University of Nottingham
School of the Built Environment
BEng Architectural Environment Engineering

Research Project (K13 3RP)

An Evaluation of the Energy Use Associated with Different Ventilation Strategies

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Abstract

Energy is a necessary part of our everyday lives without doubt. As population and economy grow, demand for energy also increases day by day. However, the energy is valuable and limited. People may face the problem of energy shortage in near future. Numbers of scientists investigate the availability of different kinds of renewable energy sources in these recent years. The control of the existing energy use seems to be inattentive. The fact is that a huge amount of energy is wasted on some unnecessary usages. One of them is excessive ventilation in buildings. According to the National Statistics of the Department of Trade & Industry, in 2001 the total energy consumption of the United Kingdom was 2764 Terrawatthours. It is estimated that more a third of all energy is consumed in buildings, added to this, about one half of this energy is dissipated through ventilation and air infiltration. Because of the significant energy loss by ventilation, energy efficient ventilation is important in controlling the existing energy consumption.

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1. Introduction

1.1 Background

Before asking the question of "How to achieve the target of energy efficient ventilation?", it is necessary to know how the energy be consumed in ventilation. Considering a simple habitable room with an extract ventilation fan, a part of energy is used directly by the fan. Due to the air change between indoor and outdoor, indirect energy is consumed by the air conditioning system for heating or cooling the indoor air. Therefore, unnecessary high rates of air change can result in an excessive energy burden. To avoid this energy loss, both improving the air tightness of the building and making use of heat recovery system are the good approaches. However, minimising the need for ventilation is fundamental. There is always a conflict between energy conservation by minimising ventilation rate and optimum indoor air quality by maximising ventilation rate. Demand controlled ventilation is one of the solutions to achieve optimum IAQ with energy saving. If the presence of occupancies or the dominant pollution can be identified and measured, then the ventilation rate can be automatically adjusted to respond to the need. In other words, demand controlled ventilation involves the application of sensing, feedback and control to modulate ventilation. Through the above process, the minimum acceptable ventilation rate with the requirement of diluting the dominant pollutant to an acceptable concentration can be achieved.

1.2 Objectives

There is no unique ventilation control strategy suitable for all different circumstances. For example, ventilation control based on humidity detection can be applied in a bathroom, but it is not a good selection for the application in office. By examination and investigation of different control strategies, the energy effective approaches for different conditions can be obtained. This is also the main objective of the project.

That is to say the purpose of this research project is to evaluate the energy use associated with different ventilation strategies.

2. Ventilation Energy Consumption

2.1 Ventilation Approaches

The ventilation approaches can be generally classified into two main natures. They are natural ventilation and mechanical ventilation.

2.1.1 Natural Ventilation

Natural Ventilation relies on openings, trickle vents or passive stacks to permit fresh air to enter and vitiated air to leave the occupied areas. The air flows are driven by wind and thermally generated pressures.

- Wind Pressure

The wind generates a pressure distribution over the external envelope. This causes air to enter openings and pass through the building from the high pressure windward areas to the low pressure downwind areas. The wind pressure depends on the wind direction and wind speed.

- Stack Pressure

Stack effect is developed due to differences in air temperature, and hence air density, between the inside and outside of the building. This generates vertical pressure difference across the envelope. It leads to inward flow at low levels and outward flow at high levels. The stack pressure depends on the temperature difference between the two air masses and the vertical spacing between openings.

The driving forces are nature and free, but lack of control at the same time. In general, the effects of wind and stack will act together. The resulting ventilation rate depends on the dominant effect. Inadequate control over ventilation rate is the main drawback. Unreliable driving forces can result in periods of inadequate ventilation, followed by periods of over ventilation and excessive energy waste. Ventilation control strategies are relatively difficult in associating with natural ventilation approach.

2.1.2 Mechanical Ventilation

Mechanical ventilation provides controlled ventilation to a space. It overcomes the shortcomings of natural ventilation by mechanical force. Generally three types of mechanical ventilation are in use. They are extract ventilation, supply ventilation and balanced ventilation.

- Extract Ventilation

Extract system removes air from a space. This induces an under-pressure which promotes the flow of incoming air into the space through purposed air inlets or infiltration openings. This is usually to remove moisture vapour and pollutants at source thereby minimizing contamination of occupied space.

- Supply Ventilation

Supply system introduces outdoor air into the building mechanically. The building is pressurised, indoor air is displaced through purposed air outlets or infiltration openings.

- Balanced Ventilation

Balanced system combines extract and supply systems as separately ductwork. Air is supplied and mixed into occupied and is extracted from polluted zones. Recirculation can be applied in this system.

Although energy is consumed to drive the flow, the ventilation can be controlled and well predicted. Heating, cooling and ventilation control strategies can be associated with mechanical ventilation system. Maintenance is often required for mechanical ventilation system.

2.2 Energy Use related to Ventilation

The energy use in ventilation can be classified into two types which are direct energy use and indirect energy use. Direct energy use includes the energy for driving the flow and the energy consumed by control system. Indirect energy involves lots of different aspects. The most significant one is the energy for heating and air conditioning.

2.2.1 Fan Power

This is the energy use of mechanical ventilation system to propel a quantity of air and to overcome the system pressure losses. Good duct design and high fan efficiency can reduce fan energy consumption, but the best way is reducing the air flow to the minimum requirement. It largely depends on the system design and control strategies.

2.2.2 Energy for Control System

Relatively small amount of energy is consumed by sensors and controllers in ventilation control system. Usually, energy saved by efficient control system is much more than the energy use by the system.

2.2.3 Energy for Heating and Air Conditioning

The displacement of air between the inside and outside of the building generates heat loss or heat gain. Energy is used for heating or cooling and conditioning of the incoming air. Over ventilation leads to excessive energy burden for heating in winter.

2.3 Approaches for Reducing the Ventilation Energy Consumption

Energy demand for ventilation can be curtailed by a variety of energy efficient approaches and techniques. The application of the different approaches should depend on the circumstances.

2.3.1 Minimising the need for ventilation

Minimising the emissions from avoidable pollutant source is the fundamental method to reduce energy use. The contaminants produced from daily necessary activities, such as cooking and showering, are realistic to be reduced. However, some pollution activities like smoking should be prevented from indoor.

