Ventilation System Design for Educational Facilities

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Abstract:

Indoor air quality is believed to have a great effect on students and teachers performance in educational facilities decreasing their ability of concentration, memorizing and solving logical tasks required in classrooms. For maintaining acceptable indoor air quality levels more ventilation rates are required for dilution of contaminants concentration indoors, which means more energy consumed for operation of mechanical ventilation systems.

Carbon dioxide (CO_2) Concentrations are often used as a surrogate of the indoor air quality inside classrooms giving an indication for the rate of ventilation required of outside supply air. Higher indoor CO_2 concentrations mean decreased performance for students and lecturers. In this paper computer software is developed for determination of ventilation rates required to maintain carbon dioxide concentration within the recommended levels by standards for best students' performance and by enhancing indoor air quality.

Key words***: Indoor Air quality – Educationl Facilities – Ventilation systems – Computer application***

Nomenclature:

V_{bz}	Breathing zone outdoor air flow	m^3/s
P_z	Largest zone population	persons
A_z	Zone floor surface area	m^2
V_{ot}	Outdoor air flow intake	m^3/s
N	Carbon dioxide production rate	L/min
ACH	Air change per hour	hr^{-1}
H	Zone Ceiling height	m
C_o	Outdoor air CO_2 concentration	ppm
Cs	Indoor air CO_2 concentration	ppm
VR	Ventilation rate per unit area	$L/s.m^2$
R	Percentage of recirculated air	

1. INTRODUCTION

To determine the adequate ventilation rate for classrooms in educational facilities three factors are mainly considered [1]:

1. Maximum population served in classroom
2. Carbon dioxide production rate by occupants
3. Outdoor air conditions

Even if a large diversity in classroom population served occurs the design of mechanical ventilation systems should depend on the maximum number of students served so that the system could serve the full capacity classes.

The carbon dioxide production rate depends on the type of activities performed in the ventilated zone, where for educational activities the production rate could be assumed to be light activity.[2]

Carbon dioxide concentration in the outdoor air has a great effect on the required ventilation rates for the dilution of the indoor concentration as it varies according to the location whether it is near roads with high emissions, in countryside or in industrial cities with high factory emissions.[5]

ANSI / ASHRAE standard 62-2004 "Ventilation for acceptable indoor air quality" recommends a maximum of 1000 ppm of carbon dioxide concentration for acceptable performance of students in educational facilities.[2]

2. DESIGN APPROACH

For mechanical ventilation systems the ANSI / ASHRAE standards 62.2004 "ventilation for acceptable indoor air quality" specifies two approaches for determining the ventilation rates required for acceptable indoor air quality which are [2]:

1. Ventilation rate procedure
2. IAQ procedure [mass balance analysis]

Where the required ventilation rates are expressed in the terms of liter per second (L/s) or in the terms of air change per hour (ACH).

The ventilation rate required for classroom depends on several factors where the number of students served in the ventilated area and the floor surface area of the served zone and its ceiling height are the main factors affecting the system design.

Also the type of the served space is affecting the system design whether it is serving a single zone or it used to ventilate several zones and spaces at the same time or it is required to ventilate by all outdoor air to the system and the amount of recirculated air if needed.

Outdoor air carbon dioxide concentration has a great effect on the system design to make the required dilution for the indoor air which is required to be maintained at certain level according to the recommendations of the standards and codes for this type of zone

Where these data are used to determine the Ventilation rate required for any classroom with any desired geometry.

3. DESIGN PROCEDURES

3.1 Ventilation Rate Procedure

To determine the required design flow rate for classrooms the following procedure may be followed:

Step 1: the following data are required:

1. Type of the served system (Single zone – Multiple – 100% outdoor air)
2. Maximum number of students served in the zone (P_z)
3. Zone Floor Area (A_z)
4. Ceiling Height (H)
5. Carbon dioxide concentration in the outdoor air (C_o)
6. percentage of recirculated air to the zone (R)

Step 2:

1. Calculate the breathing zone outdoor air flow (V_{bz}) using equation 1:[2]

$$V_{bz} = (R_p * P_z) + (R_a * A_z) \quad \textbf{(1)}$$

Where :

