

2.6.3 Advantages and Demerits of Hybrid Ventilation

The following are merits and demerits of hybrid ventilation according to the ASHRAE Green Guide (2006):

Advantages:

- It helps to minimise energy otherwise required from conventional sources
- It could cause a lower building life-cycle cost;
- It could create a healthier environment for building occupants; and improve occupant satisfaction due to the increased ability to exercise some regulation over the ventilation provided;

- There is more flexibility in the means of providing ventilation; the passive variant can act as backup to the active system and vice versa;
- It could prolong the life of the equipment involved in providing active ventilation since it would be expected to run less.

Disadvantages:

- Failure to integrate the mechanical aspects of a HV system with the architectural design could result in a poorly functioning system;
- Extra first costs could be suffered since two systems are being provided where only a single one would be provided otherwise, and controls for the passive system could be a major portion of the added cost;
- If automatic operable window openers are utilized, these could result in security breaches if appropriate safeguards and overrides are not provided;
- Building operators may have to have distinct training to comprehend and learn how best to operate the system;
- Users would perhaps need at least some orientation so that they would comprehend and be understanding of the differences in conditions that may prevail with such a system;
- Special care would need to be given to certain safety concerns, such as fire and smoke propagation in case of a fire;
- It is hard to predict situations under all possible circumstances.

CHAPTER THREE: RESEARCH METHODOLOGY

3.0 Introduction

This Chapter seeks to outline the various methods used to attain the aims and objectives outlined in Chapter one of the study. It also seeks to provide a thorough explanation on the use of the research methods, the data collection methods used and how the data is compiled, interpreted and documented.

To investigate the research problem, case studies were conducted to uncover and document the optimal blend of hybrid ventilation in modern high-rise office buildings within Nairobi, focusing on the parameters studied in Chapter 2 of this study.

3.1 Research Purpose

This is an exploratory research whose aim is to make a case for the optimal blend of hybrid ventilation in modern high-rise office buildings in Nairobi. The research seeks to find out the existing modes of ventilation used within selected high-rise office buildings in Nairobi's Central Business District (CBD) to portray an accurate state of affairs and suggest hybrid ventilation as an alternative best solution for ventilation. This is predicated on the information discussed in Chapter 2.

3.2 Research Strategy

Case studies are used as the strategy for data collection as the method is ideal for carrying out exploratory research and allows for the study of existing provisions for natural and mechanical ventilation in high-rise office buildings in addition to creating the case for the use of hybrid ventilation. The case study method also allows for comparison across the chosen study buildings and is preferred as it answers the 'what' and 'how' questions earlier on stated under research questions in Chapter one of this thesis. Analytical generalisations are then made from these cases by testing the literature reviewed (secondary data) against the data gathered (Johansson, 2003).

Criteria for case study engagement

In various studies, resource provisions bound the population to which the selection measures can be applied. However with a purposeful sample, there is a natural reciprocity between selection criteria and opportunity, or serendipity, encountered when operationalizing the study in the field of practice.

Criteria that may be used for selection include:

Enterprise/Institute Characteristics

Industry segment

Scope

Place

Number of sites

Proportion of staff employed

In addition to selecting a sample, there may be a sequence of circumstances that each case must meet to be offered for assortment such as:

Available for a specific time

Prepared to sign a covenant

Having a varied practice surroundings

Having specific practices in operation

Not having a surrounding, scope or structure duplicated by another case

The case studies considered for this study are: ICEA building, Lonrho House building and I&M bank towers.

3.3 Time Horizon

This research takes a cross-sectional study approach to acquire primary data as it is conducted within a short time frame, not exceeding six months. The kinds of ventilation used in the high-rise buildings are noted and the possibility of integrating hybrid ventilation is investigated over the said time period, after which the collected data is analysed to make conclusions and recommendations on the parameters under study.

3.4 Sampling Design

The author relied heavily on purposive sampling (also known as judgment sampling) i.e. application of author's own sound judgment when choosing members of population to participate in the study with a belief that he can obtain a representative sample which will result in saving time and money.

Based on the objectives of the study an application of questionnaire to collect primary data was done purposively on 3 (Three) buildings (ICEA Building, Lonhro House, I & M Building) which were 15 (fifteen) floors and above; judged to be homogenous and a reasonable cross-section of the other 13 (Thirteen) surveyed buildings within CBD namely; Anniversary Towers, Hazina Towers, AM Bank, View Park Towers, Nyayo House, KICC, Times Tower, Teleposta, Cooperative Bank,National Bank, Re-Insurance Plaza, Uchumi house, International Life House.

An analysis of the case studies were further conducted in order to find out how effective hybrid ventilation is, in comparison to mechanical and natural ventilation methods, this was achieved by using purposive random sampling of the respondents (building occupants) to enhance credibility.

3.5 Data Collection Methods

The research relies heavily on the following data collection methods for the collection of primary sources of data:

Observation

These included observations made within the study areas, documented using sketches, plates and measured drawings. Plates are applied as a major tool to capture the existing situation and for use later on during the study to support text during the analysis of information obtained from the field. Observation is preferred in this study as it provides reliable first hand data from the study area. Direct observation enabled the researcher to put the elements of study in context and therefore understand them better i.e the author identified mechanically ventilated buildings by observing the following attributes availability of fans, ducts, refrigeration, air tight windows etc. whereas passively ventilated building were identified by pronounced sizes of fenestrations facing North and south, narrow floor plans etc.

