EVALUATING THE ADEQUACY OF INSTALLED VENTILATION SYSTEMS IN HIGH RISE BUILDINGS IN NAIROBI, KENYA

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Sustainable passive ventilation has been promoted as the way forward in ventilation systems in Sub-Saharan Africa. Whether this is real or factual will be determined by this investigation on how well installed ventilation systems meet the comfort needs of office building occupants. The study gave an indication of the priorities that were attached to climatic suitability of ventilation designs in high rise office buildings. The study investigates the use of both mechanical and natural ventilation systems in some high rise office buildings. It provides information on one hand, on the level of adoption of ventilation systems in office buildings located in the Central Business District (CBD) in Nairobi, Kenya, and on the other hand, the adequacy of the installed ventilation systems as perceived by the building occupants. 34 tenants of high rise buildings located in the CBD area were purposively sampled and were the units of the study analysis. Analysis of their responses was presented using simple descriptive and interpretative techniques. The study finds that installed ventilation systems were inadequate and rarely meet tenants' needs in high rise buildings. Occupants require greater flexibility in ventilation design and desire ventilation systems that could incorporate some measure of individual control of air circulation to enhance their general comfort.

Keywords: CBD, Kenya, Nairobi, ventilation system

INTRODUCTION

The adoption of passive ventilation in the Central Business District (CBD) of Nairobi, Kenya is fast becoming less fashionable. Most new office buildings within the CBD, have now incorporated mechanical ventilation systems with very few relying on the natural gift of air flow. The initial outlay and maintenance/running costs of these mechanical systems are relatively expensive and one wonders if they could be considered sustainable in a place like Nairobi, Kenya. The need for proper ventilation in habitations cannot be overemphasised. Humans require oxygen for life, while a build-up of carbon dioxide is life-threatening. Also a general build-up of odour or foul air is unhealthy and could be more critical long before there is danger to life. Ventilation can be referred to the process of changing the air in a room or other internal space, which should be continuous so that expired air is replaced with new air taken from a clean source.

There are various types of ventilation systems ranging from natural ventilation, provided through openings and penetrations, to artificial ventilation which is

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facilitated with mechanical ventilation or air-conditioning systems. The New York Stock Exchange built in 1901 was the first complete comfort air conditioning system to be installed in office buildings. After the World War II, mechanical cooling systems allowed the development of modern glass-walled skyscrapers which were deemed to be the symbol of freedom from traditional construction systems as well as heating and cooling methods. Before mechanical cooling systems became common in office buildings, most buildings were based on T, H, or L-shaped floor plans designed to allow maximum number of operable windows which could provide adequate natural ventilation. The development of large air conditioning systems for office buildings altered traditional footprints, interior layouts, and exterior appearances. Thus glass-walled skyscrapers like the United Nations building (built in 1952) linked the development of modern architecture with this new technology. Mechanical cooling freed designers from conventional methods of orientating office buildings in relation to the sun or ventilating them with operable windows. Although this made buildings more highly dependent on air conditioning systems to be able to function effectively.

The adequacy of mechanical ventilated systems needs to be continuously evaluated in different environments considering that some climatic environments enjoy good air circulation for longer periods of the year. This study therefore investigates the adequacy of ventilation systems designed for high rise office buildings in Nairobi. The focus is on office buildings because they have served as important laboratories for air conditioning advances.

BRIEF LITERATURE REVIEW

Ventilation systems

Literature abounds on different ventilation systems for indoor air quality control in buildings. However the authors limit the review to three general categories of ventilations systems namely: natural, mechanical and hybrid systems all of which have the objective of controlling the indoor air quality to provide a healthy and comfortable environment (Omer, 2009). Omer describes ventilation as the process by which clean air is provided to a space to meet the metabolic requirements of building occupants and to dilute or remove pollutants within the space (Omer, 2009). Thus ventilation is essential in spaces and may need to be controlled or conditioned (by heating or cooling) depending on environmental circumstances.

