# MEASUREMENT AND PREDICTION OF CARBON DIOXIDE CONCENTRATION IN AN OFFICE BUILDING

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**ABSTRACT**

Carbon dioxide concentration in Petroleum Authority of Thailand (PTT) building has been measured. It is an office 25 stories high with each floor measured approximately 36 by 36 meters. The envelope of the building is not very tight due to a large number of windows that can be opened on each floor. The air conditioning system is VAV with one AHU on each floor. The ventilation system is a constant volume with fresh air supply to AHU room and three constant volume exhaust fans per floor. The measurements of carbon dioxide concentration were made at the return air plenum of the upper, middle and lower floors to investigate the effect of infiltration at different height. The background concentrations outside the building and the number of occupant were measured on the hourly basis. Measurements were then compared to the mathematical model results based on the mass balance of carbon dioxide in a conditioned space. Results shows that carbon dioxide concentration can be predicted quite well if the infiltration and the air flow between compartments of the building are known. This result is very encouraging because it indicates that a model prediction can be used for the design of a ventilation system for acceptable indoor air quality in high-rise building.

## KEYWORDS

$CO_2$, Energy saving, Demand Control Ventilation, IAQ, Office building, Ventilation

## INTRODUCTION

In the tropical climate country like Thailand, cooling load due to ventilation and infiltration is a large portion of total building cooling load (approximately 30 %) This portion of cooling load increases energy demand significantly. In buildings, if we can control ventilation rate according to actual need, we could save enormous energy consumption for ventilation system as well as energy consumption for cooling the outdoor air.

ASHRAE Standard 62-1989 [1] suggested that comfort (odor) criteria are likely to be satisfied if the ventilation rate is set so that 1000 ppm $CO_2$ is not exceeded. In general, $CO_2$ concentration depends on the occupant density and the ventilation rate. If we ventilate the space with constant air volume system, $CO_2$ concentration should be low when the number of occupant is small, and should be high when the number of occupant is large.

In the design of ventilation system in high-rise building, if the designer is able to predict the $CO_2$ concentration in each floor fairly closely, and understand the nature of air flow in building very well. The designer could select the right system and specify the right amount of outdoor air needed. Results presented in this paper show that the ability to predict air flow in building together with a simple equation to predict $CO_2$ concentration, one can easily access the potential saving of demand control ventilation. The measurement made at Petroleum Authority of Thailand (PTT) building to verify the model result is also very encouraging. With this strategy, one may be able to find a balancing point between IAQ and energy conservation.

## PREDICTION OF CO2 CONCENTRATION

Meckler [2] has derived equation to predict $CO_2$ concentration at any time t for indoor air quality model shown in Figure 1 as;

$$C(t) = C_v + (C_o - C_v) \exp(-Q_v t/V) + (G/Q_v)\,[1 - \exp(-Q_v t/V)] \times 10^6 \qquad (1)$$

In the above equation, C(t) is the $CO_2$ concentration at time t in ppm, $C_v$ is $CO_2$ concentration of outside air in ppm, $Q_v$ is outside air flow rate in $m^3$/hr, V is total volume of conditioned space in $m^3$. and G is $CO_2$ generation rate in $m^3$/hr. Value of G is approximately 0.30 L/min/person for an activity level of 1.2 met units (office work).

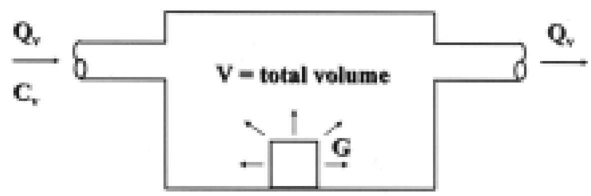


Figure 1: Indoor air quality model in equation (1).

Application of the above equation in practice requires some considerations as follow;

* Outdoor air $CO_2$ concentration ($C_v$) at any time t is not known in advance. In general, $C_v$ is approximately 350-400 ppm and does not change very much during the day. For the sake of prediction, $C_v$ at constant value of 350 ppm has been assumed.

* Value of $C_o$ at initial hour is also an unknown. Value of $C_o$ is usually close to the value of $C_v$ at the beginning of the day. In most cases, we could use value of $C_v$ in place of $C_o$ to start the calculation.