Physical measurements

Physical measurements were taken in the selected offices for the reason of spatial analysis, with reference to building design depths to further establish if the created space is suitable for either natural or mechanical ventilation.

Questionnaires

The goal of the questionnaire is to acquire data from the users of the spaces. This is to comprehend the research topic through the eyes of the users of the spaces. Structured questionnaires were furnished for this purpose.

Interviews

The exploratory nature of this research necessitated the reliance of interviews to comprehend the perception of the users of the offices as well as the architects who designed them and for them to give their judgment about the aspects under study.

Unstructured interviews were used, but bearing in mind a specific set of questions related to their perceptions in addition to its perceived impact on their wellbeing and productivity. Unstructured questions were administered to avoid leading interviewees on to answers expected from them. One question therefore led to another reliant on the response given to leave the interviewees at liberty to answer the questions extensively.

3.6 Data Processing and Analysis

After collection of data from both case studies and desk studies, the information was processed, analysed and interpreted using the subsequent methods:

Tables

Tables were used to convey columns of textual, graphical and numerical information especially for ease of comparison of findings from the buildings that were studied during fieldwork.

Plates

Photography was used for capturing and documenting parameters of the study. It aided in presenting the physical conditions of the cases. Plates were analysed through annotation and used in supporting the findings from fieldwork studies.

Architectural drawings and models

Based on measurements and plates, architectural drawings (plans, sections and elevations) were generated in order to graphically represent information gathered during fieldwork.

CHAPTER FOUR: CASE STUDIES

4.0 Introduction

This chapter document and analyse observations made during fieldwork on the ventilation design in contemporary high-rise office buildings in Nairobi's CBD.

In line with the objectives which were to study the existing state of ventilation design in high-rise office buildings in Nairobi, to establish the importance of both natural and mechanical ventilation methods in modern high-rise office buildings in the interior of Nairobi and to examine the importance of integrating hybrid ventilation in high-rise office buildings in Nairobi, this chapter will seek to meet these objectives by analysis of three buildings.

From the literature review, benefits and demerits of each kind of ventilation type in buildings were discussed and certain themes were developed that are going to be used in analysing the data in this chapter. These themes revolve around general ventilation performance, thermal comfort and indoor air quality. The three buildings will be examined in line with these themes.

A brief narrative of each of the cases studied will be given, alongside a brief overview of the ventilation strategies employed in each case. The efficacy of the ventilation strategy will be supported by occupant opinions as gathered by the questionnaires. Following the brief introduction, the chapter will then narrow down into a documentation of the observations made from the case study of high-rise buildings. A summary of the fieldwork documentation and analysis will then conclude the chapter.

4.1 Case Study 1: ICEA BUILDING

4.1.1 Introduction

ICEA is a naturally ventilated 19 story general office building completed in 1982 by architect Richard Hughes and Partners. The building sits on a rectangular site bounded by Kenyatta Avenue, Wabera Street and Banda Street. The building design includes a podium which is two storeys and a tower which goes up by 16 floors from the podium. With its distinctive staggered facade, the ICEA building represents some of the buildings designed around the 1977 period, with a strong climate responsive design.

The immediate context of the ICEA building includes the following buildings: Jamia mosque to the North West, McMillan library to the North, and the old Standard Bank Building. One challenge the architect therefore faced was how to balance in such a massive building, whose size was dictated by the plot ratio requirements, in a context of buildings of much smaller scale. The other challenge posed was to design a building that was responsive to the climatic conditions of Nairobi while maintaining the spatial requirement.

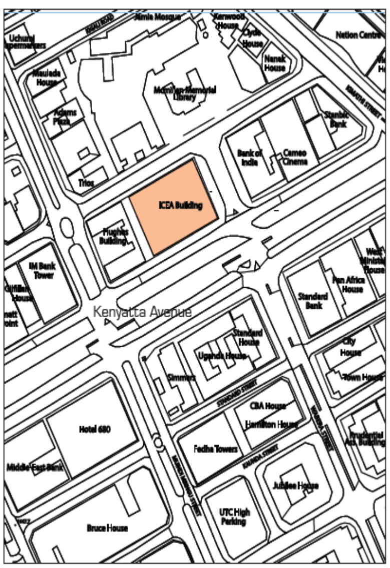

Plate. 4.01: Location of ICEA in the CBD. (Source: Author, 2016)

Plate. 4.02: ICEA building (Source: structurae.net,2016)

Plate. 4.03: ICEA building (Source:www.jkuat.ac.ke,2016)

Most high-rise buildings on Kenyatta Avenue have incorporated passive design strategies on their facade. Most of these high-rise buildings were designed through the early eras of the 1960s. Different solar control strategies have been applied on their facades.