Natural ventilation is achieved by wind, thermal, or diffusion effects through doors, windows, or other intentional openings in buildings (Khan et al, 2008). This is usually adequate for small dwellings with very conservative building envelopes but very often larger buildings will require additional ventilation with the aid of mechanical systems. Wind-driven ventilation occurs via ventilation openings (typically windows) on opposite sides of an enclosed space. It requires a significant difference in wind pressure between the inlet and outlet openings and a minimal internal resistance to flow, to ensure sufficient cross ventilation flow. Natural ventilation can also occur by density differences to draw cool, outdoor air in at low ventilation openings and exhaust warm, indoor air at higher ventilation openings. This is referred to as the 'buoyancy-driven stack ventilation'(Emmerich et al, 2001). A chimney or atrium is frequently used to generate sufficient buoyancy forces to achieve the needed air flow. However, even the smallest wind will induce pressure distributions on a building envelope that could also drive airflow. Wind effects may well be more important than buoyancy effects in stack ventilation schemes, thus successful designs usually seek ways to take full advantage of both. In a nut shell Khan et al (2008) conclude that

natural ventilation uses the natural forces of wind pressure and stacks effect to aid and direct the movement of air through buildings.

Mechanical ventilation systems are artificial means of achieving air flow within built spaces despite variations in external air conditions. Mechanical ventilation makes it possible to use spaces, such as deep within buildings, which could not be easily ventilated by natural means. Mechanical ventilation is provided by mechanically powered equipments such as motor-driven fans and blowers. The mechanical fans depend on a supply of energy, usually electricity to move air but have a limited degree of control (Gratia and De Herde, 2007). More recent plenum systems give better control of air by using duct work and usually have the ability to heat the air if necessary. Mechanical ventilation could be improved by the incorporation of heaters or refrigerators for heating and cooling. This is referred to as air conditioning to control an internal environment to maintain specified conditions for a certain purpose. For example the objective may be to provide a thermally comfortable temperature, humidity, air cleanliness and freshness for building occupants or to satisfy operational conditions for machinery or process. In a mechanically ventilated building, air movement is likely to be associated with noise (Gratia and De Herde, 2007)

Finally hybrid systems simply refer to a combination of the use of both natural and mechanical ventilation systems. Often referred to as passive systems, hybrid systems involve microclimatic improvements by convective air flows and wind movement aided by the control of openings and vents. The recent trend is to achieve sustainable ventilation through a balance of mechanical and natural systems with due consideration to cost, energy use, pollution, sustainability, health etc. Passive means those devices which generally have no moving parts although some recent modifications and innovations have integrated moving or controlled additions (Khan, et al., 2008).

Climatic conditions in Nairobi, Kenya

The following provides an understanding of the climatic conditions in the study area to provide knowledge of its ventilation systems requirements. Nairobi is situated close to the equator, which means the differences between its climatic seasons are minimal. The timing of sunrise and sunset do not vary tremendously throughout the year. There are two distinctive seasons known as the wet season and dry season. The altitude makes for some chilly evenings, especially in the June/July season when the temperature could drop to 10°C. The sunniest and warmest parts of the year are from December to March, with temperatures averaging the mid-twenties during the day.

According to a United Nations Environment Programme (UNEP) research finding, Nairobi climate is well suited to natural ventilation on account that it is endowed with reliable outdoor air ventilation rates, which is adequately admissible within office buildings, if duly harnessed (UNEP, 2007). The UNEP evaluated Nairobi climatic suitability based on a single-zone model of natural ventilation heat transfer in office buildings and through the application of Bioclimatic Charts.

However it is apparent that a good number of office buildings located in the CBD area in Nairobi have installed air-conditioning systems. Several reasons may account for this practice in spite of Nairobi's suitability to natural ventilation. Chadderton (1997) articulates that air-conditioning systems may be installed in buildings for a variety of motives that could range from a real necessity to the aesthetic appeal that could be gained from marketing the building or its use.

Nairobi's cosmopolitan nature and future orientation places it in an ambivalent position as it aspires to incorporate contemporary building materials and products which often conflict with environmental considerations of human comfort at the micro level in the spaces created and as well as the urban macro climate. Makachia (1998) explains that in tropical contexts such as Kenya, its designers are often confronted with briefs requiring the utilisation of contemporary materials in its large buildings. This means importing and implanting products tested elsewhere but whose local environmental performance has hardly been proven in the local environment.