R_p is the outdoor air flow rate required per person, which is specified by (10 L/s. person) for classrooms[2]

R_a is the outdoor air flow rate required per unit area which is recommended to be (5 L/s.m2) for classrooms[2]

2. Assuming ceiling supply air to the ventilated zone we can take an assumption that the zone distribution effectiveness (E_z) equals 1 so that the design outdoor air flow (V_{oz}) may be assumed to be equal to the breathing zone outdoor air flow :

$$V_{oz} = \frac{V_{bz}}{E_z} \quad \textbf{(2)}$$

$\because E_z = 1 \qquad \therefore V_{oz} = V_{bz}$

3. According to the system type the outdoor air flow intake (V_{ot}) is calculated.

(a) Single zone system

$$V_{ot} = V_{oz} \quad \textbf{(3)}$$

(b) Multiple Zone

(I) – 100 % outdoor air system

$$V_{ot} = \sum_{all-zones} V_{oz} \quad \textbf{(4)}$$

(II) – Multiple zone recirculated system

For a multiple zone recirculated system the following procedure may be applied for determination of the ventilation rate required start by calculating primary outdoor air fraction (Z_p) which is the ratio between the design zone outdoor air flow (V_{oz}) and the primary air flow to the zone from air handler unit (V_{pz})

$$Z_p = \frac{V_{oz}}{V_{pz}} \quad \textbf{(5)}$$

Using the primary outdoor air fraction (Z_p) the system ventilation efficiency (E_v) is determined from table 1 [2]

Table 1: values of system ventilation efficiency (E_v)

Max (Z_p)	**E_v**
≤ 0.15	1.0
≤ 0.25	0.9
≤ 0.35	0.8
≤ 0.45	0.7
≤ 0.55	0.6
> 0.55	Use equation 6

$$E_v = 1 + X_s - Z_d \quad \textbf{(6)}$$

Where:

X_s = Average outdoor air fraction (V_{ou} / V_{ps})

Z_d = Discharge outdoor air fraction (V_{oz}/V_{dz})

Then the uncorrected outdoor air intake (V_{ou}) is calculated using equation 7:

$$V_{ou} = D \sum_{all-zones} R_p P_z + \sum_{all-zones} R_a A_z \quad \textbf{(7)}$$

Where:

D = is the occupant diversity factor which may be calculated by the following equation .

$$D = \frac{P_s}{\sum_{all-zones} P_z} \quad \textbf{(8)}$$

(iv) Then the outdoor intake air flow rate may be calculated by the following relation:

$$V_{ot} = \frac{V_{ou}}{E_v} \quad \textbf{(9)}$$

3.2 Indoor Air Quality Procedure

In this procedure the design is based on the performance of the system where the ventilation system is designed to maintain the concentration of certain contaminant at or below a specific limits recommended by the standards.

This procedure can be achieved using many approaches; in this paper the used approach will be the mass balance analysis design technique [3] where in this case the ventilation rate procedure is used to determine the general limits ventilation rates and the indoor air quality procedure is used to achieve the control of concentration of Carbon dioxide (CO_2) below the values recommended by the codes and standards which is specified by 1000 ppm for educational facilities [2]

Mass Balance Analysis

For the mass balance analysis technique to be applied three main factors are considered:

1. The location of the air filter:
    - None
    - Recirculated air stream
    - Supply (mixed) air stream
2. Type of recirculated air flow rate
    - Variable air volume flow (VAV)
    - Constant air flow
3. Outdoor air flow rate
    - 100% outdoor air
    - Constant outdoor air flow rate
    - Proportional outdoor air flow rate

According to these three factors the used equation is chosen according to table 2 [2]

Where the parameters used in this table are:
A : the filter is located in the recirculated air stream
B : the filter is located in the supply air stream
V_o : is the outdoor air flow rate required per person
C_o : outdoor carbon dioxide concentration
C_s : indoor carbon dioxide concentration
N : Carbon dioxide Production rate from occupants
F_r : Flow reduction factor
E_f : Filter efficiency
e : Air change effectiveness

Where the indoor air carbon dioxide concentration (C_s) is set to 1000 ppm which is recommended by the standards for acceptable educational activities, and by taking average values for flow reduction factor (F_r) and filter efficiency (E_f) to be 0.95 and 0.8 respectively.