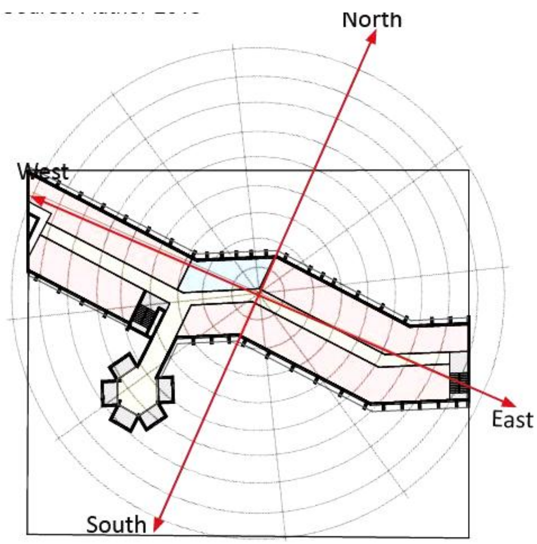

Plate. 4.04: ICEA building
(Source: Author, 2016)

Plate. 4.05: ICEA building
(Source: Google images, 2016)

The facade of this high-rise building is also oriented purposefully to sun shade itself and its interior from direct sun light coming from the east and the west directions. The longer elevations of the building facades are oriented to face the North and South directions.

4.1.2 Ventilation Design

The high-rise building's façade is characterised by the podium, the tower and the lift shaft. The podium is characterised by a slanting glazed canopy which consists of glazing shaded with metallic louvers to protect the canopy from direct sun. The podium houses the ground and mezzanine floors. The ground floor has a height of 4,500mm with a mezzanine floor of 4,400mm.

The high-rise building is designed for passive ventilation in the following ways:

Provision of operable windows: The windows in the high-rise building are operable with clear solar glass that allows in natural light during the day. They are mostly all sliding windows and measure 3,600 X 3,000 mm high allowing sufficient air in to the spaces. There are also high level louvres that allow added air movement in and out of the spaces.

On the ground floor, the windows are mainly for display for the shops which are housed here. They are 4000mm wide by 3200 high and are placed 1000mm above finished floor level. On the mezzanine level, the windows are the same as the ground level but are not visible from the external elevations because of the glazed canopy which surrounds them. They are only partly visible from the arcade inside the high-rise building. The windows on the tower are also placed on the northern and southern facades, with none on the Eastern and Western facades.

Fixed glazing is found on the lift shaft which rises above the office tower due to machine room provision. These windows go all the way to the top and provide those using the lift with a panoramic observation of the city.

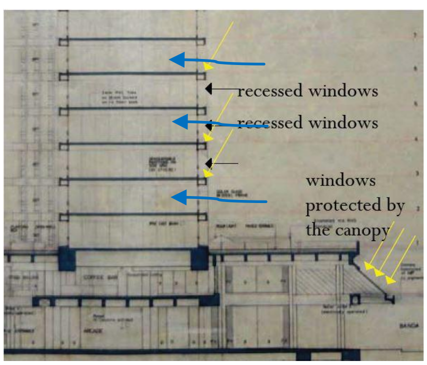

Plate. 4.06: Section through the ICEA building showing air flow.

(Source: Architect,2016)

Plate. 4.07: Entrance to the ICEA building and the arcade. (Source: Author,2016)

Plate. 4.08: Display windows at the ground floor shops. (Source: Author,2016)

Plate. 4.09: ICEA building arcade. (Source: Author,2016)

Building orientation: In Nairobi, wind direction mostly flows from North to South direction. However the building is oriented with the long facades which have all the fenestration, facing North-South. This is mostly to mitigate the effects of solar radiation. The shorter sides of the building which have no windows except on the ground floor face East-West.

Narrow floor plan: In all the office spaces the windows are located across each other to provide for cross ventilation, the interior corridor separating the northern and southern offices has a width of 2000 mm and a height 3500 mm with permanent vents on either sides enabling stack driven cross ventilation. This is facilitated by the thin plan of the office tower. Heat accumulation within the building is therefore easily flashed out by opening of the windows which allow free movement of air, flashing out accumulated heat humidity.

Plate. 4.10: Plan of the tower showing cross ventilation. (Source: Architect author, 2016)

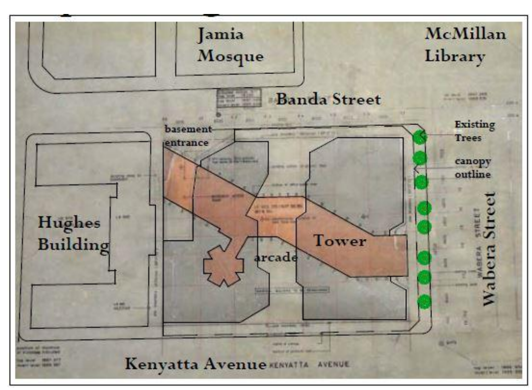

Plate. 4.11: ICEA building site plan. (Source: Architect author, 2016)

4.1.3 Questionnaire findings

Number of Respondents: 30

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE
GENERAL					
1. There is flexibility to open or close windows, easing regulation of air flow within the office.	16	11		4	
2. Air circulates adequately within the office.	7	15		6	
3. I mostly keep windows open at the following times of the day. (Indicate the number of hours within the brackets)					
7am-10am (hours)	13		7	10	4
10am- 1pm (hours)	11	10	5		
1pm- 4pm (hours)	17	5	7	6	
4pm- 7pm (hours)	10		7	6	11
4. Keeping windows open sometimes interferes with my work. (Also rate interference using the below)		18		11	7
• Distracting noise from the outdoors		12	6	10	8

• Strong winds that lift paperwork	7	8	5		17
• Winds carry foul polluted air indoors		11	5	11	12
INDOOR AIR QUALITY					
5. I find the ventilation levels within the office premises sufficient	16	7	4		8
6. The office space sometimes has mild odours.	11	7	4		8
7. Some results of the type of ventilation used within the office space include the following:					
Bad odour		7	5	6	14
Dust	19	13	2		
Dry skin		3	4	7	15
Headache			1	3	6
Nose/throat irritation	9	6	7	7	
THERMAL COMFORT					
8. The office space never gets too hot in the afternoons.	8	5	5	12	
9. On hot days, keeping windows open keeps the office space comfortable.	14	10	1	9	

4.2 Case Study 2: LONRHO HOUSE

4.2.1 Introduction

Lonrho house is a fully actively ventilated 20 storey building completed in 1991 to be Lonrho Africa’s Headquarters. It is situated between Kaunda Street, Press lane and Standard Street.