Contemporary designs which are aesthetics oriented capture intensively the plot coverage to its frontiers; without due consideration to orientation, natural ventilation and spatial requirements for natural vegetation (Saateri, 1998). Subsequently these buildings are completed with blind aping of aesthetics that create ventilation problems (Swinborne, 1998). According to Swinborne (1998) this is an ongoing trend in high rise construction, where plot sizes are maximized but with less heed to environmental considerations. Consequently, recourse is made to mechanical ventilation systems to redress the anomalies emanating from these environmentally alien designs. However as Heiselberg (2000) suggests the use of air conditioning systems are largely wasteful and bear no reference to the specific requirements of individual occupants. The comfort derived therefrom is short-lived (Swinborne, 1998) while it is difficult and costly to modify these installed systems to meet the ever changing comfort requirements of its occupants.

There are also problems with establishing natural elements in the hostile urban environment of the Nairobi CBD. Thus there now exist a landscape whose creation, maintenance and survival depends not on natural determinants, but on technology and high energy inputs. Although Lee (1990) argues that air-conditioning permits a sealing off from the outdoors, creating an atmosphere separate from the increasing problems of health and comfort in the world outside. This argument lends itself to suggestions for whole cities covered by geodesic domes.

Mechanical fans consume at least two-thirds of the total energy consumed for cooling in office buildings (Kavanaugh, 2000). While a directly comparable number is not available for Nairobi office buildings, there is a growing awareness that fans consume a large portion of the energy used to cool buildings. Brodrick and Westphalen (2001) have shown that compared to all mechanical cooling systems, naturally ventilated buildings in the UK offset from 20 kWh/m2 to 60 kWh/m2 of fan energy consumption annually for cooling purposes. Corresponding to a saving of about £1 to £3 per m2 in energy costs annually. By implication, these savings account for approximately 15% of total energy consumption in UK office buildings. These statistics from the UK support the need to revert to natural ventilation when climatic and operational conditions prove particularly suitable as may be the case of the CBD in Nairobi. Roughly natural ventilation may be expected to provide cooling energy savings on the order of 10% and fan power savings on the order of 15% of annual energy consumption.

While natural ventilation is becoming more common in Europe, significant questions exist concerning its application in Kenya particularly Nairobi office buildings. Natural ventilation is always considered to be a fundamental part of 'passive design', which is the term, used to describe the integrative design approach involving the use of daylight, thermal mass, insulation, solar radiation in ventilation design (Yao et al, 2005). Passive ventilation is the least expensive and most environmentally friendly way to ventilate a home. It could provide a comfortable indoor environment, using the

natural environment for much of the time as possible without relying on supplementary energy. Although some designers may think of natural ventilation as simply meaning operable windows, natural ventilation technology has been advanced in recent years in Europe and elsewhere into hybrid variations, wherein mechanical devices are added to enhance system performance and control.

From the foregoing, one could conclude that when human comfort is at risk, mechanical devises could be positively necessary but when conditions are such that only a degree of discomfort is in question, the use of mechanical devises could be optional. The level of environmental controls could be reduced to social-economic conditions. A value judgment is involved in deciding what degree of comfort is desired and at what cost.

METHODOLOGY

The paper is based on an evaluation of the adequacy of installed ventilation systems in office buildings located in the CBD area in Nairobi, Kenya. It seeks improvements required to the adoption of sustainable passive ventilation systems within this study area.

Data was collected from tenants residing in 48 high rise buildings located in the CBD area in Nairobi. Previous studies had indicated that there were 140 high-rise buildings (target population) that are over five storeys within the CBD area. The sample size (48) was determined after Frankfort-Nachmias (1996) formula for sample size determination.

$$n = \frac{Z^2pqN}{e^2(N-1) + Z^2pq}$$

Where N = Population size
n = Sample size
p = Sample population estimated to have characteristics being measured (95% confidence level of the target population assumed)
q = 1 - p
e = Acceptable error (e = 0.05, since the estimated should be 5% of the true value)
Z = The standard normal deviate at the required confidence level = 1.96

One tenant for each building was purposely selected on the basis of those who could provide the best information to achieve the objectives of the study (Kumar, 2005). The criteria for their selection included tenants: whose office spaces are deeply placed within the buildings, who have ever raised complaint to the property manager with respect to installed ventilation systems, and who have altered or modified their office ventilation systems at their own costs.

34 completed and usable questionnaires were received from the tenants corresponding to a 71% response rate. Mugenda and Mugenda (1999) had suggested that a 50% response rate is adequate for the analysis and reporting of questionnaire surveys. Simple interpretive and descriptive means of presentation (tabulation, charts and general statistics) in line with McQueen and Knussen (2002) are used in this study so that the findings could be communicative to readers.