Taking into consideration that carbon dioxide production rate (N) depends on the occupants' activity type according to the following curve[2].

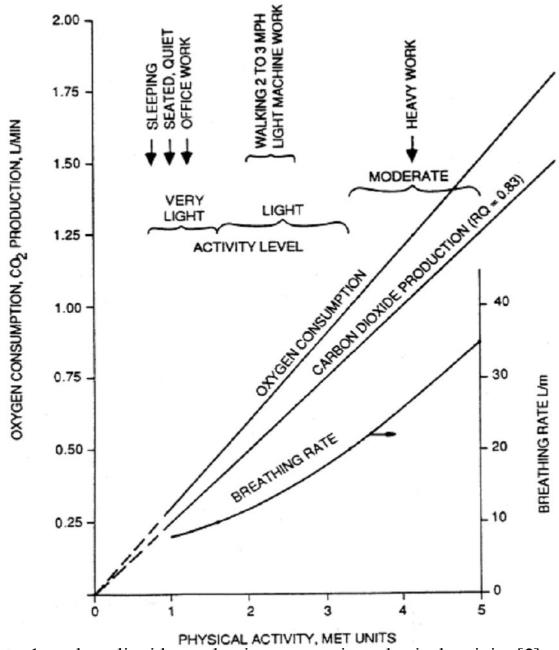

Figure 1: carbon dioxide production rate against physical activity [2]

The respiratory quotient (RQ) is the volumetric ratio of carbon dioxide produced to oxygen consumed. It varies from 0.71 for a diet of 100% fat to 0.8 for a diet of 100% protein and 1.00 for a diet of 100% carbohydrates. A value of RQ = 0.83 applies to a normal diet mix of fat, carbohydrate, and protein.

The rate at which oxygen is consumed and carbon dioxide is generated depends on physical activity. These relationships are shown in Figure 1 , so for educational activities a value of 1.2 MET UNITS can be assumed for calculations[3] .

Table 2: Required outdoor air or space contaminant concentration with Recirculation and Filtration

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Class	Required Recirculation Rate			Required Outdoor Air	Space Contaminant Concentration
	Filter Location	Flow	Outdoor air		
I	None	VAV	100%	$V_o = \frac{N}{E_v F_r (C_s - C_o)}$	$C_s = C_o + \frac{N}{E_v F_r V_o}$
II	A	Constant	Constant	$V_o = \frac{N - E_v RV_s E_f C_s}{E_v (C_s - C_o)}$	$C_s = \frac{N + E_v V_o C_o}{E_v (V_o + RV_s E_f)}$
III	A	VAV	Constant	$V_o = \frac{N - F_r E_v RV_s E_f C_s}{E_v (C_s - C_o)}$	$C_s = \frac{N + E_v V_o C_o}{E_v (V_o + F_r RV_s E_f)}$
IV	A	VAV	Proportional	$V_o = \frac{N - F_r E_v RV_s E_f C_s}{E_v F_r (C_s - C_o)}$	$C_s = \frac{N + E_v F_r V_o C_o}{F_r E_v (V_o + RV_s E_f)}$
V	B	Constant	Constant	$V_o = \frac{N - E_v RV_s E_f C_s}{E_v [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + E_v V_o (1 - E_f) C_o}{E_v (V_o + RV_s E_f)}$
VI	B	VAV	Constant	$V_o = \frac{N - F_r E_v RV_s E_f C_s}{E_v [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + E_v V_o (1 - E_f) C_o}{E_v (V_o + F_r RV_s E_f)}$
VII	B	VAV	Proportional	$V_o = \frac{N - F_r E_v RV_s E_f C_s}{F_r E_v [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + E_v F_r V_o (1 - E_f) C_o}{E_v F_r (V_o + RV_s E_f)}$

4. DEVELOPED COMPUTER SOFTWARE

Using the same procedures and equations explained in the previous section the software is used to calculate the required ventilation rates, Air changes per hour (ACH) and carbon dioxide concentration (C_s) within the ventilated zone.