2.3.2 Avoid Uncontrolled Air Infiltration

Poor building air-tightness can lead to excessive air infiltration which is a serious barrier for achieving energy efficient ventilation. The Building Regulations Approved Document L2 1.17 stated that “Buildings should be reasonably airtight to avoid unnecessary space heating and cooling demand and to enable the effective performance of ventilation systems."

2.3.3 Demand Controlled Ventilation

According to ASHRAE Standard 62-1999, efficient demand control ventilation can reduce the ventilation energy use up to 80%. Although saving 80% of ventilation energy is an extreme case, most of the demand control approaches are capable of saving energy. By identifying and measuring the dominant pollutant, then the ventilation rate can be adjusted to respond to need automatically.

2.3.4 Appropriate Maintenance

The maintenance work is important for most ventilation system. Regular checking and cleaning can improve the performance of system and as a result save energy.

3. Ventilation Requirements

3.1 Introduction

Ventilation requirements can basically divided into two natures. One is the regulations from government. The other is the recommendations from some associations. Table X shows the ventilation requirements for a range of building types.

3.2 The Building Regulations Approved Document F

According to Approved Document F, there are three types of ventilation being restricted. They are rapid ventilation, background ventilation and extract ventilation. Rapid ventilation is designed for safety purpose, ventilation opening at high level should be provided. Background is designed for respiration purpose, appropriate size of ventilation vent should be provided. Extract ventilation is used to remove the contaminants, exhaust system or PSV should be provided.

3.3 The Recommended Ventilation Requirements

Some related association, such as CIBSE and ASHRAE, provide the recommendations for ventilation in order to achieve the target of environmental comfort and healthy. Table 3.1 shows the ventilation requirements for a range of building types.

Table 3.1--The ventilation requirements for a range of building types

Room or Building type	Rapid Ventilation	Background Ventilation	Recommended Fresh Air Supply or Extract Ventilation Rates
Habitable Room	1/20th of floor area	8000mm^2	8L/s per person
Kitchen	ventilation opening (no minimum size)	4000mm^2	Depend on cooking duty
Bathroom	ventilation opening (no minimum size)	4000mm^2 per bath/shower	15 L/s per bath/shower
Toilet	1/20th of floor area	4000mm^2 per WC	6 L/s per WC
Office	1/20th of floor area	400mm^2 per m^2 of floor area (minimum of 4000mm^2)	8L/s per person
Conference Room	1/20th of floor area	400mm^2 per m^2 of floor area (minimum of 4000mm^2)	8L/s per person
School	1/20th of floor area	400mm^2 per m^2 of floor area (minimum of 4000mm^2)	10L/s per person
Library	1/20th of floor area	400mm^2 per m^2 of floor area (minimum of 4000mm^2)	8L/s per person
Dinning Room	1/20th of floor area	400mm^2 per m^2 of floor area (minimum of 4000mm^2)	8L/s per person
Smoking Room	1/20th of floor area	400mm^2 per m^2 of floor area (minimum of 4000mm^2)	33L/s per person

The above information is according to “The Building Regulations Approved Document F”, “CIBSE Guide B” and “ASHRAE Standard 62-1999”

4. Ventilation Control Strategies

4.1 Control Algorithms

The most common control algorithms using in ventilation system are two-position control, proportional control and PID control.

4.1.1 Two-position control

Two-position control is known as on-off control. The control device can be positioned only to a maximum or minimum state. Because this type of control is simple and inexpensive, it is used extensively for industrial, commercial and domestic control.

4.1.2 Proportional Control

Within the proportional band the output of the controller is proportional to the difference between the sensed value and its set point. This can provide much finer response to load changes than the two-position types.

4.1.3 Proportional Integral Control

This approach improves the simple proportional control by adding another component to the control action that eliminates the offset typical of proportional control. Generally, PI control improves the stability of the system.

4.2 Conventional Ventilation Strategies

Many existing control approaches of ventilation do not have satisfied performances. The reasons of poor performances are various. General problems are human mistakes and improper predictions at the beginning.

4.2.1 Manual Control

The most basic control is manual control. The occupants switch on the ventilation systems or equipments when they have demand. Since it is difficult for people to identify the condition of indoor air quality, lots of mistakes may be made in operation of the system. The inappropriate operation may result in IAQ problems and excessive heat loss.

4.2.2 Light Switch

The ventilation components are energised when the occupants turn on the lights. If the lights are on during occupied times, so is the ventilation device. This control approach is often applied to bathroom case. The system assumes that most people switch on the lights when using bathrooms, therefore the lights-on represents the occupancy. Then the appropriate ventilation will be provided to maintain the designed IAQ.

A very common problem in this application is that many people forget switching off the lights after use. The ventilation system keeps running with the lights-on, energy is wasted on the unnecessary ventilation.

4.2.3 Clock Timer

Clock timers may be used to control ventilation devices and/or the entire HVAC system. The most basic one is simple spring-wound countdown timer. When the occupants arrive, they have to set the timer to the number of hours they will be in the conditioned space. Some digital clock timers can be programmed with a daily, weekly or yearly schedule. Timer controls are often used in commercial offices and schools which have relatively stable using schedule.

The drawback of timer control is lack of flexibility. Since this is only time-based, the ventilation devices are always supposed to operate for designed occupancy. In practical, the actual occupancy is less than the design from time to time. Again, over ventilation problem exists. In other words, clock timer is not able to control the quantity of ventilation.

4.3 Sensor-based Demand Controlled Ventilation

Occupancy and indoor pollutant emission rates vary with time in most building. With SBDCV, the ventilation rate also varies with time to compensate the changes in pollutant generation. SBDCV involves the application of sensing, feedback and control to modulate ventilation. Different from basic demand controlled ventilation, SBDCV operates in fully automatic. The problem of human mistake can be reduced to a minimum level.

The sensing and responding part are most valuable component of sensor-based demand control. To understand the potential of SBDCV, it is necessary to have a general understanding of equilibrium relationships between ventilation rate and indoor air pollutant concentrations and also an understanding of the nature of the temporal response of indoor pollutant concentrations to a change in ventilation rate. In other words, the responds for modulating ventilation rates are some calculation results based on the properties of the parameter being sensed. At present, there are many of different types of sensor-based control device for various circumstances.

