Improving cooling energy efficiency in Hong Kong offices using demand-controlled ventilation (DCV) and adaptive comfort temperature (ACT) systems to provide indoor environmental quality (IEQ) acceptance

Cooling is a significant energy consumer in office buildings in the subtropical climate zone. An adequate energy policy for indoor spaces should accordingly incorporate both energy conservation and an acceptable level of indoor environmental quality (IEQ). This study investigates the cooling energy consumption for IEQ acceptance in Hong Kong offices adopted for four space-cooling strategies: the ventilation strategies of conventional constant air volume (CAV) systems with a fixed fresh air flow rate; demand-controlled ventilation (DCV) by indoor CO_2 concentration; adaptive comfort temperature (ACT) set-point adjustment; and a combination of DCV and ACT operations. Numerical equations and multiple regression formulae were used to evaluate the cooling energy consumption and IEQ acceptance in the target offices, respectively. The results show that systems equipped with DCV are more energy efficient than conventional CAV systems, while a temperature set-point adjusted between 22°C and 23°C should satisfy the occupants' thermal requirements at a reasonable rate of energy expenditure. Meanwhile, the DCV + ACT method was found to be an effective ventilation strategy in terms of its energy saving potential (21.4%--24.3%) and an "average" IEQ acceptance, as presented in the sample office. The results of this study could be useful for the promotion of energy saving measures with IEQ consideration in air-conditioned office buildings in Hong Kong.

KEYWORDS:

Adaptive comfort temperature (ACT); air-conditioned office; cooling energy consumption; demand-controlled ventilation (DCV); indoor environmental quality (IEQ)

Nomenclature

A	Area (m^2)
$\boldsymbol{C_L}$	Clothing value (clo)
$\boldsymbol{C_p}$	Specific heat capacity ($kJkg^{-1}K^{-1}$)

E	Total energy (MJ)
g	Moisture content ($kgkg^{-1}$)
$\boldsymbol{h_{fg}}$	Latent heat of evaporation (2454 kJ kg^{-1})
k	Regression constant
L	Hourly cooling load (W)
$\boldsymbol{M_e}$	Metabolic rate (met)
N	Carbon dioxide generation rate (m^3s^{-1})
n	Number of occupants (ps)
$\boldsymbol{R_h}$	Relative humidity (%)
SD	Standard deviation
T	Temperature (°C)
U	U-value (W $m^{-2}K^{-1}$)
V	Air flow rate (m^3s^{-1})

$\boldsymbol{v}$	Air velocity (ms^{-1})
$\boldsymbol{\rho}$	Air density (1.2 kg m^{-3})
$\boldsymbol{\lambda}$	Acceptance level
$\boldsymbol{\gamma}$	Fanger's predicted mean vote (PMV)
$\boldsymbol{\theta}$	Indoor Environmental Quality Acceptance Index
$\boldsymbol{\phi}$	Occupant load factor
$\boldsymbol{\varphi}$	Operation schedule
$\boldsymbol{\gamma^*}$	Preferred predicted mean vote (PPMV)
$\boldsymbol{\zeta_1}$	Predicted percentage of dissatisfaction (PPD)
$\boldsymbol{\zeta_2}$	Carbon dioxide concentration (ppm)
$\boldsymbol{\zeta_3}$	Sound pressure level (dBA)
$\boldsymbol{\zeta_4}$	Illuminance level (lux)

Subscripts

1	of thermal comfort
2	of indoor air quality
3	of aural comfort
4	of visual comfort
a	of indoor air
AC	of air conditioning
bz	of breathing zone
c	of cooling
coil	of coil
i	of input hour
j	of cases
le	of leaving coil
m	of mixing air

max	of maximum
o	of fresh air
r	of mean radiant
room	of room
total	of total

1. Introduction

There is a great demand for high-quality office buildings in Hong Kong, which is located in a subtropical region and characterised by a hot and humid climate. Space cooling consumed 53.7% of the total electricity in the Hong Kong office segment in 2012 [1]. Cooling energy conservation measures and policies were broadly discussed, including improving the building envelope thermal insulation, enhancing the air-conditioning and ventilation (ACV) system efficiency, and adjusting indoor environmental parameter set-points [2,3].

Controlling the indoor temperature set-point and the amount of fresh air is one of the best solution for achieving savings in energy use. It is believed that the conventional fixed temperature set-point concept is inappropriate for optimising energy use; the indoor thermal comfort temperature should depend on the outdoor air temperature and the business culture, such as the nature of the activities in the building, the type of clothing worn by its occupants, and so on [4,5]. Unfortunately, design engineers still put great emphasise on energy-saving techniques rather than providing an integrated solution and comfortable built environment. Demand-controlled ventilation (DCV) systems offer another solution by modulating outdoor air quantities according to the CO_2 concentration in the indoor space, in order to save energy on the fresh air supply. This DCV system can reduce operating costs, especially for large buildings which are designed for high occupation densities and also have fluctuating occupancy [6,7]. However, the conventional DCV system implementations do not take into account any rise in contaminant sources in a building when the fresh airflow rate is reduced, which is hazardous to the health of the occupants.

A preliminary survey had identified cooling energy-saving potential in a balance of indoor air quality (IAQ) and thermal comfort demands [8]. Maintaining indoor environmental quality (IEQ) is one of the major cooling energy expenditures in air-conditioned offices. The IEQ for offices in terms of thermal comfort, IAQ, visual and aural comfort was investigated [9,10]. In one study, a regression model was established to estimate the individual aspects and overall IEQ acceptance in a workspace based on several selected indoor environmental parameters [10]. In another study, the reduction in staff productivity was found to be associated with poor IEQ in an office environment [11].