The study establishes the adequacy and the design knowhow of different ventilation systems available to office buildings as well as determining the balanced combination

of these different systems. The findings of this investigation will benefit all stakeholders in construction projects.

RESULTS AND DISCUSSION

The following sub-headings give an outline of the results on major themes covered by the questionnaire survey administered to the office buildings tenants.

On the operability of openings and their adequacy

The questionnaire required tenants to comment on the operability of window openings within the building envelope and their adequacy in ventilating their office spaces. The objective was to cluster the tenants into two groups, those tenants with natural ventilation and those with mechanically ventilated systems. Therefore 35% (12) of the tenants said the windows were operable and that they relied solely on natural air circulation. The remaining 65% (22) said that their office windows were not operable because their offices were air-conditioned and therefore completely sealed from the external environment.

The 12 tenants who relied on natural ventilation were asked to comment further on the adequacy of air-circulation within their office environment. Table 1 gives a summary of their responses. 58.3% were of the opinion that the ventilation provided through the openings was adequate while 41.7% held contrary views. 83.3% of these category of tenants were unaffected by power failure and ventilation system maintenance since with or without power, that had nothing to do with the admissibility of air flow through intentional openings. This could suggest that naturally ventilated office buildings within the CBD are harnessing the climatic endowment of air circulation in Nairobi.

Table 1: Tenants opinion on ventilation systems provided in office buildings

Ventilation Attributes	Naturally Ventilated Office Spaces (n=12)		Mechanically Ventilated Office Spaces (n=22)	
	Yes	No	Yes	No
Adequacy of air circulation within the office	58.3%	41.7%	41.2%	58.8%
Ventilation inadequacy during system maintenance &/or power failure	16.7%	83.3%	54.5%	45.5%
Desire to have alternative ventilation system	66.7%	33.3%	95.5%	4.5%

Source: Field Survey, 2008

However on closer observation, it was discovered that this category of tenants were not deeply placed within the office buildings. The remaining 16.7% were deeply placed within the buildings and therefore required some mechanically-assisted ventilation to ensure adequate air circulation in the event of power outages. Notwithstanding the benefits associated with natural ventilation, 66.7% of the tenants desired to have alternative ventilation systems. This would suggest that the quality of air circulated naturally was low and some form of mechanical ventilation systems was needed to supplement natural ventilation. Conversely tenants (33.3%) who do not desire alternative ventilation seem to enjoy entirely the benefits associated with natural ventilation. It could be concluded from both set of responses that natural ventilation systems within the CBD were inadequately designed with little considerations to sustainable ventilation attributes.

The remaining 22 tenants that had mechanically ventilated office spaces were asked to comment on the adequacy of their installed ventilation systems. Their responses are summarized in Table 1 also. 41.2% of the office tenants were of the opinion that air-

circulation provided by their air-conditioning systems were adequate for their office environments. On the contrary, 58.8% held alternative views, implying that the incorporated air-conditioning systems have failed to meet comfort needs of buildings located in the CBD area.
12 (54.5%) out of the 22 office tenants confirmed that in the event of power failure or periods when the mechanical ventilation systems were undergoing maintenance, air-circulation was inadequate. The remaining 45.5% of these tenants do not experience discomfort during these down periods. These responses could imply that alternative ventilation was required in office buildings that are solely dependent on mechanical systems. Further investigation confirms that tenants (95.5%) had a strong desire for alternative ventilation systems. Remarkably, the tenants (45.5%) who had indicated that air circulation was adequate during power failure or shut down maintenance also desired alternative sustainable ventilation systems. The reasons given for desiring alternative ventilation systems by the tenants include: the need for lower energy consuming units and to have more easily accessible units to ease maintenance.

On the control of ventilation systems

The question in this section required tenants to indicate how they could control/ improve existing ventilation systems installed in their office spaces. The objective was to confirm the responses received in the first part of the questionnaire on the adequacy of ventilation systems in office buildings. Tenants were to select among five alternative means of controlling air circulation within their office spaces. The alternatives included the use of drapes or blinds, opening or closing windows to the external environment, use of heaters, use of local fan and opening or closing doors to the interior space. A summary of the results obtained from the two clusters of tenants is given in Table 2.