4.3.1 Humidity-based

Ventilation devices are controlled by using the approach of humidity detection. When the humidity sensor detects the relative humidity over the design limit, a sign is given out to operate the ventilation. Two types of humidity sensors are often used in general, they are capacitive type and resistive type.

Capacitive sensors use a foil sensitive to humidity placed between two electrodes. The variation of the relative humidity causes the material to absorb a variable amount of water, which causes the dielectric constant of the foil to change, thus changing the capacitance of the sensor. The cost of these sensors is low, but they are sensitive to contamination by dust and organic compounds. These sensors are often used in bathrooms and shower rooms.

Resistive sensors feature a plastic substrate covered with a hygroscopic film. Due to the absorption of the moisture vapours, the resistance of the sensor drops exponentially with the decrease in the relative humidity. These sensors have good precision and short response time, they are however sensitive to free water and very high humidity. They are often used in galleries and museums.

4.3.2 Current-based

The control approach is designed for some electrical appliances which emit contaminants during operation. The current sensing control devices activate the ventilation devices when electrical appliances are in use. The operation processes of some electrical appliances, such as photocopiers, printers and cookers, produces contaminant. The control system can identify appearance of contaminants by checking the states of electrical devices. Thus, the system can provide suitable ventilation to remove the pollutant. Generally, current-based approach cannot control the quantity of ventilation. It is usually used in local exhaust systems with on-off control only.

4.3.3 Temperature-based

This temperature detection is not talking the one controlling HVAC units or ventilation devices for thermal comfort. It is used to detect the object temperature but not air temperature for control controlling local exhaust systems. Take the application in bathroom as an example. The temperature sensors are usually connected with the hot water pipe. When the relatively high temperature is detected from the hot water pipe, it means that the occupants are using the hot water. Generally, moisture vapours will be produced when using hot water. Thus, appropriate ventilation will be provided to remove the humidity in bathroom. This is similar to the current detection concept. Both of them are not going to identify the appearance of contaminant, but to speculate the room condition from the use of facilities or equipments.

4.3.4 Motion Detection

Usually a passive infrared device is chosen for motion detection, because unlike standard infrared sensors, passive infrared takes a warm-blooded body to energize. Any movement triggers passive infrared sensors, energizing the unit. It is however difficult to define the actual occupancy in space. Passive infrared sensors usually energize the ventilation devices to the maximum occupancy position immediately after the first occupant enters the room. The objective is to ventilate, even if the room has only one occupant. Motion detection control is with options that can control the heating/cooling, ventilation, and lights. Therefore, it is always applied in public toilets. When someone enters the toilet, the control system will switch the light on with ventilation.

4.3.5 Carbon Dioxide-based

CO_2-based demand controlled ventilation is increasingly used to modulate outside air ventilation based on real-time occupancy. The basic of using CO_2 for ventilation control is established in well-quantified principles of human physiology. All humans exhale CO_2 at a predictable rate based on occupant age and activity level. Due to this relationship, CO_2 can be used as a good indicator of occupancy. The objective of a CO_2 control strategy is to modulate ventilation to maintain the design ventilation rate per person based on actual occupancy. The strategy should allow for reduced overall ventilation during periods of occupancy that are less than full occupancy and as a result save energy. Typical control approaches have used a proportional or proportional-integral control algorithm to modulate ventilation between a base ventilation rate established for non-occupancy-related sources and the design ventilation rate for the space.

Take CO_2DCV in office as an example. For the recommended fresh air supply rate of 8L/s per person and the general office activities of occupants, the difference of CO_2 concentration between indoor and outside is about 600ppm. The 1000ppm guideline for CO_2 used in ASHRAE standard 62-1999 is the equilibrium level for 8L/s per person assuming a 400ppm outside level of CO_2. Based on the equilibrium level, the control system can estimate the real-time occupancy. Thus, suitable quantity of ventilation can be provided to the occupants.

Several precautions should be taken in CO_2DCV application. First, the control strategy must provide adequate lag time response to ensure IAQ. Second, CO_2 filtration or removal methods other than dilution cannot be implemented in the space. Third, a base ventilation rate should be provided during occupied periods to control for non-occupant related sources. Fourth, the location of sensors should be selected carefully. Avoid installing in areas near doors, air intakes or exhausts or open windows. Because people breathing on the sensor can affect the reading, find a location where it is unlikely that people will be standing in close proximity to the sensor.

4.3.6 Pollutant-based

By detecting the particular contaminant directly, pollutant-based DCV provides appropriate ventilation to a space. Like humidity-based control, pollutant-based DCV responds for the fundamental demands and control the ventilation devices with good precision. Usually, proportional algorithm is associated with pollutant-based DCV to modulate the ventilation. Ozone detection control is an example of pollutant-based DCV. The photocopiers generate various contaminants during operation. Ozone is the most dominant one. Therefore, ozone sensors can be used in some photocopier rooms. This approach can ensure a good IAQ for users with excessive energy loss. However, the initial cost of this control approach is relatively high comparing with the others. Due to lack of low-cost, sensitive and reliable pollutant-sensors or air quality sensors, the application of pollutant-based DCV is not common.

5. Ventilation Control Performance Analysis

5.1 Domestic Kitchen Analysis

Most of the exhaust fans in domestic kitchen are manual-controlled. The fans are expected to be switched on by users when cooking. According to a domestic habit research from exhaust fan manufacturer, less than 30% of users do so. About 60% of people tend to open the windows when the odour appears. Then the windows may be left open for few hours. As a result, not only the contaminants cannot be removed when cooking but also excessive heat loss in winter.

For general domestic kitchen, the cooking time is usually less than an hour daily. With using appropriate control, both of good IAQ and energy saving can be achieved. The frequency of re-decoration and false fire alarms could also be reduced.

Current-based control is one of the choices. The sensor monitors the current drawn by an electric cooker, once the flow of electricity is detected the fan is turned on by the controller.