The architects were asked to design a modern commercial high-rise that was to be constructed above and within an current, poorly built, three floor building occupied by users who could not be lawfully ejected, and whose day to day business had to progress. The building was also envisioned to depict a corporate image and use modern technology. The result was a fully air-conditioned building which was technically and materially modern.

The rectangular site is confined by two streets and a minor lane: Standard Street to the north, Banda Street to the south and Press lane to the west. The main entrance of the building was designed to be along Press lane. Eventually the architect moved the primary entrance from Press lane to Standard Street since it was more frequently used.

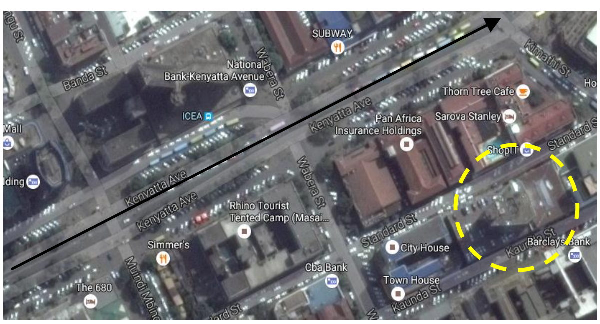

Plate. 4.12: Lonrho house aerial view.
(Source: Google maps, 2016)

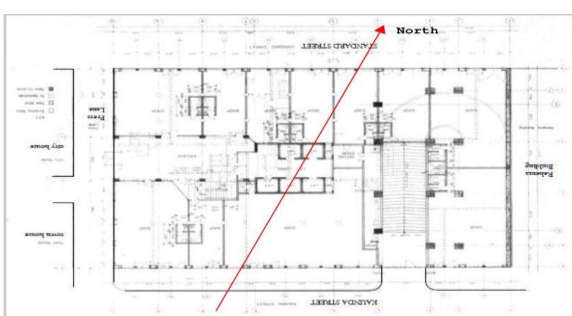

Plate. 4.13: Lonrho house site plan
(Source: Architect, author 2016)

In its context, Lonrho house is the only building with a fully glazed airtight facade on its tower. The building houses shops offices and a ground floor restaurant which occupies the space that was initially the main entrance to the building. This restaurant space also spans vertically to the height of the mezzanine floors. The mezzanine floors are all designed around the restaurant space as a form of a courtyard.

The high-rise office tower has 15 floors which house offices organized along horizontal circulation corridors. The existing building upon which the tower was built became the new podium. This is accessed through the lifts and stairs located within the service core. The wash rooms are positioned behind the lift shafts and the stairs. Their location makes them easily accessible from all the offices. The skin of the building at the tower level is purely glass with steel supports.

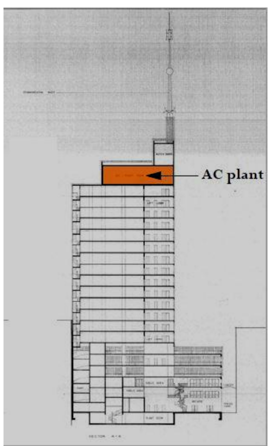

Plate. 4.14: Lonrho house elevation (Source: Architect author 2016)

Plate. 4.15: Lonrho house building in its context (Source: planning-kenya.com (2016)

4.2.2 Ventilation Design

As it is fully mechanically ventilated, the building consists of an air tight outer skin. There are no operable windows both at the podium and the tower level. Only the parking level is open to allow unrestricted flow of light and air and remove exhaust from vehicles. At the ramps, the curtain wall is substituted with a mesh, which allows the free movement of air in and out of the spaces.

The high-rise building is supplied with air by a main plant located at the top floor of the building. The high-rise buildings users are able to control the internal temperatures of the high-rise building by setting a certain desired room temperature. The air conditioning also resets fluctuating temperatures to a dictated internal temperature. The external climate does not interfere with the building in any way.

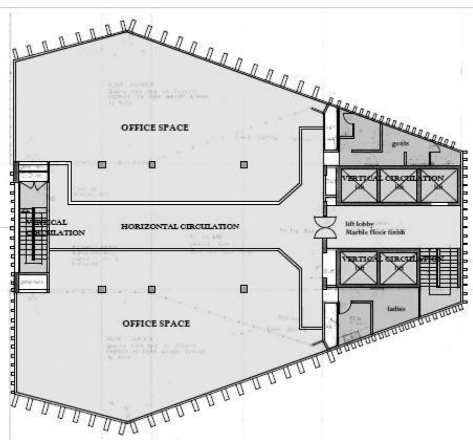

Plate. 4.16: Lonrho house typical floor plan Source: Architect (author modified)

Plate. 4.17: Lonrho house view of the sealed façade from the interior.
Source: Architect (author modified)

On the ground level, air flows in through the main doors although this area is still air conditioned as well. Hot air leaves these spaces through the high level vents located at the ceiling level of the floors. The mechanical means used in this building require additional energy and this kind of building therefore has greater energy consumption than buildings that use passive design strategies.