For tenants occupying naturally ventilated office buildings, there was a strong desire to control of ventilation in the office spaces using all five means of control. The least was 60.2% for the use of local heating units during cold weather. While the generality of tenants will turn on the local fan to assist in cooling the office environment, or drawing the drapes or blinds to block direct sun rays from finding its way into the office spaces.

Table 2 also presents a summary of the responses of tenants in mechanically ventilated office spaces. 63.4% and 95.6% of this cluster of tenants had the desire to control their office environment through the use of drapes or blinds and through opening or closing window to the external environment respectively. This implies that despite the incorporation of air-conditioning systems in their office buildings, users would need to have some control of the environment in which they operate.

Table 2: Control of existing environment by tenants

Office Environmental Control	Naturally Ventilated Office Spaces (n=12)		Mechanically Ventilated Office Spaces (n=22)	
	Yes	No	Yes	No
Using drapes or blinds	96.9%	3.4%	63.4%	36.6%
Open or closed window to external environment	98.6%	1.4%	95.6%	4.4%
Using heater	60.2%	39.8%	80.2%	19.8%
Using local fan	90.3%	9.7%	85.3%	14.7%
Open or close a door to interior space	62.7%	37.3%	57.5%	42.5%

Source: Field Survey, 2008

57.5% also indicated the desire to control their office environment through opening or closing doors to interior spaces for air to circulate within the interior space. 80.2% indicated the desire to adjust how the office space is to be heated, and 85.3% were of the opinion that they would adjust air flow using local fans.

Wider scale consultation with the end-users of office facilities will allow for the integration of their needs into proposed ventilation designs. Thus in the event of ventilation system inefficacies, the user could be provided with the option of varying air circulation to meet their individual needs.

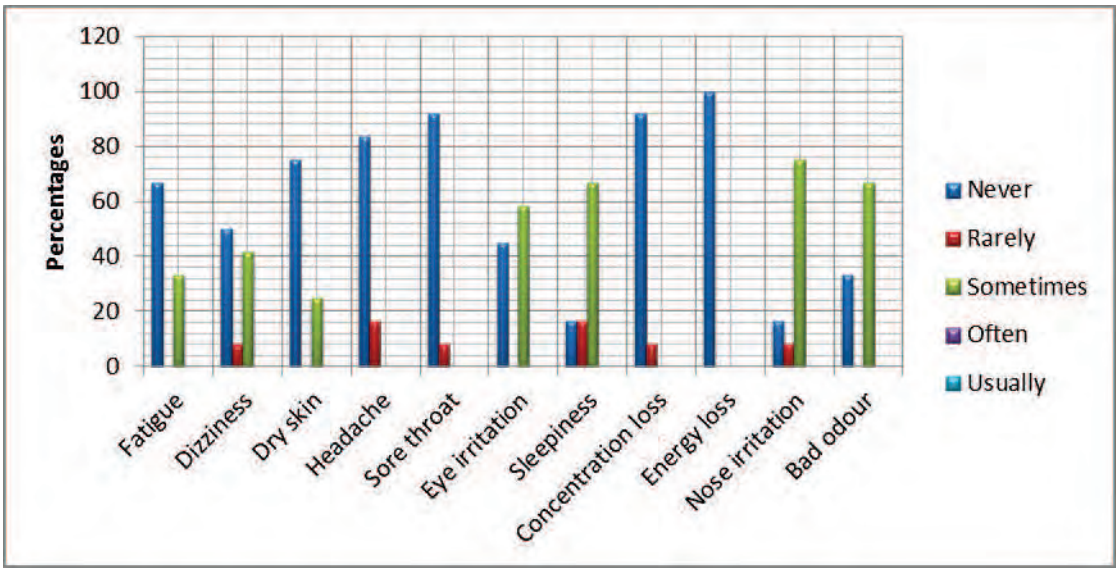
On the manifestations of inadequate ventilation

Tenants of office buildings in the CBD, Nairobi were required to indicate how inadequate ventilation has affected their comfort within the spaces. 11 effects were presented to them for which they were to indicate how often they experienced each of these 11 effects. The result of the investigation is presented in Figure 1 and 2.

For tenants occupying naturally ventilated office buildings, the result is presented in Figure 1. Most of the manifestation, except for bad odour, nose irritation, sleepiness and eye irritation were never or rarely experienced as indicated on the figure. Bad odour was experienced sometimes when windows were opened to promote air circulation, only to let in bad odour from the external environment. Tenants also experienced nose irritation as a result of cold weather which was prevalent around the month of July according to them.