5.2 Smoking Area Analysis

Ventilation system operates with the light-on in most existing smoking rooms. The ventilation rate for smoking room largely depends on the number of smokers. According to "Implications of ASHRAE's Guidance on Ventilation for Smoking-Permitted Area", ventilation rate of 33 litres / second per person should be provided for smoking lounge. Light-on control is not able to identify the real-time occupancy, the ventilation system can only work as maximum occupancy condition from time to time. This again results in energy wasting. CO_2DCV with proportional control algorithm can be used instead of light-on light.

Appropriate quantity of ventilation is thus provided according to the real-time occupancy.

5.3 Photocopier Area Analysis

An analysis about ventilation energy use for the photocopier area in Hallward Library of the University of Nottingham was accomplished.

5.3.1 Condition

The photocopier area was on second floor of Hallward Library. There was only one photocopier of general commercial size in the area. The existing ventilation approach was simple local exhaust with one exhaust fan. The purpose of the ventilation was to remove the harmful contaminants produced by the photocopier. The fan was supposed to operate during the opening hours of library. However, the actual operating time of the photocopier was usually less than the opening hours. Ventilation energy consumption might be reduced by using appropriate control strategies.

5.3.2 Principle

The analysis was based on the comparison between the existing ventilation system and the current-based demand controlled ventilation with time lag. As the purpose of ventilation is to remove the contaminants produced by photocopier, appropriate control approach is supposed to identify the appearance of contaminants. Because of direct relationship between operation of photocopier and production of contaminants, the current-based demand control is capable to provide ventilation according to the operating time of machine. The purpose of time lag is to ensure most of contaminants are removed before the ventilation stop. According to the guideline of photocopier manufacturer, three minutes of time lag operation of appropriate ventilation device are capable to remove most of the contaminants.

5.3.3 Process

From 7th March 2005 to 13th March 2005, the numbers of paper copies per day of the target photocopier were recorded. The operating time and operating characteristic of photocopier were estimated from the numbers of copies per day with some assumption. Assume the photocopier took 2 seconds to finish the process for one copy and the users made ten copies each time. The collected data is showed in Table 5.3.3.

Table 5.3.3--The Collected Data of the Proposed Photocopier

		Numbers of Copies	Estimated Operating Time of Photocopier (seconds)	Estimated Times of Use
7 March, 2005	Monday	975	1950	98
8 March, 2005	Tuesday	1090	2180	109
9 March, 2005	Wednesday	806	1612	81
10 March, 2005	Thursday	1026	2052	103
11 March, 2005	Friday	764	1528	77
12 March, 2005	Saturday	318	636	32
13 March, 2005	Sunday	217	434	22

The opening times of library during analysis period were 800am-945pm for Weekdays, 900am to 945pm for Saturday and 930am to 945pm for Sunday.

5.3.4 Fan Operating Time

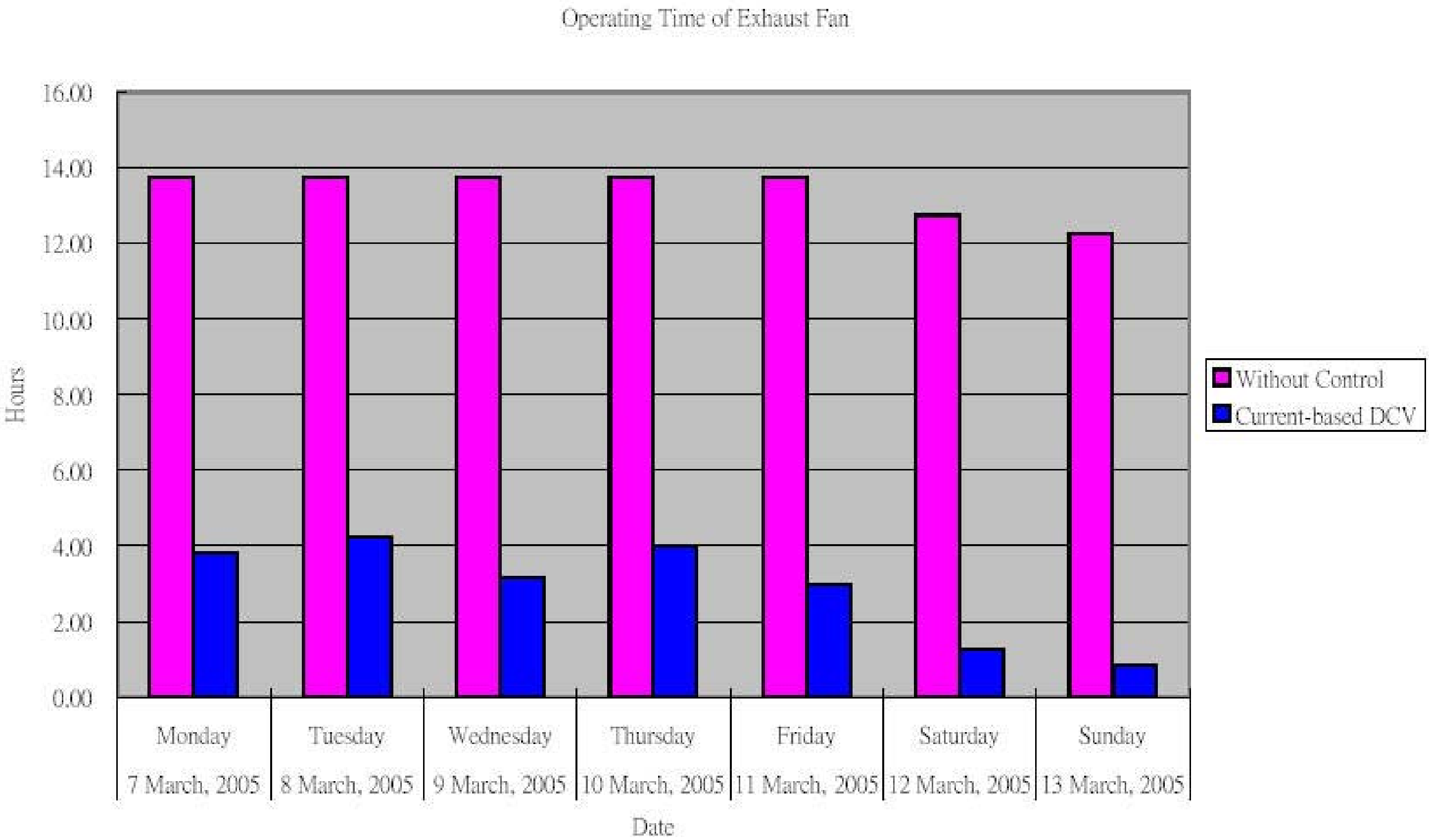
The operating time of exhaust fan was estimated when using the current-based DCV with 3 minutes time lag. The result is showed in Table 5.3.4a.