Prediction tools for cooling energy consumption and IEQ acceptance in indoor spaces are closely related to this topic but discussed separately in the literature. The strategy of using a higher set-point temperature and a lower fresh air ventilation rate were found to be effective for cooling energy conservation [12,13], but it was also associated with resulting in an unacceptable thermal environment and poor air quality in the office environment [14]. A step forward for these separate case studies is to integrate energy conservation strategies with minimal environmental quality penalties in office spaces. Temperature resets with adaptive comfort temperature controls and a new fresh air DCV system in air-conditioned buildings in Hong Kong is investigated in this study with a view to maximising the occupants' thermal comfort.

2. The surveyed Hong Kong offices

Based on the definitions described in [15], office buildings are graded as follows:

- Grade A: modern with high-quality finishes; flexible layout; large floor plates; spacious, well-decorated lobbies and circulation areas; effective central air conditioning; good lift services zoned for passengers and goods deliveries; professional management; parking facilities normally available.
- Grade B: ordinary design with good-quality finishes; flexible layout; average-sized floor plates; adequate lobbies; central or free-standing air conditioning; adequate lift services; good management; parking facilities not essential.
- Grade C: plain with basic finishes; less flexible layout; small floor plates; basic lobbies; generally without central air conditioning; barely adequate or inadequate lift services; minimal to average management; no parking facilities.

In this study, 1341 grade A, 466 grade B and 326 grade C offices were surveyed in Hong Kong. These open-plan offices were located in all districts among the city and ranged in size from 20 m^2 to 2000 m^2. The parameters of the indoor temperature T_a (°C), relative humidity $R_{h,a}$ (%) and the CO_2 concentration in breathing zone $\zeta_{2,bz}$ (ppm) were measured in the offices during working hours. The sensors used are specified as having an accuracy judged to be acceptable by a general study of office environments (air temperature sensor: shielded thermistor with an accuracy of ±0.5°C and a response time of 5 seconds; relative humidity sensor with an accuracy of ±5% and a response time of 2 minutes; CO_2 sensor: non-dispersive infrared with an accuracy of ±50 ppm and a response time of 3.5 minutes). The ACV system type – including variable air volume (VAV), constant air volume (CAV), fan coil unit (FCU), variable refrigerant volume (VRV) and split type air conditioner – was noted. In order to minimise uncertainty due to manual control and practicability of the ACV system installation in relatively small offices, this study focuses on CAV systems in grade B and C offices.

3. Energy efficiency prediction for different types of system control

Figure 1 illustrates a diagram for the air flow inside a conventional CAV system with a fixed volume of fresh air intake. The operation strategies of such systems can be energy inefficient, especially during overtime work hours when there is occupancy that is higher than expected and the lunch break when occupancy is reduced. Therefore, the improved strategy of DCV that is based on real-time indoor CO_2 concentrations has been introduced for comparison [16]. The concept of adaptive comfort temperature (ACT) set-points based on outdoor temperature variations is also considered for maximising the occupants' thermal comfort [17]. The procedures of predicting cooling energy use for the conventional CAV systems (the base case), DCV and ACT set-point adjustment are illustrated in Figures 2–4.

Figure 1. Diagram for a conventional CAV system.

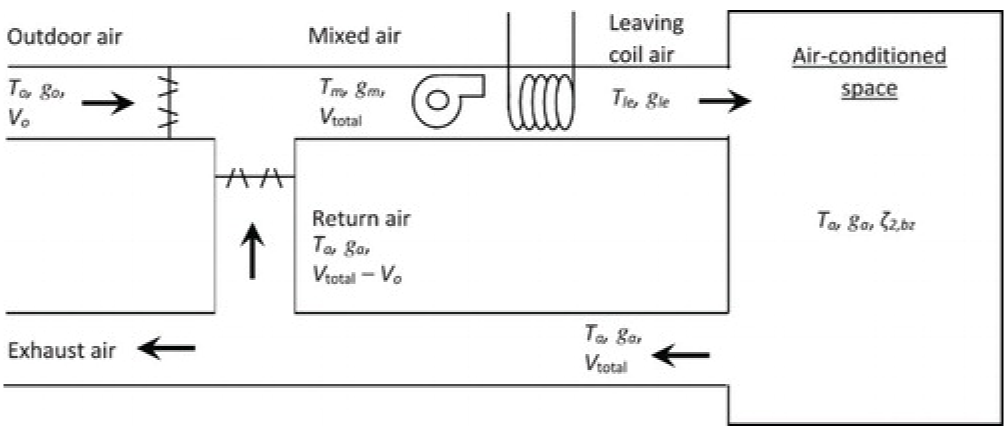


Figure 2. Procedures for the base case cooling energy prediction.