With reference to air quality, different offices have different air qualities depending on their function and number of people using the space. This also contrasts according to the AC settings used. The corridors however are slightly stuffy and warmer than occupied office spaces; a fact occasioned by deeper space planned to be ventilated mechanically but probably inefficient.

Plate. 4.18: Lonrho house entrance. (Source: Author, 2016)

Plate. 4.19: AC in one of the shops (Source: Author, 2016)

4.2.3 Questionnaire Findings

Number of Respondents: 24

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE
GENERAL					
1. There is flexibility to open or close windows, easing regulation of air flow within the office.				3	20
2. Air circulates adequately within the office.		11	6	5	
3. I mostly keep windows open at the following times of the day. (Indicate the number of hours within the brackets)					
7am-10am (hours)					23
10am- 1pm (hours)					25
1pm- 4pm (hours)					24
4pm- 7pm (hours)					
4. Keeping windows open sometimes interferes with my work. (Also rate interference using the below)				8	15
• Distracting noise from the outdoors					

• Strong winds that lift paperwork					
• Winds carry foul polluted air indoors					
INDOOR AIR QUALITY					
5. I find the ventilation levels within the office premises sufficient	11	7	2	3	
6. The office space sometimes has mild odours.	13	5	7		
7. Some results of the type of ventilation used within the office space include the following:					
Bad odour	9	7	3	6	
Dust		1	2	3	2
Dry skin	12	4	3	6	
Headache	10	4	4	7	
Nose/throat irritation	9	6	5	3	
THERMAL COMFORT					
8. The office space never gets too hot in the afternoons.	11	6	5		
9. On hot days, keeping windows open keeps the office space comfortable.					25

4.3 Case Study 3: I&M BANK TOWERS

4.3.1 Introduction

I&M is a hybrid ventilated building completed in 2001. It is situated in the CBD on a rectangular site bounded by Kenyatta Avenue, Muindi Mbingu Street and Banda Street. The building has seventeen storeys and additionally it's the main headquarters for I&M bank limited. The high-rise building has a conspicuous blue curtain walled façade and stands out as the most modern looking building along Kenyatta Avenue. The plan of the high-rise building is profoundly inclined by the Global style of architecture which heavily applies full glazing on building facade. It also towers above a number of buildings along that street.

This building is comprises of a podium, annex and a tower. The tower goes up by 17 floors while the annex is composed of 3 levels. The tower appears to be continuous from the ground along Kenyatta Avenue. The high-rise building is mainly an office building with shops at the ground floor and an auditorium at the top floor.

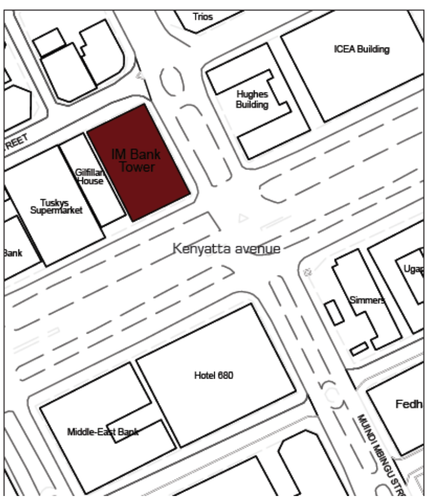

Plate. 4.20: Location of I&M in the CBD.
(Source: Author (2016)

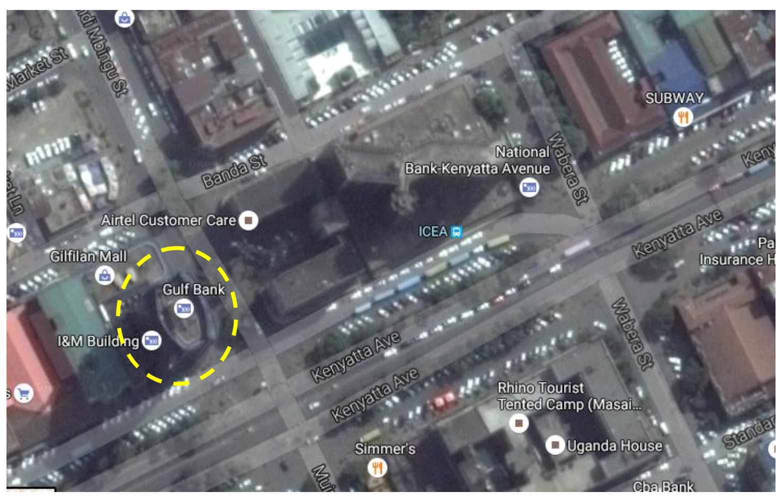

Plate. 4.21: Google map showing location of I&M in the CBD.
(Source: Google maps (2016)

I&M Bank Tower was also not built on site. Its blocks were made off site and re-assembled to site. It is also one of the few high-rise buildings that can accommodate whole side deconstructed and re-plugged. The reason for this is that throughout its construction, its transformers and generators were to be installed in the basement, which had been assigned as parking space.