Table 5.3.4a--The Estimated Result of the Analysis

		Estimated Operating Time of Photocopier (seconds)	Estimated Times of Use	Estimated Operating Time of Exhaust Fan (hours)	The Actual Operating Time of Exhaust Fan (hours)
7 March, 2005	Monday	1950	98	3.81	13.75
8 March, 2005	Tuesday	2180	109	4.24	13.75
9 March, 2005	Wednesday	1612	81	3.15	13.75
10 March, 2005	Thursday	2052	103	4.00	13.75
11 March, 2005	Friday	1528	77	2.99	13.75
12 March, 2005	Saturday	636	32	1.24	12.75
13 March, 2005	Sunday	434	22	0.85	12.25
Total				20.28	93.75

The Table 5.3.4a shows that the total operating time of exhaust fan during the analysed period was 93.75 hours, and the estimated operating hours with current-based demand control was 20.28 hours. The difference was about 73 hours. The estimated operating time with ventilation control was only about 22% of the actual one. The Figure 5.3.4b shows the comparison of fan operating times.

The Figure 5.3.4b--The comparison of fan operating times



5.3.5 Energy Saving

According to the guideline of photocopier manufacturer, the ventilation rate of about 30L/s should be provided during the operation of a photocopier of general commercial size. The power used for an exhaust fan providing a ventilation rate of 30L/s is about 20 watts. The fan controlled by current detection device was estimated to run less 73 hours during the analysed period. Therefore, about 1.46kWh of fan energy can be saved.

Most of similar current detection controller in the market consumes less than 2.5 watts of power. The estimated amount of energy consumed by the control device was about 0.233 kWh.

The ventilation causes heat loss. According to the UK weather channel (www.weather.co.uk), the outside temperature was about 7^{o}C in Nottingham during the analysed period (March). Assume the indoor design temperature of library was about 21^{o}C, the temperature difference between indoor and outdoor was 14K. Table 5.3.5 shows the heat loss calculation.

Table 5.3.5--The Calculation of Heat Loss

Volume Flow Rate (m^3/s)	Specific heat capacity of air (J/m^3K)	Indoor Temperature (^{o}C)	Outdoor Temperature (^{o}C)	Temperature Difference (K)	Heat Loss (W)
0.03	1210	21	7	14	508.2

The result showed that 508.2 watts of heat was lost to outside when the fan was running. Assume the efficiency of heating system in library was about 90%, about 41.2 kWh of space heating energy was consumed for 73 hours of over ventilation.

Therefore, about 42.5 kWh of electricity could be saved in the analysed week due to the application of current-based demand control ventilation.

5.3.6 Cost and CO^2 Emission

According to the report of "Energy Consumption in the United Kingdom" produced by The Department of Trade and Industry, the 2004 average UK non-domestic electricity price was 4.5 pence per kWh. About two pounds could be saved for a week. For electricity generated from fossil fuels, 0.43 kg of carbon dioxide is emitted when using 1 kWh of electricity. About 18.28 kg of CO^2 emission was reduced in a week. The Table 5.3.5 shows the predicted benefits.

Table 5.3.6--The predicted benefits

	For Analysed Period (A Week)	*For An Year
Electricity Saved (kWh)	42.5	2210
CO2 emission reduced (kg)	18.28	951
Money Saved (pounds)	2	104

* assume the figure obtained in the analysed week was an average

5.3.7 Comments

The study result showed that current-based control could provide appropriate ventilation which was capable to remove most of the contaminants without excessive energy loss. For this case, pollutant-based DCV can be another option. As ozone was the main contaminant produced from photocopying process, ozone detection control is also feasible. The ozone detection is usually used to measure the quantity of ozone in space, so variable speed fan is suggested for providing accurate quantity of ventilation. For the proposed case, the high cost ozone detection control is predicted to have similar control performance with the low cost current detection control. Therefore, current-based DCV was more recommendable. Consider an area with numbers of photocopiers, the ozone detection associated with proportional control algorithm and variable speed fan may suit the case most.

6. Case Study

6.1 Brief

A practical study about the ventilation energy consumption of bathrooms was accomplished with assistance of West Energy Saving Technologies Limited and Derby Hall of the University of Nottingham. The experiment was hold at two identical bathrooms of Matlock House of Derby Hall. A temperature-based control device was installed to control the exhaust fan in first floor bathroom, when the existing light-on control system was maintained in second floor bathroom. The ventilation energy consumption was studied by measuring the operating time of exhaust fans.

6.2 Control Device

The control device used in this study was called "Showermiser" which was developed by West Energy Saving Technologies Limited. The Showermiser was aimed for the ventilation control in shower rooms. It could work as temperature-based for conventional heating shower and current-based for electrical heating shower respectively. Showermiser is shown in figure 6.2.

Figure 6.2--Showermiser

6.2.1 Working Principle

The main purpose of ventilation in bathroom is to remove the humidity produced from using hot water. The appropriate control system for bathroom should be able to identify either the appearance of humidity or the operation of hot water device. The basic concept of Showermiser is to identify the later.

Showermiser is a current or temperature sensing control device which activates an extract fan when a bath or show is being use. The device has a built in timed off switch which can be adjusted to suit requirements.

6.2.2 Working Process

The temperature sensor connected to the hot water pipe is used to detect the presence of hot water running through the pipe. Once hot water is sensed the controller automatically turns on the exhaust fan for providing ventilation. When showering has finished the fan is turned off immediately or with a time lag. There is an adjustable fan run-on facility which will allow the fan to run on for 1-25 minutes for removing the humidity completely.

