OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

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DESIGN OF OCCUPANCY RELATED VENTILATION CONTROL SYSTEM FOR A NEW ENTERTAINMENT CENTRE IN HONG KONG.

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SYNOPSIS

A design process is developed for an OCCUPANCY-RELATED VENTILATION CONTROL SYSTEM (ORVCS) in a new entertainment centre in Sha-tin, Hong Kong. The aim is to reduce the cost of space cooling. Little work appears to have been done in using ORVCS in conjunction with space cooling up to the present time. The design process includes (a) the selection of a control parameter to modulate the fresh air supply rate (b) assumptions about the occupancy load profile and (c) estimation of the possible energy savings.

It is concluded that for certain zones of the building the annual energy savings due to use of an ORVCS could be as high as 29% and the pay-back time about 9 months.

SYMBOL LIST

		Units
La	Appliance Cooling Load	kW
Lc	Occupant Cooling Load	kW
Ls	Solar Cooling Load	kW
Lt	Fabric Transmission Cooling Load	kW
Lv	(Mechanical) Ventilation Cooling Load	kW
Qf	Maximum Cooling Load	kW
Qp1	Partial Cooling Load (Existing)	kW
Qp2	Partial Cooling Load with ORCVS	kW
Qm1	Monthly Cooling Energy Requirement (Existing)	kWh
Qm2	Monthly Cooling Energy-Requirement with ORVCS	kWh

1. INTRODUCTION

In a building having an occupancy related ventilation control system (ORVCS) an attempt is made to relate the (mechanically assisted) input rate of fresh air to the number of people occupying a given (large) zone of the building. It is therefore necessary to select a measurable physical characteristic of the building exhaust air which correlates with building occupancy (e.g. the CO_2 level in the exhaust air). Such systems have been installed in several public entertainment buildings[1] in the UK to reduce heating costs. A similar system has also been considered for installation in a university library[2]. The present work relates to the possibility of reducing the costs of cooling rather than heating a building by the adoption of an ORVCS. Here the input rate of (relatively warm) fresh air to a building zone would be reduced if the occupancy of the zone reduced and the rate of input of (relatively cool) recirculated air would be increased. The load on cooling coils and associated refrigeration equipment, would therefore be reduced and energy savings should result. The building is a new family entertainment centre located in the New Territories of Hong Kong. One of the authors (W.L.L.) was responsible for the design of the air conditioning system.

2. SHA-TIN ENTERTAINMENT CENTRE AND THE HONG KONG CLIMATE

The entertainment centre is situated in a residential area with an estimated population of 400,000 in Sha-tin New Town.[3] The ground floor area is 1956m^2 and the estimated maximum occupancy is 4050 people. It has the following facilities.

Basement Bowling centre, lounge

Ground Floor Fast food centre, coffee shop, entrance hall

First Floor Twin cinemas and foyer

Second Floor Upper part of cinemas, childrens ride area

Third Floor Theatre restaurant

Fourth Floor Family club (including multipurpose game area, gymnasium, dining area, library and conference room)

Roof Lounge

The Hong Kong climate is tropical with relatively hot summers (mean outdoor air temperature ~ 28°C July-September) and rather warm winters (mean outdoor temperatures ~ 16°C January-February). Relative humidity levels are generally high (especially during February to June when the mean level exceeds 70°%). The air conditioning requirements of the entertainment centre are therefore for cooling. There is no provision for heating. Cooling is provided either by cooling coils in the inlet air duct of given building zones or by free cooling i.e. when (during the winter months) the outside air temperature falls below the design internal temperature of 22°C there may be no need for use of the cooling coils and associated refrigeration systems. Use of ORVCS is applicable during April to October but not during the remaining months of the year when free cooling is possible.

3. SHA-TIN ENTERTAINMENT CENTRE AIR-CONDITIONING SYSTEM AND APPLICABILITY OF AN ORVCS TO CERTAIN BUILDING ZONES

The Sha-tin centre has a central refrigeration system consisting of 6 roof mounted Hitachi chillers each having a cooling capacity of 460kW. Water, chilled by these units, is pumped to cooling coils in seventeen air handling units and fourteen fan-coil units. A separate fresh air supply is ducted to each of these units and is independently controlled. It is therefore possible, in principle, to install independent ORVCS units in various building zones. Use of an ORVCS is considered to be applicable only to the first to the fourth floors of the building. It is not applicable to kitchen areas or to the basement which has a fixed requirement for fresh air at all times (and is slightly pressurised.)

Several properties of the building air were considered as possible control input parameters for an ORVCS. These were levels of CO_2, relative humidity, CO, O_2 and body odour. The choice of parameter was based on the following criteria: measurability, correlation with occupancy, provision of a sufficiently stringent ventilation requirement, availability of control equipment.