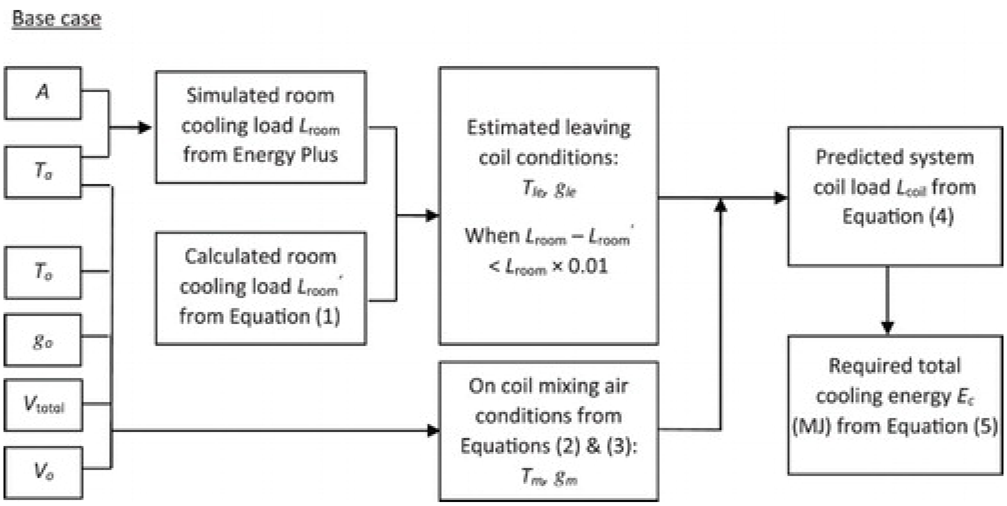


Figure 3. Procedures for the DCV strategy.

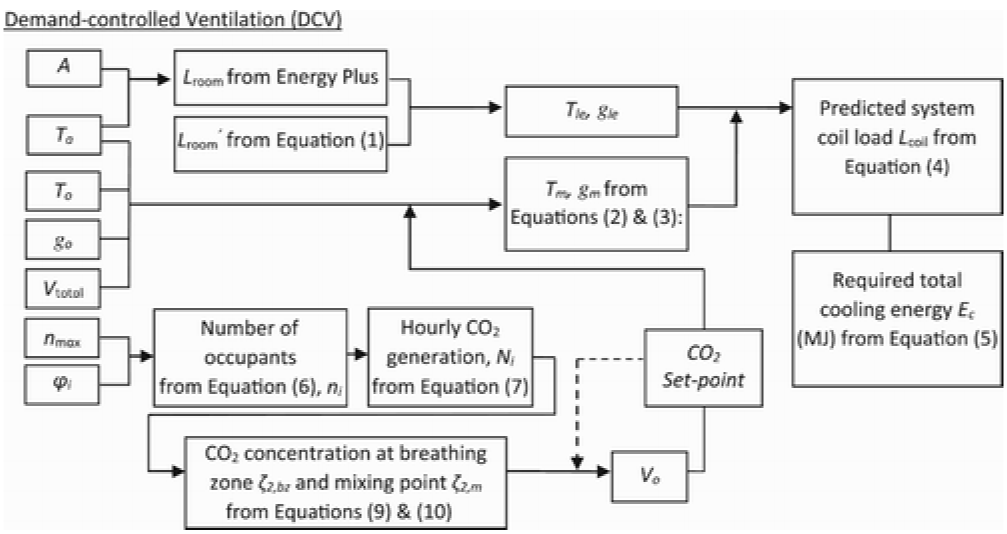
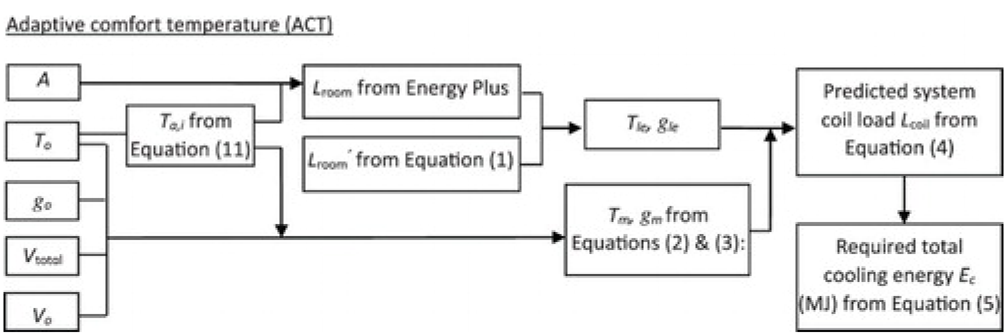


Figure 4. Procedures for the ACT adjustment.



The base case, in Figure 2, is described as a conventional CAV system with a constant fresh air flow rate V_o (m^3s^{-1}) (i.e. 20% of the total supply air volume V_{total}) intake coming from outside. The hourly room cooling load L_{room} (W) is predicted by interpolation from a database previously simulated by EnergyPlus using the floor area A (m^2) and an indoor temperature set-point T_a (°C). This database is constructed by 24 simulations from six floor areas (100 m^2, 300 m^2, 500 m^2, 700 m^2, 1000 m^2 and 2000 m^2) and four set-point temperatures (20°C, 22°C, 24°C, 26°C) using the outdoor weather data file in 1989 [18]. Detailed simulation parameters are referenced from a former survey of Hong Kong offices [10], including the U-value of the walls, the U-value of the windows, the window to wall ratio, the shading coefficient, the lighting system load, the electrical equipment load and the relative humidity, which have average values of 2.0 Wm^{-2} K^{-1}, 4.5 Wm^{-2} K^{-1}, 0.5, 0.47, 23 Wm^{-2}, 12 Wm^{-2}, and 60%, respectively.