6.3 Place and Duration of Experiment

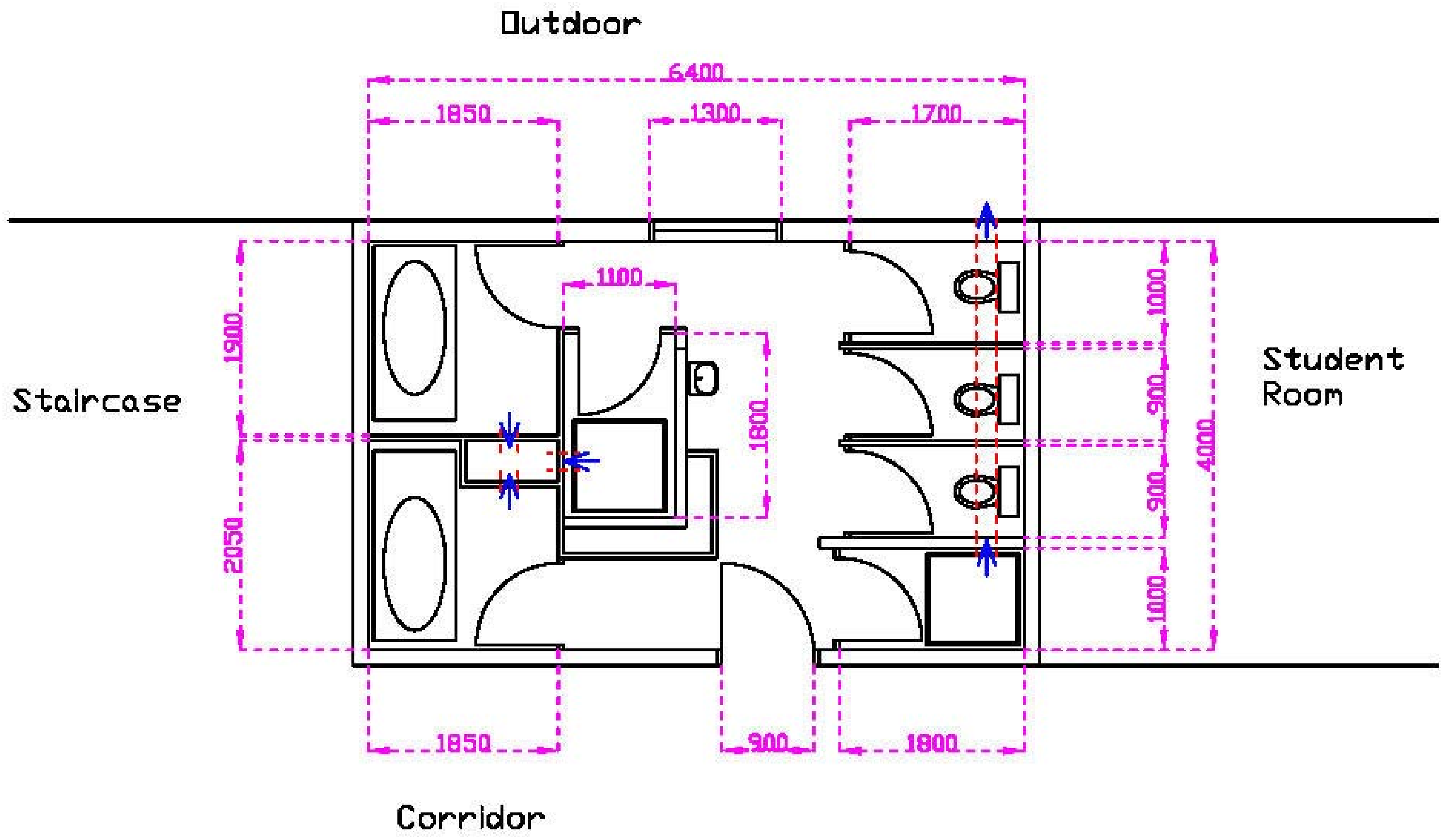
The experiment took place at the first floor and second floor bathrooms of Matlock House of Derby Hall. Two bathrooms were identical. Both of them got three toilets, two showers and two bathes. There were two simple local exhaust systems in the proposed bathrooms. One was local exhaust vent which provided the ventilation for the bathes and shower on left hand side of entrance. This was supposed to operate for 24 hours per day. The other was the target system which provided ventilation for the shower on right hand side. The system got an exhaust fan and a vent duct which connected the fan to outside. There was an open able window sized of 1.3m x 1m in each bathroom. A conventional radiators flowing with low temperature hot water was used for space heating in each bathroom. Figure 6.3d shows the floor plan of the both bathrooms.

Figure 6.3a—Shower room condition

Figure 6.3b—Exhaust Fan

Figure 6.3c—Vent duct connected to outside

Figure 6.3c--The floor plan of the both bathrooms



6.4 Experiment Process

Showermiser was used to control the ventilation of the proposed shower on the first floor, and the one on the second floor kept using light-on control.

When someone used the shower on the first floor, the showermiser detected the temperature change of hot water pipe. Thus, it switched the fan on for removing the humidity in space. When the user finished showering, the fan ran on for more 10 minutes to ensure relative humidity at the design level. The time lag of 10 minutes was according to the recommendation from the control device producer.

The control on the second floor was light-on control with time lag. When the occupants switched on the light of shower room, so was the ventilation. After switching off the light, the exhaust fan ran on for more 5 minutes. From the observation after showering, 5 minutes of time lag are not capable to remove an excess of humidity. For the all-round analysis, all the settings of the existing control system on the second floor were kept. Figure 6.4 shows the device installation condition.

Figure 6.4--The device installation condition

6.5 Measured Results

The control device and operating time meters were install on the 22nd February 2005. The monitoring period was from 22nd February 2005 to 18th March 2005. The data of the fan operating time was recorded at around 2pm everyday. Table 6.5c and Figure 6.5d show the accumulative operating time of two exhaust fans.