On the ground level the high-rise building has an arcade opening up the high-rise building to both Kenyatta Avenue and Muindi Mbingu Street. The cornered design of the arcade discourages secondary users from walking through it. Even then, present day management of the high-rise building has seen the arcade closed along the Kenyatta Avenue entrance due to security issues. Access to the high-rise building is therefore restricted to one main entrance along Muindi Mbingu Street.

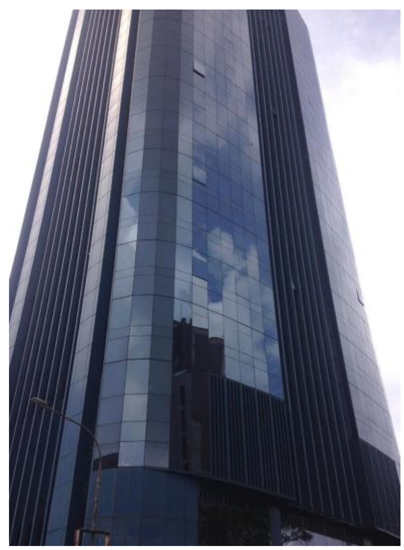

Plate. 4.22: I&M building.
(Source: Author 2016)

Plate. 4.23: I&M building façade
(Source: Author 2016)

4.3.2 Ventilation Design

The high-rise building is oriented with the extended facades facing East-West. The western facade of the podium has no openings mainly because it is in direct connection with the neighbouring building. The eastern façade of the tower is fully glazed. This façade is also where services are located.

On the ground floor level, the high-rise building has shops which have wide display windows. The windows are 2,000 mm high, with clear glass that permits light to penetrate into the shop interiors. The wide display windows however are air tight and are not operable. The ventilation of these spaces is through vents provided at the top of the display windows. Air also streams through the wide double doors that open up the shops to the street. Hot air therefore exits the space through the vents at the top of the display windows. However some shops at this level like the Safaricom shop have sealed off the high level vents provided for natural ventilation, citing dust penetration into the usable space through these vents.

The second level of the tower houses the main plant room. This space is naturally ventilated by use of grilles to allow the free movement of air in and out of the generator room. The grilles are noticeable on the building's facade. On the rest of the tower, top hung windows are allowed for which are operable and allow in passive ventilation into the building. This allows the users of the high-rise building to opt for passive ventilation if they require it.

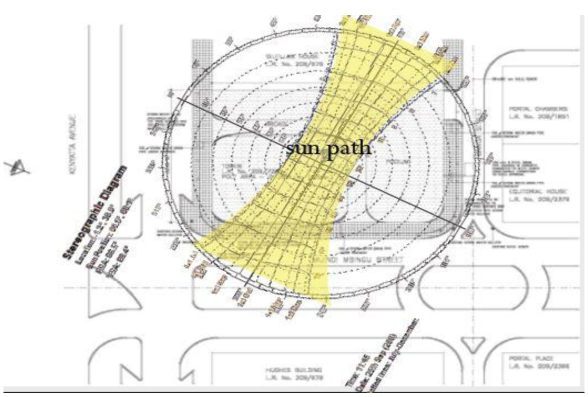

Plate. 4.24: Site plan of I&M indicating sunpath. (Source: Author (2016)

Plate. 4.25 Entrance to I&M arcade. Natural air vents also indicated. (Source: Author (2016)

However the high-rise building also uses artificial ventilation which ensures that when the internal temperatures are above or below comfort zone, they are rectified to the prescribed temperature. Owed to the glazed curtain walling, the interior spaces rely heavily on mechanical means to provide acceptable indoor temperatures. The floor plan is also too deep (spans beyond 7000 mm) to be naturally ventilated. The number of AC in the high-rise building is 61 units.

The high-rise building has four basement levels; the top level of the basement has some natural ventilation which flows into the space through the vents that are located under the display windows on the ground floor level. These vents let out hot air from the basement allowing in the flow of unpolluted air into the space. The rest of the levels use mechanical ventilation. At the roof level, there are smoke extractors that remove smoke out of the region below in case of fire.

Plate. 4.26: Interior view. Source:

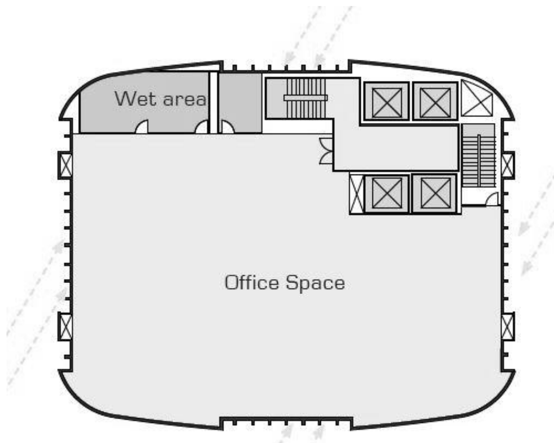

Plate. 4.27: Typical floor plan. Source: Planning Systems Services (Author 2016)