The indoor moisture content g_a (kgkg^{-1}) is evaluated by psychometric charts based on the indoor temperature T_a and the relative humidity $R_{h,a}$. Assuming a negligible fan heat gain for the ACV system and a 95% saturation leaving coil condition, the room cooling load L_{room} is analytically expressed as follows:

where $\rho = 1.2$ kg m^{-3} is the air density, C_{pa} =1.023 kJkg^{-1} K^{-1} is the specific heat capacity of air, $h_{fg} = 2454$ kJkg^{-1} is the latent heat of the evaporation of water, T_{le} is the leaving coil temperature, and g_{le} is the leaving coil moisture content. Since the fresh air flow rate V_o is fixed at 20% of the supply air flow, the mixing air conditions, i.e. T_m and g_m, from outdoors and the return air can be expressed as follows:

$$T_m = \frac{V_o T_o + (V_{\text{total}} - V_o) T_a}{V_{\text{total}}};$$
$$g_m = \frac{V_o g_o + (V_{\text{total}} - V_o) g_a}{V_{\text{total}}}. \quad (2)$$

The required supply air flow V_{total} (m^{3}s^{-1}) is predicted by engineering practice using the floor area as follows: $V_{\text{total}} = 0.004 \times A.$ (3)

Finally, the hourly system coil load L_{coil} (W) and total cooling energy E_c (MJ) are calculated as follows:

$$L_{\text{coil}} = \rho \times V_{\text{total}} \times [C_{pa} \times (T_m - T_{le}) + h_{fg} \times (g_m - g_{le})], \quad (4)$$

$$E_c = 0.0036 \times \sum L_{\text{coil},i} \Phi_{AC,i} \ \text{for } \Phi_{AC,i} = 1, \quad (5)$$

where $\Phi_{AC,i}$ is the hourly ACV system operation profile and $i = 1, 2, \dots, 24$ hours. The leaving coil air conditions, i.e. T_{le} and g_{le}, are used for calculating L_{room} and L_{coil}, respectively.

The system with DCV control as shown in Figure 3 is similar to the base case, but V_o is controlled by the level of CO_2 concentration in the breathing zone $\zeta_{2,bz}$ (ppm) and the mixing chamber $\zeta_{2,m}$ (ppm). According to the maximum number of occupants in the target office $n_{\max}$ (ps) and the corresponding hourly occupant load factor ϕ_i, the hourly occupancy n_i (ps) and the CO_2 generation rate N_i ($m^3 s^{-1}$) in office can be predicted as follows:

$$n_i = n_{\max} \times \varphi_i \ \text{for}\ i = 1, 2, \ldots, 24\ \text{hours}, \tag{6}$$

$$N_i = n_i \times 0.000005167. \tag{7}$$

If n_{max} is not confirmed, it is predicted by the occupant to area ratio of 0.074 (ps m^{-2}) [10]:

$$n_{\max} = A \times 0.074. \tag{8}$$

The hourly CO_2 concentrations in the breathing zone and the mixing chamber

$$\zeta_{2,bz,i} = \frac{N_i + E_z V_{\text{total}} \zeta_{2,m,i-1}}{E_z V_{\text{total}}}, \tag{9}$$

($\zeta_{2,bz}$ and $\zeta_{2,m}$) are expressed as follows:

$$\zeta_{2,m,i} = \frac{V_o \zeta_{2,o,i} + (V_{\text{total}} - V_o)\zeta_{2,bz,i}}{V_{\text{total}}}, \tag{10}$$

where $E_z = 0.9$ is the zone air distribution effectiveness. It is noted that $\zeta_{2,bz}$ at hour i is dependent on the value of $\zeta_{2,m}$ from the previous hour, while $\zeta_{2,m,0}$ is assumed to be equal to the constant outdoor CO_2 concentration of $\zeta_{2,o} = 400$ ppm. If $\zeta_{2,bz}$ is higher than the space CO_2 set-point, more V_o is introduced into the system to maintain the CO_2 concentration level as equal to or lower than the set-point, otherwise, V_o is designed at a minimum level based on the floor area, i.e. 0.3 Ls^{-1} m^{-2} [19]. The ACT control as shown in Figure 4, is the same as the base case, while the hourly indoor temperature set-point $T_{a,i}$ is dependent on the outdoor temperature $T_{o,i}$ [17]:

$$T_{a,i} = 0.158 \times T_{o,i} + 18.303. \tag{11}$$

4. IEQ assessment

A quantitative measure for the IEQ acceptance index θ is used to rank the IEQ of an air-conditioned office environment:

$$\theta = 1 - \frac{1}{1 + \exp(k_0 + \sum_{j=1}^{4} k_j \lambda_j(\zeta_j))}, \tag{12}$$

where $k_j = [-15.02, 6.09, 4.88, 4.74, 3.70]$ is the regression constant for $j = 0, \ldots, 4$ [10]. An index of $\theta \geq 0.9$, $0.8 \leq \theta < 0.9$, $0.4 \leq \theta < 0.8$ and $\theta < 0.4$ represents good, average, below average and bad office IEQ values, respectively. The θ index is contributed by the acceptance level of thermal comfort λ_1, IAQ λ_2, aural comfort λ_3 and visual comfort λ_4:

$$\lambda_1 = 1 - \frac{\zeta_1}{100}, \tag{13}$$

$$\lambda_2 = 1 - 0.5\left(\frac{1}{1+\exp(3.118 - 0.00215\zeta_2)} + \frac{1}{1+\exp(3.23 - 0.00117\zeta_2)}\right), \tag{14}$$

$$\lambda_3 = 1 - \frac{1}{1+\exp(9.54 - 0.134\zeta_3)}, \tag{15}$$

$$\lambda_4 = 1 - \frac{1}{1+\exp(-1.017 + 0.00558\zeta_4)}, \tag{16}$$

where ζ_1 is the predicted percentage of dissatisfaction (PPD) of thermal comfort, ζ_2 (ppm) is the CO_2 concentration, ζ_3 (dBA) is the equivalent noise level and ζ_4 (lux) is the illumination level. The PPD ζ_1 is determined by the preferred predicted mean vote (PPMV) γ^*, where it is correlated with Fanger's PMV index γ [10,20]:

$$\zeta_1 = 100 - 95\exp(-0.03353\gamma^{*4} - 0.2179\gamma^{*2}), \tag{17}$$

$$\gamma^* = 3.86\gamma + 3.05; \quad -3 \le \gamma^* \le 3. \tag{18}$$

The PMV index γ is expressed as a function of

T_a, R_h:$\gamma \sim \gamma\ (T_a, R_{h,a}, T_r, v, M_e, C_L)$, (19)

where T_r (°C) is the mean radiant temperature, v (ms^{-1}) is the air velocity, M_e (met) is the metabolic rate and C_L (clo) is the clothing value [20].

5. Results and discussion

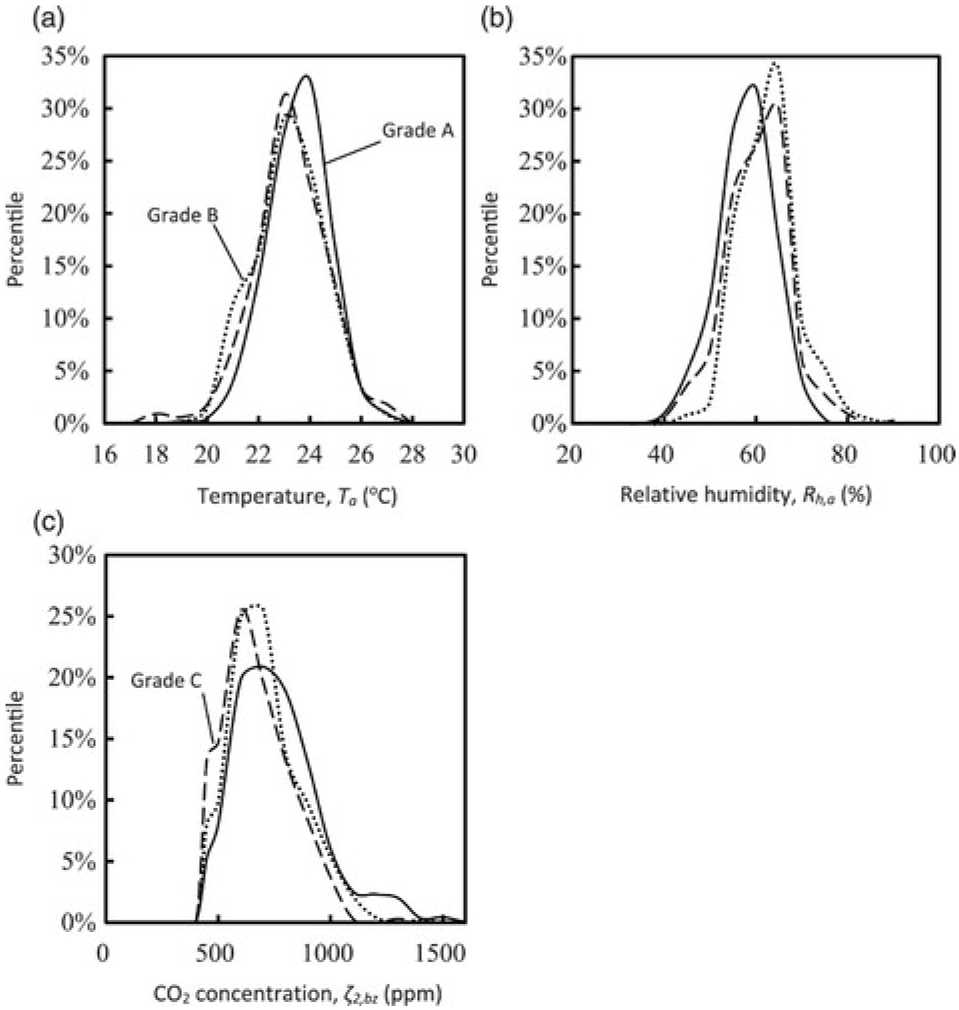
5.1. Building and system survey

Table 1 summarises the count of the ACV systems used in the surveyed grade A, B and C offices. For the grade A offices, the surveyed samples were dominated by VAV systems, followed by CAV systems. A few samples were served by FCU or VRV systems, while no split type air conditioners were observed. The majority of grade B offices were ventilated by FCU systems, followed by CAV, VRV, VAV systems and split type air conditioners. The largest portion of grade C offices was served by FCU systems, then split type air conditioners and CAV systems. This suggests that the ACV systems in grade A offices are less likely to allow for manual adjustment as compared with other offices.

Table 1. Air-conditioning systems used in the surveyed offices.