4.1 Program inputs:

The inputs of the program are:

- Ventilation system type (Single or Multiple zone)
- Largest number of served population (P_z)
- Ventilated zone floor area (A_z)
- Outdoor area carbon dioxide concentration (C_o)
- Percentage of recirculated air (R)
- Ceiling height of recirculated air (H)

4.2 Program outputs:

The outputs of the program are:

- Ventilation rate required for ventilated zone
- Air change per hour for the zone
- Carbon dioxide concentration indoors

4.3 Program flowchart

Figure 2 shows the flow chart of the developed program for the ventilation rate required calculation procedure.

5. RESULTS AND DISCUSSION:

By running the software for several times with changing the inputs the following characteristic curves can be obtained to be used as a tool for designing the Ventilation rates required by the mechanical ventilation system for Educational facilities.

The following procedure may be followed to get the required ventilation rate and the air change per hour (ACH) for the ventilated educational facility.

Using the maximum population to be served in the classroom and its floor surface area we can get the ventilation rate required (VR) in (L/s) from figure 3 , then from figure 4 by using (VR) got from figure 3 the Ventilation rate required per unit surface area of the floor may be obtained in ($L/s.m^2$).

Then from Figure 5 using the ventilation rate per unit floor area got from figure 4 to get the air change per hour (ACH) , Then the three charts are drawn on one plot to make it easier to use it as shown in figure 6 with the same procedure stated before for the three charts .

6. SUMMARY AND CONCLUSIONS:

In this paper, the design method to determine the minimum ventilation rate for Educational facilities was presented. This design procedure can account for several factors including the maximum acceptable CO_2 level, the number of population served in the classroom, the production rate of carbon dioxide from the population.

Computer based software is developed to calculate the ventilation rate required for the ventilated educational zone considering the procedures recommended by the ANSI/ASHRAE standards to maintain the carbon dioxide concentration within the recommended limits and levels for educational facilities.

Also design curves for determining the ventilation rates and air changes per hour required for the ventilated educational zone which may used by designers as a simple and fast design tool for required ventilation rates are presented where using the population of the zone and the floor surface area are used to get the ventilation rates required the using the ventilation rate another chart is used to get the air change per hour for the ventilated zone.

Then for easier procedure the three graphs were put together in one plot with common axes to make it faster and easier to be used in design.