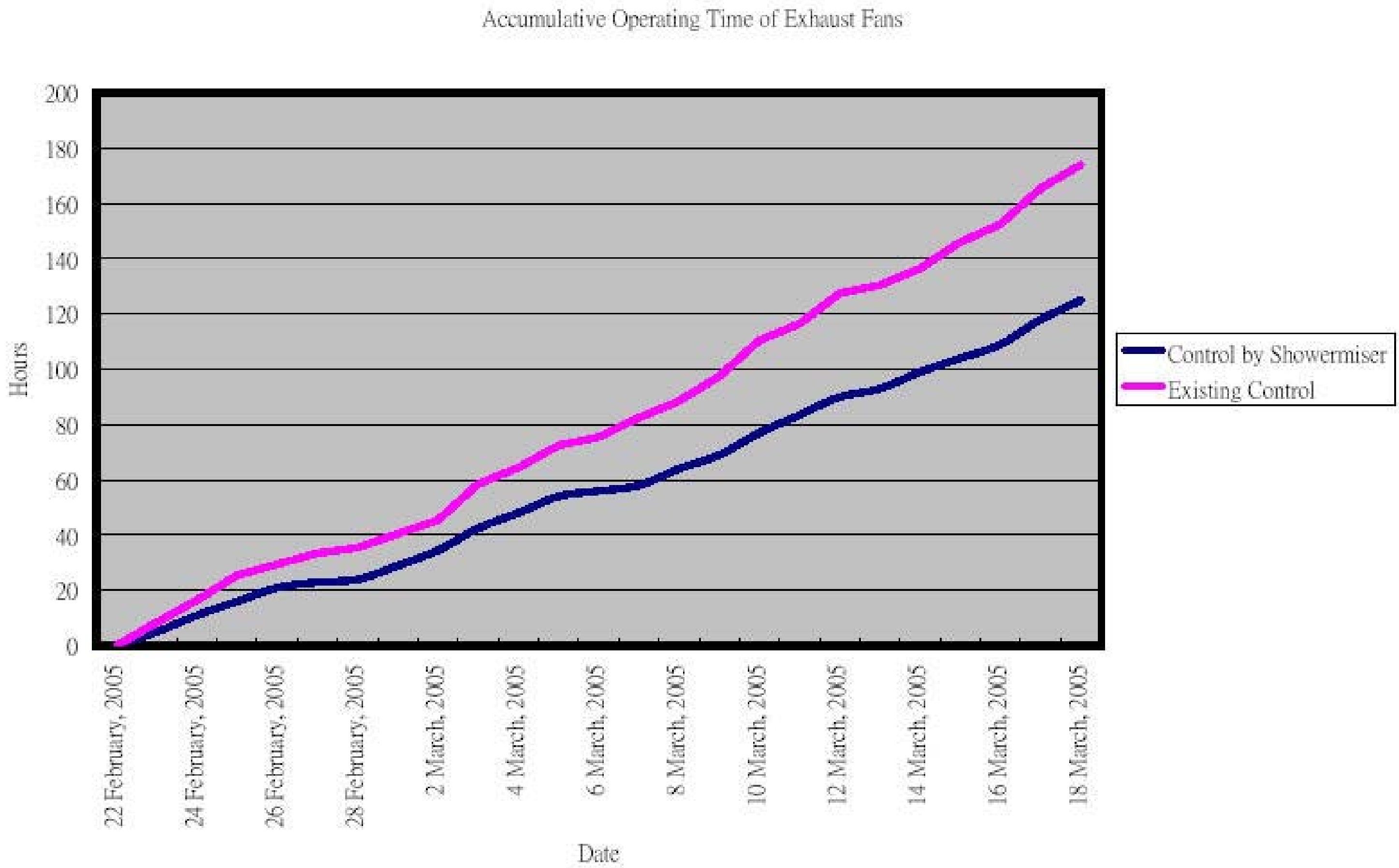
Figure 6.5a—The existing control device

Figure 6.5b—The operating time meter

Table 6.5c--The accumulative operating time of two exhaust fans

Date		Operating Time of Exhaust Fan on 1st Floor (Temperature-based Control) (hours,mins)	Operating Time of Exhaust Fan on 2nd Floor (Light-on Control) (hours,mins)
22 February, 2005	Tuesday	0,12	0,12
23 February, 2005	Wednesday	4,52	8,31
24 February, 2005	Thursday	10,44	16,35
25 February, 2005	Friday	15,52	25,26
26 February, 2005	Saturday	21,12	29,42
27 February, 2005	Sunday	23,02	33,35
28 February, 2005	Monday	24,07	35,57
1 March, 2005	Tuesday	29,10	40,48
2 March, 2005	Wednesday	34,37	45,46
3 March, 2005	Thursday	42,17	58,23
4 March, 2005	Friday	47,54	64,35
5 March, 2005	Saturday	53,51	72,26
6 March, 2005	Sunday	55,42	75,42
7 March, 2005	Monday	58,11	82,19
8 March, 2005	Tuesday	63,50	88,55
9 March, 2005	Wednesday	68,47	97,21
10 March, 2005	Thursday	77,15	110,35
11 March, 2005	Friday	83,46	116,42
12 March, 2005	Saturday	90,06	127,29
13 March, 2005	Sunday	93,12	130,52
14 March, 2005	Monday	98,41	136,34
15 March, 2005	Tuesday	104,17	145,52
16 March, 2005	Wednesday	108,47	152,41
17 March, 2005	Thursday	118,02	165,42
18 March, 2005	Friday	124,56	174,11

Figure 6.5d--The accumulative operating time of two exhaust fans



6.5.1 Results Comparison

The duration of monitoring was 24 days. The average operating times of fan per day in 1st floor and 2nd floor bathrooms are 5.21 hours and 7.25 hours respectively. The utility rate of showers was relatively high compared with other shower facilities. A possible reason might be its conspicuousness in the monitoring bathroom. The exhaust fan on the 2/F ran more about 50 hours for the whole monitoring period and about 2 hours per day. Although the time lag setting of 2/F was 5 hours less than the recommended time lag, the fan operating time of 2/F was still more than that of 1/F for about 40%. This meant that when the fan of 2/F operated with recommended time lad, the operating time difference would be larger. The main reason of the relatively poor performance of light-on control was predicted to be human mistake. Lot of users left the light on after showering. The control system thus assumed that someone was still using the shower, and kept providing ventilation to space. Because there is no direct relationship between the light-on and humidity produced, the light-on control cannot respond to humidity in accurate. In other words, the lighting device is not a good tracer of humidity.

6.6 Control Performance

The ventilation control performance should be determined according to the ability of maintain design IAQ, energy and cost saving and environment impact.

6.6.1 Energy

The energy saved by the control system can be classified into direct energy saving and indirect one.