It could be concluded that designers of naturally ventilated buildings have to take proper cognisance of conditions in the external environment as this could affect the quality of air within office spaces. Pollution is a key consideration in ventilation design for densely populated city centres which could manifest as poor health of building occupants.

Figure 1: Manifestation of inadequate natural ventilation in office buildings

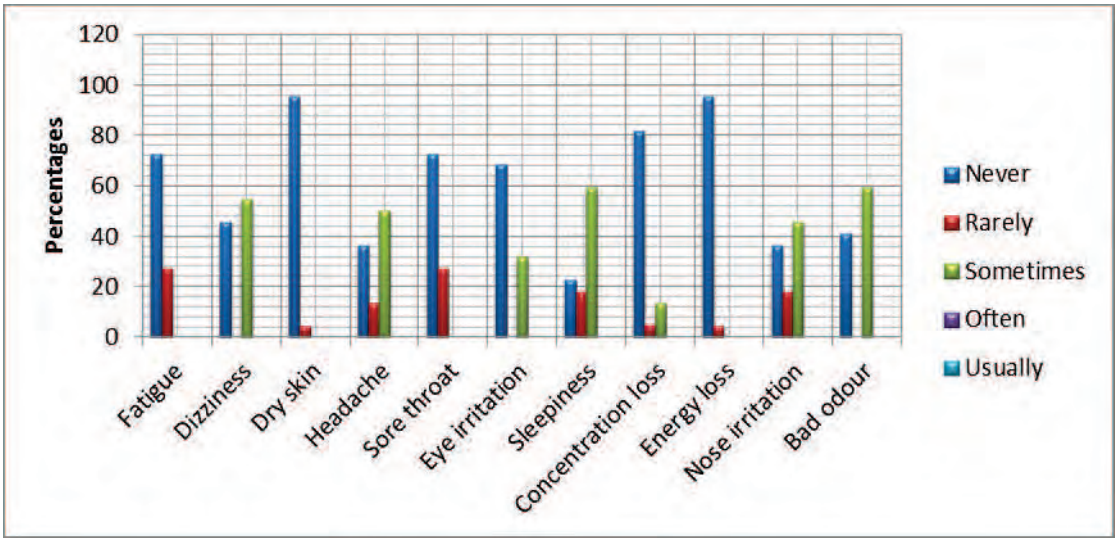


Source: Field survey, 2008

On the other hand, inadequate mechanically ventilated office buildings affect tenants in many ways. The manifestations of these inadequacies are presented in Figure 2. With the exception of dry skin, concentration loss, and energy loss, which office

tenants did not experience in significant percentage. The remaining effects of inadequate mechanical ventilation were significantly experienced by the tenants. This could imply that mechanical ventilation systems needed to be evaluated more not only in terms of their installation but their operation and maintenance over the life of the office buildings vis-a-vis health concerns.

Figure 2: Manifestation of inadequate mechanical ventilation in office buildings



Source: Field survey, 2008

In one instance, bad odour experienced within the office space was the result of dust accrual in an inadequately maintained duct system. The adequacy of mechanical ventilation systems installed in office buildings would depend on its ability to vary the thermal environment it provides at different seasons and for different users.

CONCLUSION

This study has shown that there are both benefits and dis-benefits to the use of natural and mechanical ventilation systems in the CBD area in Nairobi. Quite often the driver for the installation of mechanical ventilation systems is aesthetics and not necessarily its functional benefits over natural ventilation. Climatic conditions in Nairobi are not relatively unsuitable as is the case in temperate regions where significant measure of control over air circulation is essential. More focus is required to inoperable ventilation systems in naturally ventilated buildings, while the product specification for cladding materials (buildings facades) used in mechanically ventilated office buildings could be improved to make the materials suitable to the Nairobi climate.
It is apparent from the study that considerable flexibility in the design and installation of ventilation systems is highly desired by the end users, and that a balance between both natural and mechanical systems would need to be evaluated in future buildings in Nairobi. In some instances, it was observed that tenants had installed single isolated air conditioning units because they found the central air-conditioning provided inefficient. A lot more end-user evaluation of office building designs are needed across a wide range of modern building technologies. This way users' requirements are more accurately determined and the benefits of such technologies could then flow on to the end users.

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