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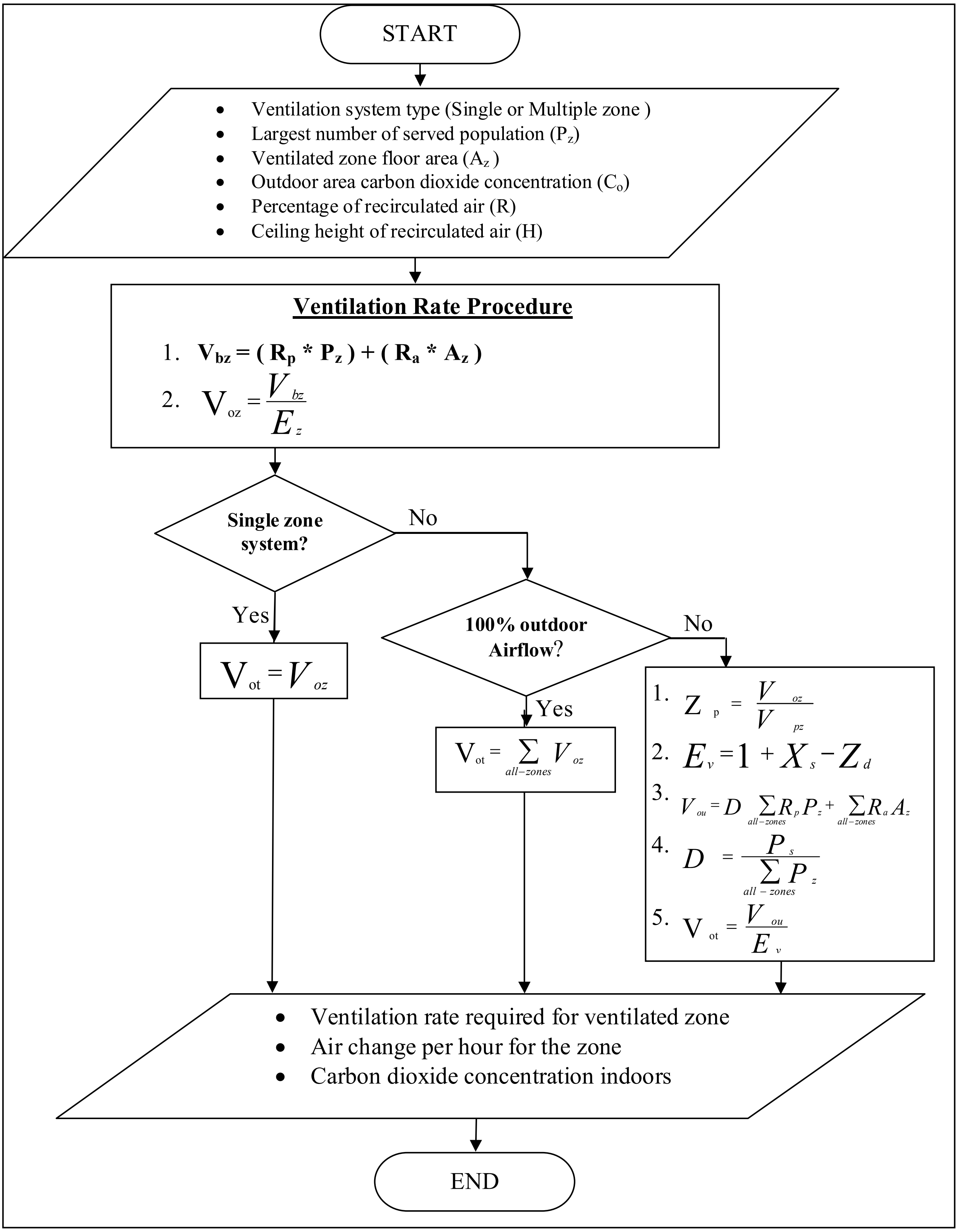