* The outside air flow rate $Q_v$ for high-rise building is very difficult to predict. The value of $Q_v$ depends on several factors such as wind effect, stack effect, air tightness of the building envelope, flow passage of air in the building and the HVAC system design. Value of $Q_v$ is not the value of air flow rate of ventilating fans specified in the drawing. It is the actual value of the net flow in to the building compartments or floors.

* Stack effect causes the air to move up or down within building shafts such as stairwells, elevator shafts and mechanical shafts. In Thailand, stack effect will cause the air to move downward through building shafts and bring pollution from upper floors to lower floors as shown in Figure 2. On the upper floor, large amount of outside air will leak in through building envelope, causing $CO_2$ concentration on the upper floors to become low. Part of the air on the upper floor is vented out by the exhaust fan in the toilet. The rest will moved down the shafts to the lower floors through stairwell and elevator doors. This air has $CO_2$ concentration higher than outside air and will cause $CO_2$ concentration of the lower floors to become even higher than it was expected. The prediction of $CO_2$ concentration on the lower floor is more difficult than on the upper floor. Equation (1) has to be applied with care because not all $Q_v$ on the lower floor has $CO_2$ concentration of $C_v$, some parts do not. In applying equation (1) to lower floor, one must calculate new $C_v$ by mixing those $CO_2$ concentration from various parts of the building before calculating C(t).

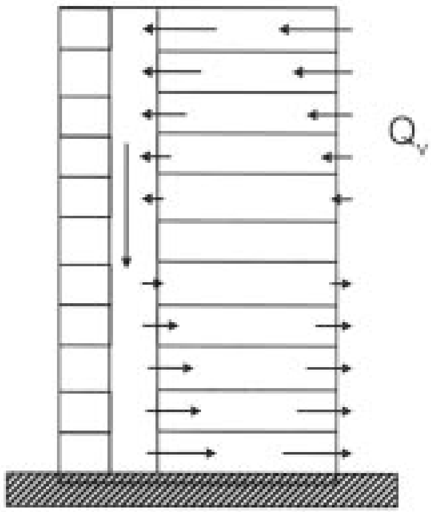


Figure 2: Stack effect in PTT building.

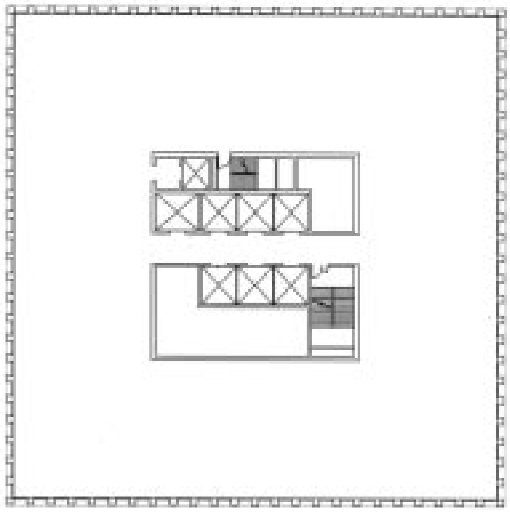

Figure 3: Typical floor plan of PTT building.

## MEASUREMENT OF $CO_2$ CONCENTRATION

PTT building is an office building with 25 stories and approximately 36 by 36 meters floor space. This building is located near the center of Bangkok. The typical floor plan is as shown in Figure 3.

The height of each floor is 4 meters except the first and the second floors which are 5 meters. Each side of the building has a large number of windows as shown in Figure 4.

There are 24 windows per floor on each side of the building. On each floor, the air conditioning system is VAV with a set of AHU and three sets of exhaust ventilation, of constant volume fans. A fresh air unit on the roof supplies fresh air to AHU room through a shaft.

Measurement of C(t) was done on the 5$^{th}$, 7$^{th}$, 12$^{th}$ , 15$^{th}$, 18$^{th}$, and 20th floor respectively. Hourly occupant level and Cv concentration were recorded approximately every hour during the measurement day. C(t) in the conditioned space was recorded by TELAIRE model 1050 at the exit of return air chamber in the AHU room. Temperature and humidity in the occupied zone, stairwells, and outdoor were also recorded. Supply fresh air to AHU room and the amount of exhaust air were also measured by propeller type anemometer.