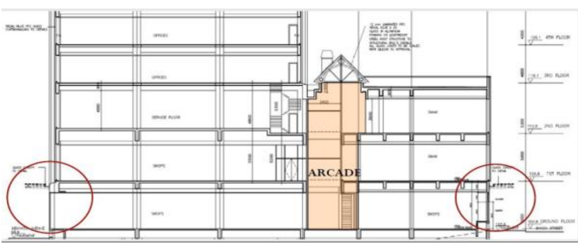

Plate. 4.28: Section through the building. (Source: Planning Systems Services (Author 2016)

4.3.3 Questionnaire Findings

Number of Respondents: 28

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE
GENERAL					
1. There is flexibility to open or close windows, easing regulation of air flow within the office.	11	8	3	4	
2. Air circulates adequately within the office.	8	7	9		
3. I mostly keep windows open at the following times of the day. (Indicate the number of hours within the brackets)					
7am-10am (hours)			7	12	8
10am- 1pm (hours)		6	8	13	
1pm- 4pm (hours)		12	6	8	
4pm- 7pm (hours)		4	4	9	12
4. Keeping windows open sometimes interferes with my work. (Also rate interference using the below)		19		8	
• Distracting noise from the outdoors		15	8	4	

• Strong winds that lift paperwork		8	4	14	
• Winds carry foul polluted air indoors		16		12	
INDOOR AIR QUALITY					
5. I find the ventilation levels within the office premises sufficient	12	8	8		
6. The office space sometimes has mild odours.		14	4	8	
7. Some results of the type of ventilation used within the office space include the following:					
Bad odour	4	13	5	8	
Dust		8	4	15	
Dry skin	12	7	4	4	
Headache	17		3	8	
Nose/throat irritation	12	8	4	4	
THERMAL COMFORT					
8. The office space never gets too hot in the afternoons.	16	7	5		
9. On hot days, keeping windows open keeps the office space comfortable.	11	9	7		

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

Having undertaken a study looking into the optimal use of hybrid ventilation carried out by looking into case studies of selected offices located in Nairobi's CBD, this chapter is geared to summarize the results of the undertaken case studies and conclude the study by addressing the objectives set out in Chapter 1 of this study.

In addressing the objectives of this study, which include establishing the current ventilation systems used in high-rise office buildings in an effort to propose hybrid ventilation as an optimal solution, it became clear that hybrid ventilation is still not widely considered as an optimal resolution and has not been well documented in Nairobi.

In concluding this study, this chapter will therefore be the platform for generating recommendations, which will be guidelines on the practical importance of hybrid ventilation in office with the aim of understanding its benefits. As such, this is the peak of this research.

5.1 Summary of Findings

From the literature review, data collection and analysis of three high-rise buildings in Nairobi CBD, various findings were deduced. A summary of the findings are presented in accordance with the objectives of this dissertation, which were to study the existing state of ventilation design in high-rise office buildings in Nairobi, to establish the benefits of both natural and mechanical ventilation methods in modern office buildings within Nairobi and to investigate the importance of integrating hybrid ventilation in high-rise office buildings in Nairobi.

On examining the existing state of ventilation design in high-rise office buildings in Nairobi, buildings in Nairobi have various ventilation systems as examined in chapter four of this study. With the knowledge of different kinds of building ventilation systems, accumulated in literature review, the author was seamlessly able to study the particular conditions of each ventilation system and its effects on the occupants of the buildings.

The three buildings that were examined; ICEA building, Lonrho house building and I&M building, provided comprehension into the state of ventilation strategies in high-rise buildings in Nairobi, exhibiting their different characteristics and implications on the buildings occupants. They all have different ventilation strategies which had different and in some situations similar attributes. The general findings were that most high-rise buildings in the CBD use either natural or mechanical ventilation while few are intentionally designed to support hybrid systems.

On establishing the importance of both natural and mechanical ventilation methods in modern high-rise office buildings within Nairobi, the results from the questionnaires showed that building occupants generally prefer natural ventilation as it brings in clean air from the outside, however, active ventilation is mostly used to offer a certain design aesthetic to a building and for easier flexibility in design without being constrained by climatic factors.

On investigating the importance of integrating hybrid ventilation in high-rise office buildings in Nairobi, the study revealed that this would actually be a good solution for buildings in the CBD as they would be in a position to maintain some flexibility in design as they do not have to fully rely on passive ventilation while at the same time cutting the costs of using a fully passively ventilated building. The building users would also be relatively satisfied as they would be allowed more choice with reference to the comfort of their work environment.

5.2 Case Study Conclusions

ICEA Building

ICEA is a naturally ventilated building. From the data collected by observation and from the users' opinions, the following assumptions can be drawn. Natural ventilation is an effective method, if a building is well designed for it.

Some offices in the high-rise building however had floor to ceiling partitions which interrupted cross ventilation and caused the spaces to be stuffy. Cross ventilation worked best in the open plan offices and was most effective and pleasant in these cases. During cold periods however, users do not prefer to have their windows open, which causes the interior air quality to decrease and odours to easily spread. Also dust was a major factor that deterred occupants from leaving their windows open for long periods.

Lonrho House building

Lonrho House is a fully actively ventilated building. From the data collected by observation and from the occupant's opinions, the following assumptions can be drawn. Active ventilation is beneficial as it is easily controls the internal environment of a building and prevents unnecessary dust from accumulating. It also allows a building to be designed flexibly according to the client's tastes and without too much restriction from climatic conditions. However it costs more in the long run as the systems consume a lot of energy. It also contributes to SBS (sick building syndrome) and can affect the occupants.