Figure 2: Ventilation Rate procedure flow chart

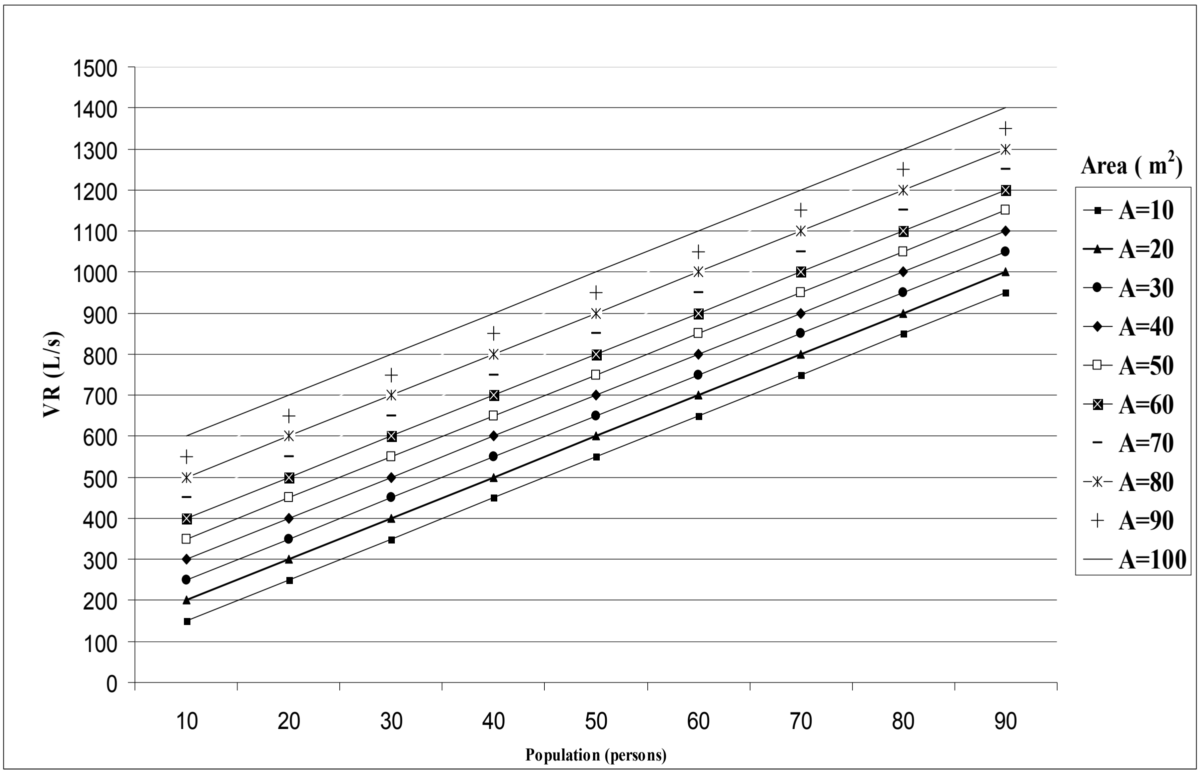

Figure 3 : Required ventilation rates against zone population at different floor areas

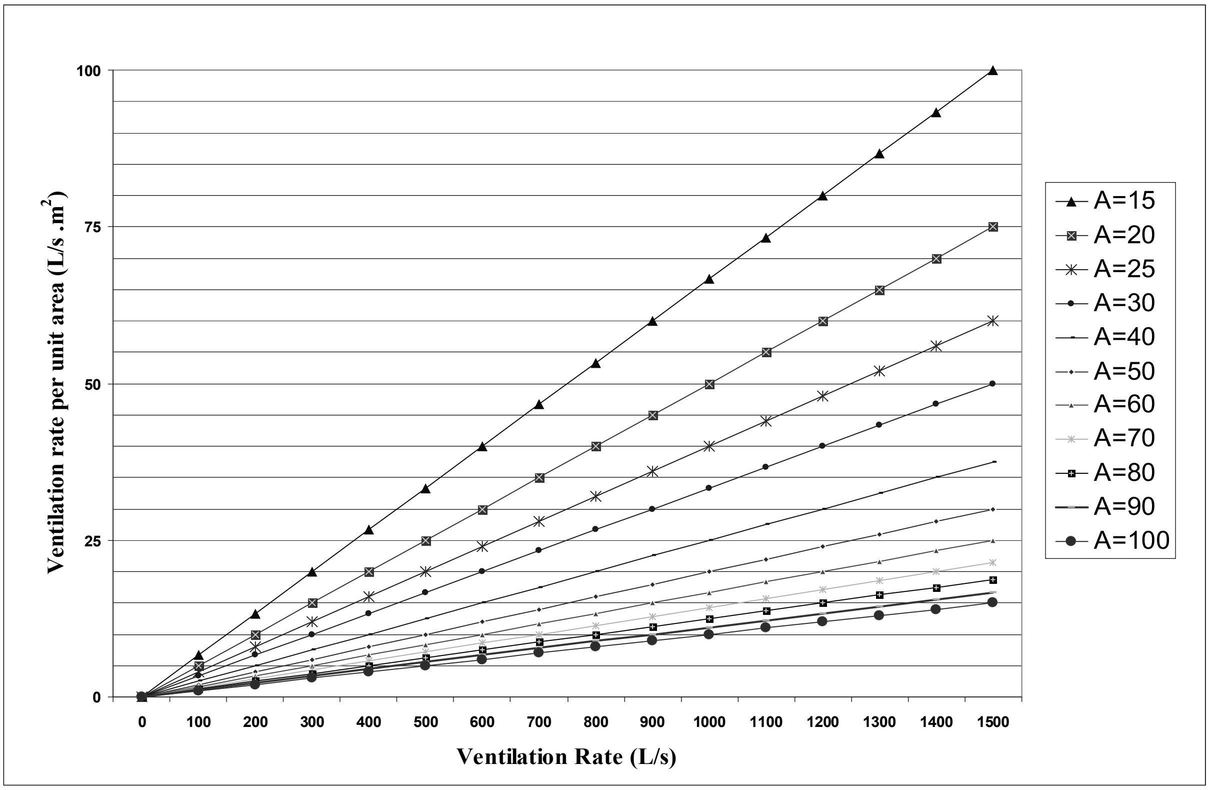

Figure 4 : Required ventilation rates per unit area against ventilation rates at different floor areas