Humidity does not correlate well with building occupancy and is already used in the Shatin centre to determine when free cooling is possible. Body odour might be difficult to assess using objective techniques (e.g. gas chromatography) on a continuous basis.

Equipment is readily available to control ventilation systems using CO_2 level or O_2 plus combustible gases (e.g. CO from tobacco smoke). Either technique might be applicable to a leisure centre. There is some evidence that the second would have the advantage of dealing more effectively with smoking.[4] For the sake of simplicity the present work will be related to the use of CO_2. The CO_2 control parameter is based on the following. The CO_2 level in outdoor air is usually about 300ppm. An acceptable level of CO_2 indoors is 1000 ppm and at an exhalation rate of about $4.7 \times 10^{-6}\ M^3\ S^{-1}$ per person this corresponds to a fresh air rate of 6.7 l/s per occupant of a given zone. Contamination of outdoor air is unlikely to be a problem in Sha-tin although permitted levels for NO_x, SO_2 are exceeded in certain more densely populated parts of Hong Kong.[5]

4. SAVINGS IN CINEMA 'A' COOLING LOAD USING A CO_2 BASED ORVCS

Cinema A has a maximum occupancy of 800 people and a design maximum fresh air rate of 4.6 m^3/s. (This corresponds to approximately 1100 ppm of CO_2). It is assumed in what follows that the required fresh air rate for lower occupancies will be the corresponding fraction of the above maximum rate. In practice it is usual to set the controls to give a minimum ventilation rate regardless of occupancy. It is also assumed that for safety purposes the ORVCS could be over ridden manually if required. Cooling load and supply air rate calculations have been made for the building using ASHRAE procedures[6]. It is assumed that the total cooling load is given by

$$Q = Ls + Lt + La + Lo + Lv$$

An example of the results of the mean cooling load calculations with and without an ORVCS for cinema A in the month of July is given in table 1. The occupancy profile has been simplified to a constant level of 100% (of 800) for weekends and 33% for weekdays. (The predicted occupancies for weekdays used by the architects are 20% around noon rising to 45% later in the day). The partial occupancy of 33% is assumed to apply to 22 days per month while the remaining days correspond to full occupancy. The occupancy cooling load is taken as proportional to the number of occupants of the cinema (ie. Lop < Lo table 1). However, the ventilation cooling load (due to the requirement to cool fresh air to the design value of 22°C) will remain constant at Lv with the existing control system. Use of an ORVCS will allow this to fall to Lvp when the cinema is only partly occupied.

TABLE 1 CINEMA A. JULY COOLING LOADS AND COOLING ENERGY REQUIREMENTS WITH AND WITHOUT ORVCS

Maximum number of occupants	800
Mean partial weekday occupancy	33%
Solar Load Ls	0
Fabric Transmission Load (Lt)	2.8kW
Appliance load (La)	2.3kW
Maximum occupancy load Lo	80 kW
Partial occupancy load (Lop = 0.33 Lo)	26.4kW
Maximum ventilation load (Lv)	138 kW
Partial ventilation load (Lvp = 0.33Lv)	46 kW
Maximum cooling load (Qf = Lt + La + Lo + Lv)	223.1kW
Partial cooling load for existing control system (Qp1 = Lt + La + Lop + Lv)	169.5kW
Partial cooling load with ORVCS (Qp2 = Lt + La + Lop + Lvp)	77.5kW
Monthly cooling energy requirement for existing system (Qm1 = 12 [22 * Qp1 + 9Qf] assuming 12 hours operation per day)	68843 kWh
Monthly cooling energy requirement with ORVCS (Qm2 = 12 [22 * Qp2 + 9Qf])	44555 kWh
Saving in cooling energy requirement (Qm1-Qm2)	24288 kWh
% saving for July	35.3

Calculations show that the annual percentage saving in electrical energy usage for cinema A is 29%. This amounts to 31440 kWh. Here the coefficient of performance of the chillers in satisfying the cooling load has been taken as 3.4. The saving in energy costs is 19272 HK $ (at a tariff of 0.613 HK$/kWh). The estimated cost of the ORVCS is 13490 HK$ so that the pay back time is about 9 months. A similar time applies to the Theatre Restaurant. In general longer pay back times apply to other parts of the building.

5. CONCLUSIONS

(a) Measurement of the CO_2 level or total O_2 plus combustible gases in the exhaust air are the recommended means of regulating an occupancy related ventilation control system (ORVCS). The second method may deal more effectively with removal of tobacco smoke though more field trials would be desirable to make a comparison.
(b) An ORVCS appears to be appropriate to certain zones of a building requiring cooling rather than heating (such as the Sha-tin leisure centre). Those zones have variable occupancy and large open areas e.g. cinemas or the theatre restaurant. The estimated pay-back time for a cinema is 9 months with annual energy savings of 29%.
(c) Further work is required to develop the design of an ORVCS in conjunction with cooling systems and to evaluate actual pay-back times.

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