In general, all systems offer efficient indoor environmental control and result in a good degree of control for the temperature and humidity of the space, and the indoor CO_2 concentration depends on the design for the quantity of outdoor fresh air for ventilation and the occupancy capacity of the building, thus the effects of the outdoor environmental parameters are insignificant. Figure 5 illustrates the percentile of the values of T_a, $R_{h,a}$ and $\zeta_{2,bz}$ measured in the offices. The surveyed averages (ranges) of T_a and $R_{h,a}$ are 23.1°C (*SD* = 1.2°C, range = 18.2°C–26.6°C) and 58.5% (*SD* = 8.8%, range = 30.7%–79.2%) for grade A; 22.7°C (*SD* = 1.3°C, range = 19.0°C–26.5°C) and 65.3% (*SD* = 6.3%, range = 46.3%–87.4%) for grade B; and 22.8°C (*SD* = 1.5°C, range = 17.1°C–26.7°C) and 63.0% (*SD* = 7.0%, range = 41.4%–91.5%) for grade C. Similar values of T_a and $R_{h,a}$ were observed among the grade B and C offices ($p > 0.7$, *t*-test), while higher T_a and lower $R_{h,a}$ values were recorded in the grade A offices ($p < 0.05$, *t*-test). Since the grade B and C offices were dominated by manually controllable air-conditioning systems, i.e. FCU and spilt type, the T_a in these offices was on average adjusted to be cooler than the occupants' preferred level at about 22.6°C [10], while the mean set-point in the grade A offices was mechanically maintained at 23.1°C. The average (range) of CO_2 concentration $\zeta_{2,bz}$ recorded was 709 ppm (*SD* = 198 ppm, range = 430 ppm–1668 ppm) for grade A, 650 ppm (*SD* = 160 ppm, range = 411 ppm–1313 ppm) for grade B, and 612 ppm (*SD* = 205 ppm, range = 401 ppm–1219 ppm) for grade C. It was noted that open windows were observed in some grade B and C offices, especially for those equipped with split type air conditioners, but the windows in the grade A offices were always closed. The energy-saving potential in the grade B and C offices is confirmed with strategies of optimal indoor temperature set-points and fresh air intake using a centralised control ACV system, as the rate of infiltration will be reduced.

Figure 5. The percentiles in the surveyed offices of (a) temperature; (b) relative humidity; and (c) CO_2 concentration.



5.2. Simulation results for the DCV and ACT systems

Taking the hottest summer day, 28 July, and $T_a = 24°C$ as a reference, Figure 6 shows the profile of hourly cooling energy consumption, thermal comfort acceptance, IAQ acceptance and overall IEQ acceptance via the four ACV cooling strategies: the base case (constant fresh air flow), DCV, ACT set-point, and DCV + ACT. The input parameters of the office environment and the ACV system used in the simulation are summarised in Table 2. Most of the environmental parameters – including temperature, relative humidity and the CO_2 concentration – were based on the mean values for the working hours as per the survey (eight hours), while the other subjective response parameters such as the occupancy profile, metabolic rate and clothing values were referenced from previous IEQ surveys of Hong Kong offices [10].

Figure 6. Data on the four ACV cooling strategies at $T_a = 24°C$ on 28 July for the hourly (a) cooling energy consumption; (b) thermal comfort acceptance; (c) IAQ acceptance; and (d) overall IEQ acceptance.

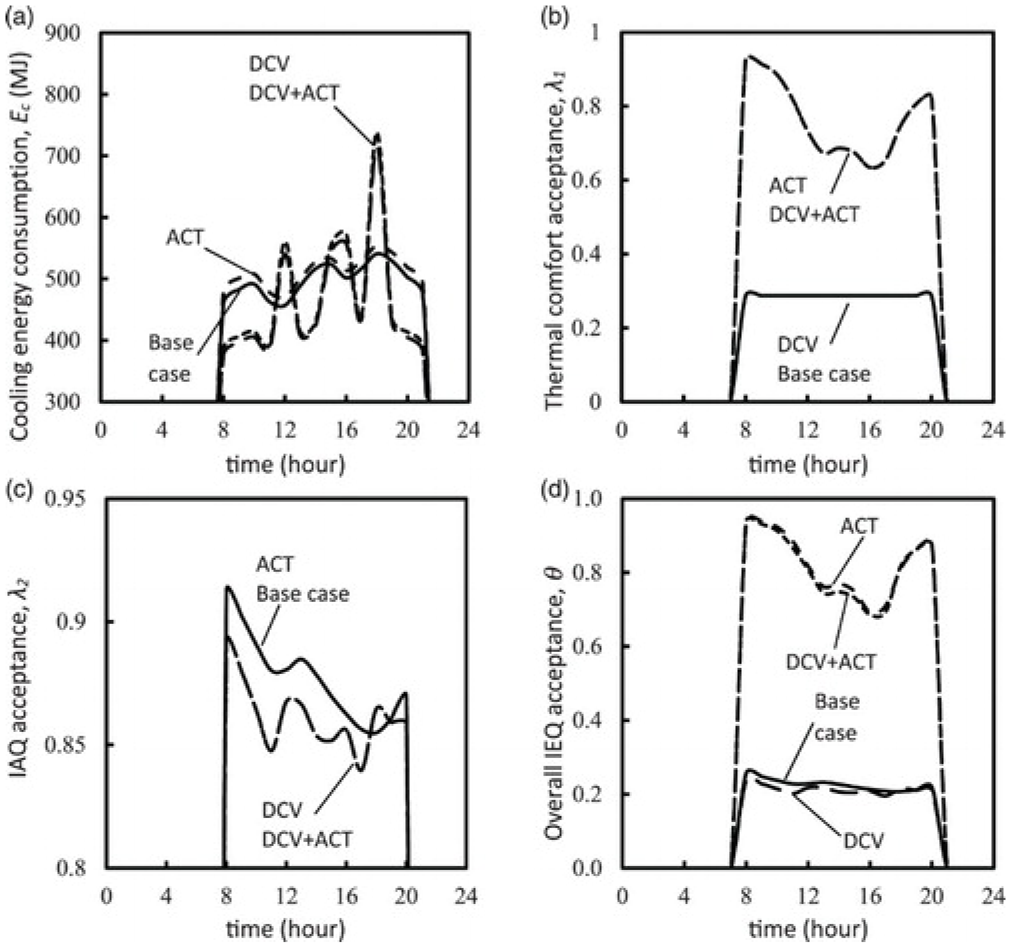


Table 2. Input parameters for the office environment in different ACV systems.