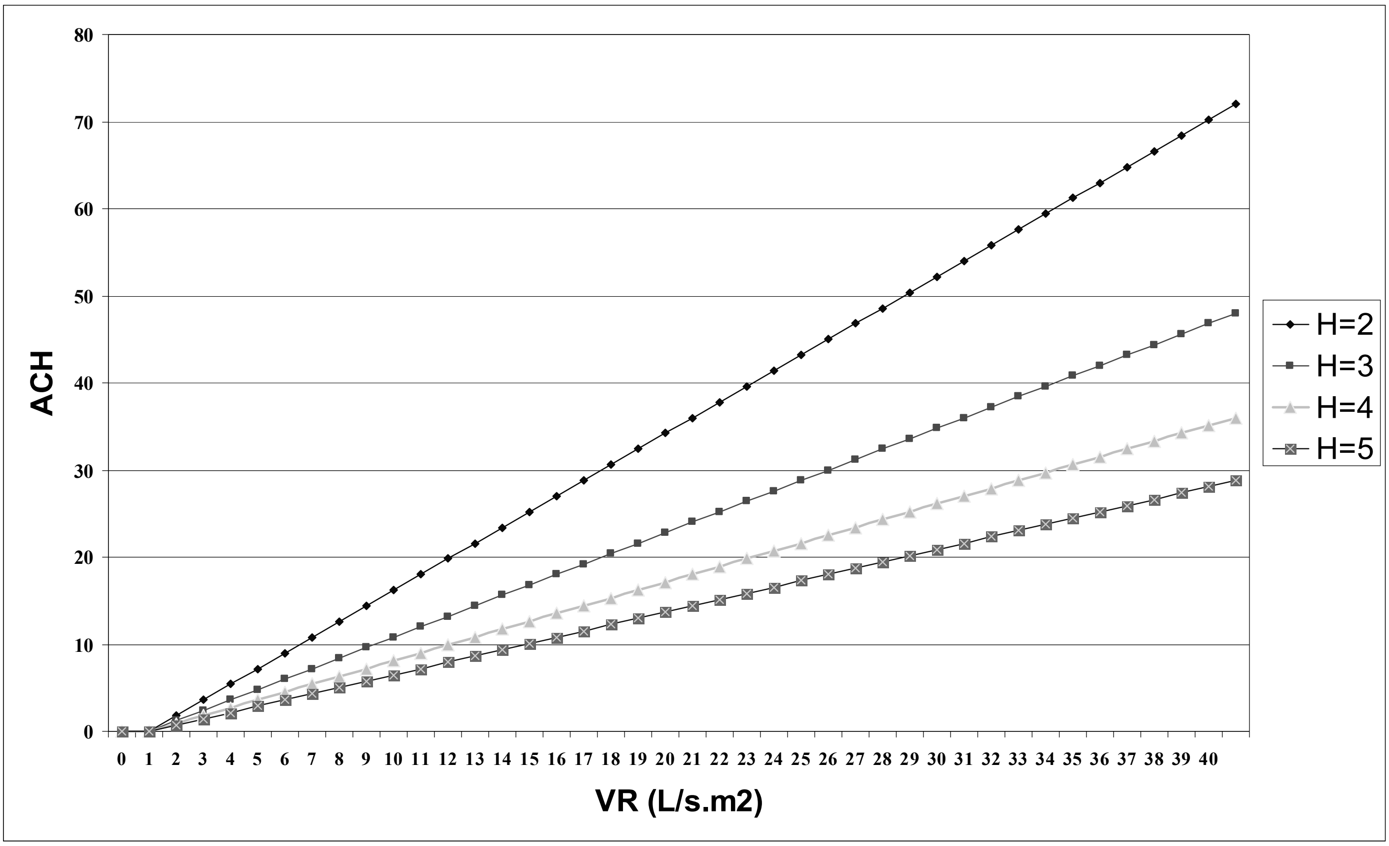

Figure 5: Air changes per hour against ventilation rates per unit area at different ceiling heights