I&M building

I&M is a hybrid ventilated building. It uses both passive and active means of ventilation. From the data collected by observation and from the occupant's opinions, the following conclusions can be drawn. Hybrid ventilation can be concluded to be a middle ground between active and passive ventilation. The building occupants have more control of their environments. Energy consumption is much less than in a fully mechanically ventilated building and the occupants are able to get the best sides of each system of ventilation, as when one is not sufficient, the other kicks in to regularise their internal environment.

5.3 Recommendations

With reference to the findings from the certain case studies and the conclusions drawn from them, recommendations can be ascertained with respect to the main objective of this thesis, which was: to examine the importance of integrating hybrid ventilation in high-rise office buildings in Nairobi. Lessons can also be drawn from the literature reviewed on the different ventilation systems so as to inform on appropriate design considerations for future developments. The recommendations are as follows:

Passive ventilation and hybrid ventilation emerge as the most favourable means of ventilation especially in Nairobi where climatic conditions are constructive. In cases where one wants to use mechanical ventilation for flexibility of design, hybrid ventilation strategies should be considered as a strategy instead as it consumes less energy. Hybrid ventilation design is more involving however the results are more satisfying than opting for a fully mechanical building.

Whereas this study has reached some useful conclusions, it is recommended that future work be carried out within the study area, on a wider scale for purposes of generalizability. Also it will be useful to capture the opinions of the architects who designed the buildings in order to gain more insight.

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APPENDIX 1: LETTER OF INTRODUCTION TO THE FACILITY MANAGER

Omolo. P. Sagi.
School of the Built Environment,
Department of Real Estate and Construction Management,
University of Nairobi,
P.O. BOX. 30197.
Nairobi.

To

Respondent,

I am a student at the University of Nairobi conducting a research study on **"An investigation into the Optimal Combination of Hybrid Ventilation Design (A case study of Contemporary office Buildings in Nairobi Central Business District)** as part fulfillment for the award of Master's degree in Construction Management.

<u>DECLARATION</u>

THE INFORMATION COLLECTED THROUGH THIS QUESTIONNAIRE AS WELL AS YOUR IDENTITY SHALL BE TREATED AS CONFIDENTIAL AND WILL ONLY BE USED FOR RESEARCH PURPOSES ONLY.

Your assistance in the completion of this questionnaire will be highly appreciated.

Questionnaire No……………..

<u>INSTRUCTIONS:</u>

Please tick {✓} and/ or state the appropriate answer in the space(s) or box (es) provided. More than one answer may be ticked or stated where applicable.

Your assistance will be highly appreciated.

Thanks.

Omolo. P. Sagi.

RESEARCHER

APPENDIX 2: LETTER OF INTRODUCTION TO THE OFFICE BUILDING TENANTS

Omolo. P.Sagi.,
School of Built Environment,
Department of real Estate and Construction Management
P.O. BOX 30197-00100,
Nairobi-Kenya.

To
Respondent,

I am a student at the University of Nairobi conducting a research study on **"An investigation into the Optimal Combination of Hybrid Ventilation Design (A case study of Contemporary office Buildings in Nairobi Central Business District)** as part fulfillment for the award of Master's degree in Construction Management.

DECLARATION:

THE INFORMATION COLLECTED THROUGH THE QUESTIONNAIRE(S) OR INTERVIEW(S) AS WELL AS YOUR IDENTITY SHALL BE TREATED AS CONFIDENTIAL AND WILL ONLY BE USED FOR THE PURPOSE OF THIS RESEARCH ONLY.

Your assistance in the completion of this questionnaire will be highly appreciated

Questionnaire No……………….

INSTRUCTIONS:

Please tick ( ) and/ or state the appropriate answer in the spaces(s) or box (es) provided. More than one answer may be ticked or stated where applicable.

Your assistance will be highly appreciated.

Thanks.

Omolo .P. Sagi.,

RESEARCHER

QUESTIONNAIRE (VENTILATION PERFORMANCE)

Building: ______________________________ Floor: ________ Gender: Male [ ] Female [ ] Age: ___________

Occupation: ____________________________ Years of working within the premises: _________ Hours spent daily at the workplace: ___

Gauge the various qualities described below. Use a tick [√] for the choice that best describes your opinion.

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE
GENERAL					
10. **There is flexibility to open or close windows, easing regulation of air flow within the office.**					
11. **Air circulates adequately within the office.**					
12. **I mostly keep windows open at the following times of the day. (Indicate the number of hours within the brackets)**					
7am-10am (hours)					

10am- 1pm (hours)					
1pm- 4pm (hours)					
4pm- 7pm (hours)					
13. **Keeping windows open sometimes interferes with my work. (Also rate interference using the below)**					
• **Distracting noise from the outdoors**					
• **Strong winds that lift paperwork**					
• **Winds carry foul polluted air indoors**					
INDOOR AIR QUALITY					
14. **I find the ventilation levels within the office premises sufficient**					
15. **The office space sometimes has mild odours.**					
16. **Some results of the type of ventilation used within the office space include the following:**					
Bad odour					
Dust					

Dry skin					
Headache					
Sore throat					
Concentration loss					
Nose irritation					
THERMAL COMFORT					
17. **The office space never gets too hot in the afternoons.**					
18. **On hot days, keeping windows open keeps the office space comfortable.**					
Thank you for your input.					