The highest daily cooling energy consumption was observed using the ACT system (6671 MJ), followed by the base case (6491 MJ), DCV + ACT (6183 MJ), and finally DCV (6042 MJ), which was found to be the most energy efficient strategy. Nevertheless, higher thermal comfort acceptance was reported with ACT set-point adjustment, while ventilation methods without ACT adjustment were found to be below 0.3. For the air quality, the IAQ acceptance for all ventilation strategies was found to be above 0.8 during working hours, which suggests an acceptable IAQ in the target office. The overall IEQ acceptance was found to be dominated by the thermal comfort acceptance under this environmental arrangement. Similarly, ventilation strategies with ACT adjustment were found to have good to average IEQ acceptance ($\theta > 0.7$), while the IEQ acceptance for the base case and DCV strategies was bad ($\theta < 0.4$). The results show that the ACV system with DCV + ACT is the most energy efficient option with IEQ at an acceptable level.

The per-hour cooling energy consumption and IEQ acceptance for the four ACV ventilation methods were tested for the indoor temperature set-points of $T_a = 20°C$, 22°C and 26°C (Figure 7). Since the occupant load profile, CO_2 set-point and ACT set-point (which depends on the outdoor temperature) were the same, the cooling energy consumption and IEQ acceptance for the ACT (6671 MJ, $\theta > 0.7$) and DCV + ACT (6183 MJ, $\theta > 0.7$) systems remained unchanged. The cooling energy use for the base case and DCV were found to be decreased with a T_a of 20°C (7309 MJ and 6701 MJ), 22°C (6928 MJ and 6397 MJ) and 26°C (5995 MJ and 5633 MJ), while the corresponding IEQ acceptance levels for the three temperatures are bad ($\theta < 0.05$), good ($\theta > 0.9$) and bad ($\theta < 0.05$), respectively. Despite the lowest cooling energy being recorded at $T_a = 26°C$ for DCV, the occupants still feel hot and thus result in a bad overall IEQ. Maximum IEQ acceptance for the base case and DCV was observed when $T_a = 22°C$, but a greater amount of cooling energy is required as compared with the DCV + ACT system.

Figure 7. Data on the four ACV cooling strategies for the hourly (a) cooling energy consumption; and (b) overall IEQ acceptance at (i) $T_a = 20°C$; (ii) $T_a = 22°C$; and (iii) $T_a = 26°C$.

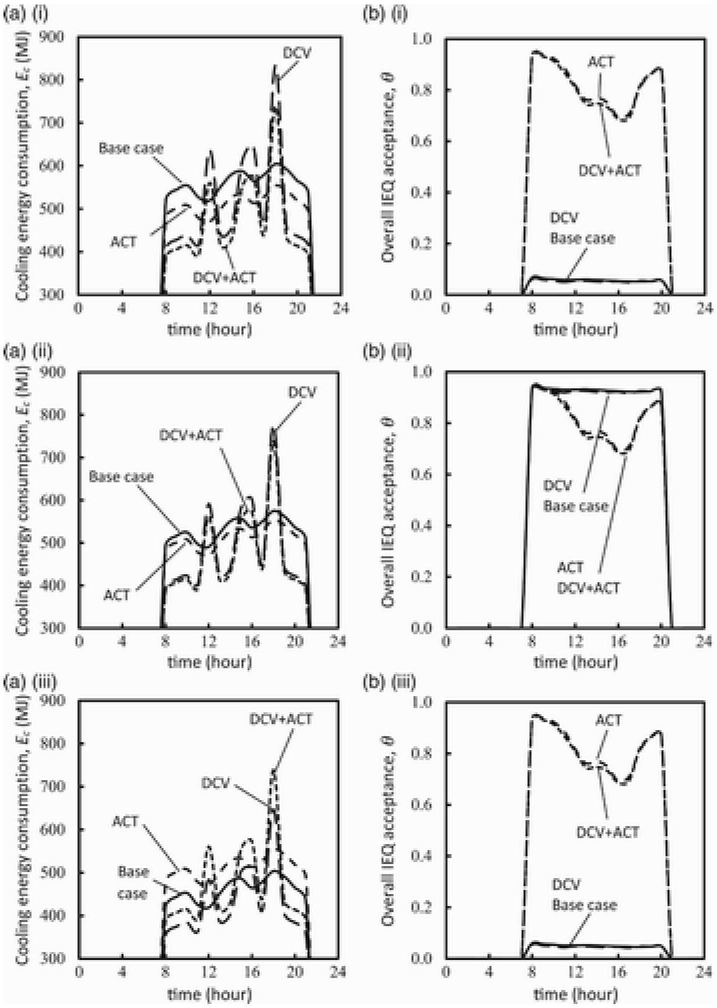


Table 3 summarises the cooling energy use for the two hottest summer months, July and August, in a 1400 m^2 office via the four ventilation strategies, with T_a adjusted to 22°C and 23°C. The extra cooling energy use and average IEQ acceptance during overtime working hours, i.e. 21:00 on weekdays, were also evaluated. Despite zero cooling energy use during the overtime working hours when the air conditioning was turned off, bad IEQ acceptance was observed in the office environment which could significantly reduce productivity [11]. Using a conventional CAV system, the base case, with T_a adjusted to 22°C and 23°C, good IEQ acceptance could be maintained in the office, but the highest cooling energy consumption (336,799 MJ–348,365 MJ) was required. For those ventilation strategies using ACT adjustment, average IEQ acceptance was reported. Meanwhile, less cooling energy (307,155 MJ) was required for DCV + ACT ventilation, with an energy saving potential of 21.4%–24.3% compared with the base case during the overtime working period. In terms of a simpler system control, greater energy effectiveness (16,907 MJ–17,315 MJ) and better office IEQ acceptance levels (0.89–0.92), a ventilation strategy with DCV control and a temperature set-point between 22°C and 23°C are recommended during overtime working hours.