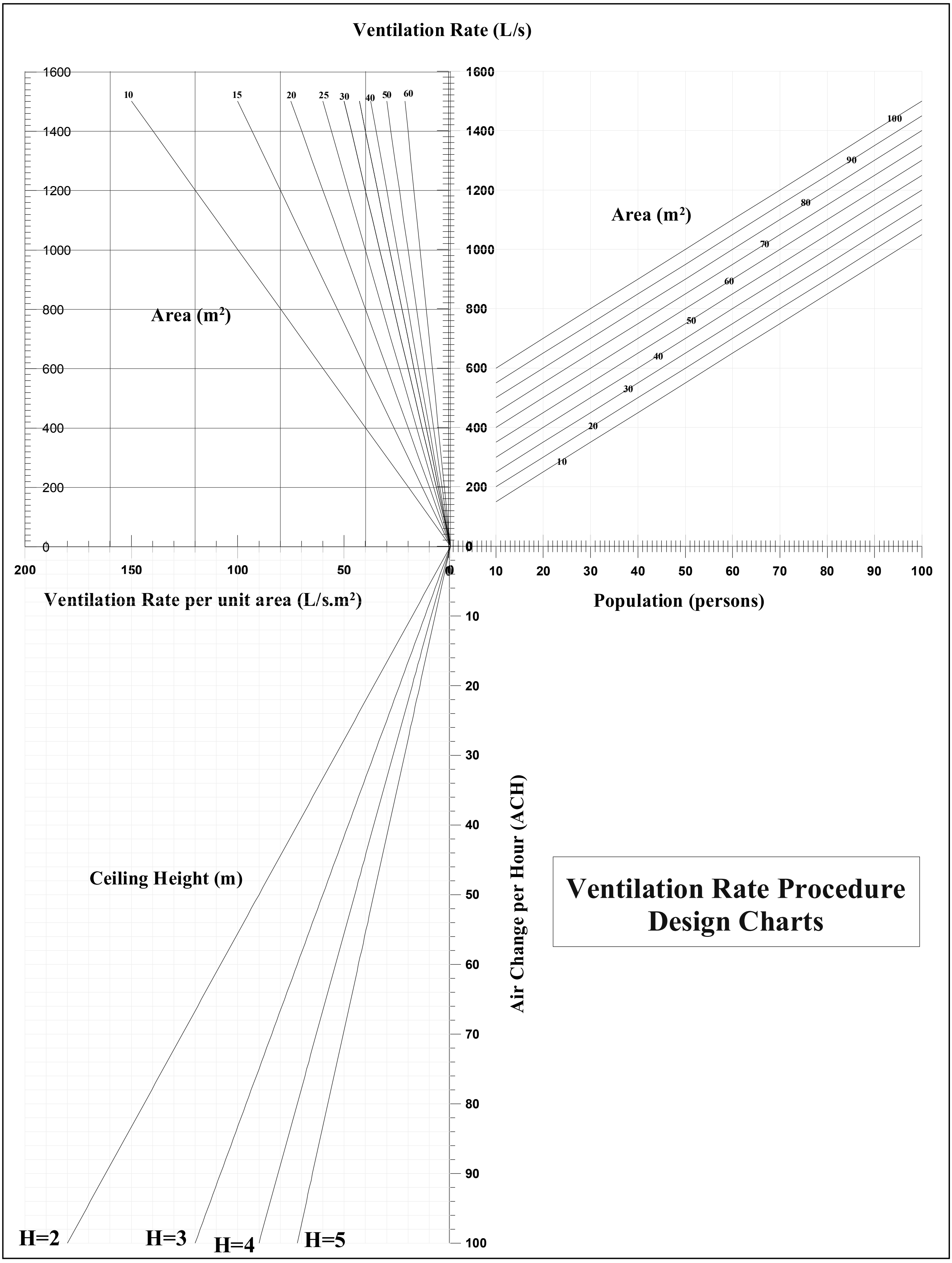

Figure 6: The three design curves in one figure for easier procedure