6.6.1.1 Direct Energy Saving

According to information provided form exhaust fan manufacturer, the fan had a design ventilation rate of 15L/s, and it consumed about 20 watts of power.

The temperature-based control reduced about 50 hours of fan operating time, about 0.6 kWh of electricity for operating exhaust fan was saved during the monitoring period.

Showermiser consumed about 2.5 watts of power when operating, about 0.3 kWh of electricity was used in the period.

6.6.1.2 Indirect Energy Saving

The volume flow rates of the exhaust fans and ventilation vents were measured. Table 6.6.1.2a shows the measuring results.

Table 6.6.1.2a--The measured volume flow rates of the exhaust fans and ventilation vents

	Volume Flow Rate (m^3/s)	
	1st Floor	2nd Floor
Exhaust Fan of Analyesd Shower	0.0125	0.0068
Ventilation Vent of Another Shower	0.0098	0.0093
Ventilation Vent of Bath No.1	0.0089	0.0096
Ventilation Vent of Bath No.2	0.0085	0.0091

The expected volume flow rate of the exhaust fan of the proposed shower was $0.015m^3/s$. Both of the measured values were lower than the expected values. The difference of $0.0025m^3/s$ between the measured flow rate of 1st floor fan and the expected rate might be due to the pressure loss of ventilation duct connected to outside. The most possible reason of relatively large difference occurred on the 2nd floor was lack of maintenance of exhaust fan and ventilation duct. Before installing Showmiser on the 1st floor, the fan and the duct had been cleaned to ensure the availability of the system for removing humidity.

Because of the difference of ventilation rate, the heat losses caused by the ventilation systems were also different. According to The Building Regulations Approved Document F, the requirement of extract ventilation fan rate for domestic bathroom is 15L/s. Therefore, the ventilation rate of 2nd floor was below the standard and basically not able to ensure the design relative humidity. The ventilation rate of 1st floor should be taken for heat loss calculation.

According to the UK weather channel (www.weather.co.uk), the outside temperature was about 7°C in March. Assume the indoor design temperature of bathroom was about 21°C. The heat loss calculation is showed in Table 6.6.1.2b.

Table 6.6.1.2b--The heat loss calculation

Volume Flow Rate (m^3/s)	Specific heat capacity of air (J/m^3K)	Indoor Temperature (°C)	Outdoor Temperature (°C)	Temperature Difference (K)	Heat Loss (W)
0.0125	1210	21	7	14	211.75

In the monitoring period, about 10.6 kWh of heat loss could be reduced with using Showermiser ventilation control.

6.6.1.3 Energy Saving for heating Season

The temperature varies through the year, so is heat loss rate. The estimation of heat loss for the whole heating season should be based on assumed monthly average temperature and the similar operating characteristic of exhaust fan through the year.

Table 6.6.1.3 shows the average temperature of several months in heating season and predicted heat loss caused by the ventilation in the case.

Table 6.6.1.3--Estimated average temperature and heat loss

	*Average Temperature (^{o}C)	The heat loss reduced for whole month (kWh)
Sep	12	8.17
Oct	10	9.98
Nov	7	12.71
Dec	4	15.43
Jan	3	16.34
Feb	4	15.43
Mar	7	12.71
Apr	10	9.98
May	12	8.17
Total		91.42

* Information from “www.weather.co.uk”

The estimation showed that more than 91 kWh of heat loss could be reduced by the proposed temperature-based DCV.

The total energy saved for whole heating is about 95kWh.

6.6.2 Cost

The running cost about the ventilation during the heating season was considering about two main aspects. One was the electricity consumed by exhaust fan and control devices. The other was the gas used by boiler for space heating.

According to the report of “Energy Consumption in the United Kingdom” produced by The Department of Trade and Industry, the 2004 average UK domestic electricity price was 4.5 pence per kWh. And the average gas price was 1.6 pence per kWh.

For 9 months of heating season, about 15 pence of the running cost for electricity consumption could be saved. And about 2.5 pounds of the running cost for gas consumption could be saved by assuming the efficiency of the gas boiler used by Derby Hall was 60%.

6.6.3 Carbon Dioxide Emission

For energy generated from fossil fuels, 0.43 kg of carbon dioxide is emitted when using 1 kWh of energy. For the proposed control approach, about 0.2 kg of CO^2 emission per day could be reduced and 50 kg for whole heating season.

6.7 Comments

The high utility of showers and low exhaust rates caused the energy and cost saving seemed to insignificant. Practically, 30% of energy was saved by the Showermiser control compared with the existing system. Also the maintenance and renovation of fans could be also reduced due to the reduction of fan operating time.

The more important is that this temperature-based demand control was capable to remove most of unwanted moisture, thus maintain the design relative humidity. The existing light-on control could not complete the work of removing humidity because of under expected flow rate and not appropriate time lag setting. More energy has to “throw in” to ensure the humidity control performance of light-on system. Obviously, Showermiser control is much closer to the target of energy efficient ventilation.

For the monitoring bathroom, there were another three shower/bath facilities with 24 hours running ventilation system. If using Showermiser to control all of shower/bath facilities in bathroom, about 2800 kWh of energy is estimated to be saved for a heating season with the assumption of equal utility rate of all shower/bath facilities. From the economical viewpoint, about 75 pounds can be saved.

One precaution of this case study is that the window in 2nd floor bathroom was often opened. It is guessed that some users opened the windows because of poor ventilation in 2nd floor bathroom. Without doubt, much more heat lose to outside through the window. And more energy is used to compensate the heat loss. This again shows the importance of energy efficient ventilation.

Figure 6.7—Opened window of 2nd floor bathroom

7. Conclusion

Ventilation control strategies are used to maintain indoor air pollution within acceptable limits in an energy-efficient way. In other words, the control strategies help to identify the “Balance-Point” between optimum indoor air quality and energy efficiency. The definition of “balance-point” is different under every particular circumstance. Thus, various control strategies with different characteristics are necessary to suit different cases. Through the investigations and the examinations, the appropriate control strategies can be determined in order to contribute to the building maximally. The technologies of sensor-based demand control are still developed. In the future, more sensitive and reliable control technologies with low-cost will improve the ventilation performance by providing accurate control responds and saving more energy.

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