Table 3. Cooling energy consumption and IEQ acceptance performance in summer months.

		Cooling energy consumption in July and August (MJ)			
	Ta (C)	Without OT	With OT	Extra energy used during OT hours (MJ)	Average IEQ acceptance, during OT hours
Base case	22	325,960	325,960	-	0.19
(no AC for OT)	23	315,214	315,214	-	0.12
Base case	22	325,960	348,365	22,450	0.93
(with AC)	23	315,214	336,799	21,585	0.9
DCV	22	298,249	315,564	17,315	0.92
	23	289,783	306,689	16,907	0.89
ACT	Outdoor-dependent	316,072	337,795	21,723	0.88
DCV + ACT	Outdoor-dependent	290,184	307,155	16,971	0.87

6. Conclusion

The choice of air-conditioning and ventilation strategy affects the energy consumption and IEQ acceptance levels in office buildings. This study presents a mathematical model that can enable the integration of cooling energy consumption evaluation and corresponding IEQ acceptance levels in Hong Kong offices via four ventilation strategies: conventional CAV system with a fixed fresh air flow rate, DCV based on indoor CO_2 concentration levels, ACT adjustment, and combined DCV + ACT system. The application examples show that the DCV method is more energy efficient than the conventional CAV system. Considering both energy efficiency and IEQ acceptance level, an air-conditioning and ventilation system which uses an ACT set-point that is dependent on the outdoor temperature is recommended. Otherwise, to avoid complicated system control and operation, the office temperature set-point should be adjusted to between 22°C and 23°C to maintain a decent thermal environment during both standard and overtime working hours. This study demonstrates a low-cost tool that is quick to use for predicting cooling energy consumption and IEQ acceptance levels in offices, which can provide a useful reference for building management officers before any action is taken to improve existing or pre-constructed air-conditioning systems in Hong Kong offices.

Additional information

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Notes on contributors

K W Mui

Ir Dr K W Mui, Ph.D., BEng (Hons), MHKIE, MCIBSE, MASHRAE, CEng, R.P.E., obtained his BEng (Hons) and Ph.D. degrees in Building Services Engineering from The Hong Kong Polytechnic University (PolyU) in 1996 and 2001, respectively. After gaining industrial work experience in building services design and project management while working at an international electrical and mechanical consulting company, he joined the Department of Building Services Engineering at the PolyU as an academic staff in 2000 and was promoted to an Associate Professor in 2010. He also founded an IAQ bioaerosol laboratory at the university. Over 100 of his refereed SCI and journal papers in relation to building environmental performance and environmental systems for built environments have been published in various academic journals and conference collections. Ir Dr Mui is a recipient of the 2011 Emerald Literati Network Awards for Excellence and his papers are recognised as being amongst those that were cited the most from Elsevier's journal *Building and Environment* between 2005 and 2008. His current roles include Honourable Advisor to the Hong Kong Indoor Air Quality Society (HKIAQS), Co-Chairman of the ASHRAE Technical Working Group (Moisture and Mold Control), Affiliate Faculty Member of the School of Nursing at the PolyU, Corporate Member of some local and international professional bodies, and Member of many local and international scientific committees.

L T Wong

Ir Dr L T Wong, Ph.D., BEng (Hons), MHKIE, MCIBSE, CEng, R.P.E., is an Associate Professor at the PolyU. He obtained his BEng (Hons) and Ph.D. degrees in Building Services Engineering from the PolyU in 1992 and 1997, respectively. His research interests include water management and IEQ for buildings. He is a Secretary of the Asian Saving Water Council (Japan) and a Working Commission Member of W062-water supply and drainage for buildings of the Council for Research and Innovation in

Building and Construction (CIB). He organised the 34th CIBW062 International Symposium of Water Supply and Drainage for Buildings in Hong Kong in 2008. He is a recipient of the 2006 Hans B. Thorelli Award for Excellence, and the highly commended award winner at the 2011 Emerald Literati Network Awards for Excellence.

C T Cheung

Ir C T Cheung is a Postdoctoral Scholar from the Berkeley Education Alliance for Research in Singapore (BEARS). He received his BEng and Ph.D. degrees in Building Services Engineering from the PolyU in 2009 and 2015, respectively. His thesis highlights a hybrid physical-statistical approach for housing cooling energy simulation, covering the areas of building energy simulation, building-occupant interaction and statistical modelling. His current research work in BEARS focuses on personal thermal comfort and air quality, wearable sensor experimentation and mega database analysis. He has recently begun working with the Center for the Built Environment on an ASHRAE project to develop the world's largest thermal comfort database.

H C Yu

Mr H C Yu obtained his M.Sc. degree from the University of Warwick, the UK in 1997. He is studying as a Ph.D. candidate under the supervision of Ir Dr K W Mui at the PolyU. His research interests focus on computational fluid dynamics (CFD) simulation for bioaerosol movement in ventilated environments.

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