The behavior of air flow in PTT building was studied. The actual shaft temperature and the hourly outdoor air temperature were used in the prediction of $Q_v$. The amount of air flowing downward form upper floors to the lower floors was used to approximate the mixing of $CO_2$ entering the lower floor (through stairwell and elevator doors). Comparisons between the predicted C(t) and the measured C(t) are shown in the next section.

Figure 4: PTT building.

## RESULTS

Predicted Results of C(t) on the 5th, 7th, 12th, 15th, 18th, and 20th floor were plot against measured results in Figure 5, 6, 7, 8, 9 and 10 respectively. Predicted C(t) as shown in figure 5 to 10 come from, equation (1) by setting Co equal to Cv at the starting hour. The actual occupancy schedules were used. In case that $C_v$ of the initial hour is not known, one may use value of 350 to 400 ppm as the starting value of C(t). In the actual prediction, one may assume occupancy schedule the same way as it is assumed in the energy simulation. Wind and temperature may be obtained from the TRY weather data file. Predicted results show reasonable agreement especially in the middle floors. Prediction at the fifth floor is not as good.

Sensitivity of all parameters affecting the end results were studied and analyzed. It was found that;

* Wind velocity does not affect C(t) as much as it was expected. This problem should be investigated further. Stack effect plays an important role in the movement of air inside the building and $Q_v$.

* Changing G from 10.59 x $10^{-3}$ cfm/person to some smaller value gives better results. The value of 10.59 x $10^{-3}$ cfm/person was recommended in appendix D of ASHARE Standard 62-1989. Since G is the product of metabolic rate and area of the body, value of G for Thais could be less.

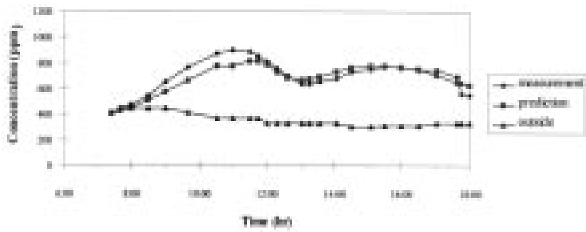

Figure 7: Predicted and Measured $CO_2$ Concentration on the 12th floor.

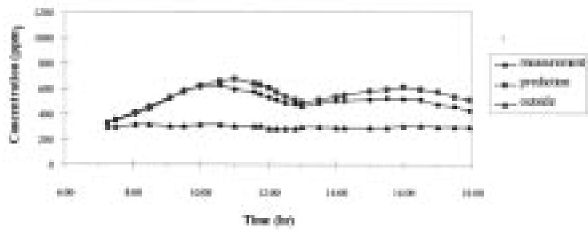

Figure 8: Predicted and Measured $CO_2$ Concentration on the 15th floor.

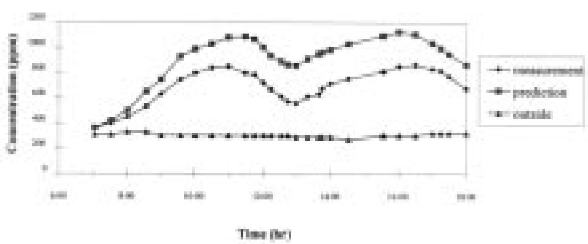

Figure 5: Predicted and Measured $CO_2$ Concentration on the 5th floor.

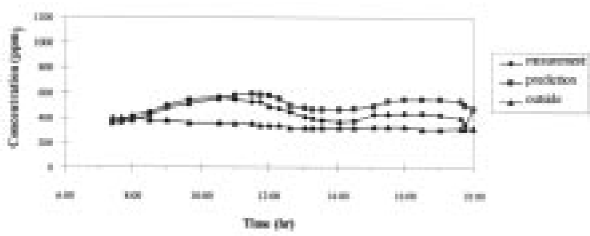

Figure 9: Predicted and Measured $CO_2$ Concentration on the 18th floor.

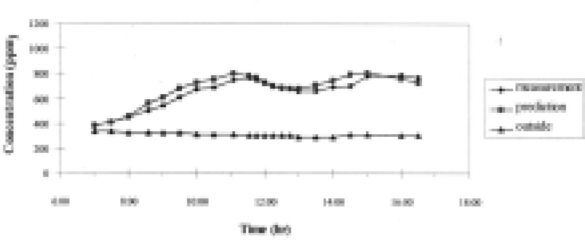

Figure 6: Predicted and Measured $CO_2$ Concentration on the 7th floor.

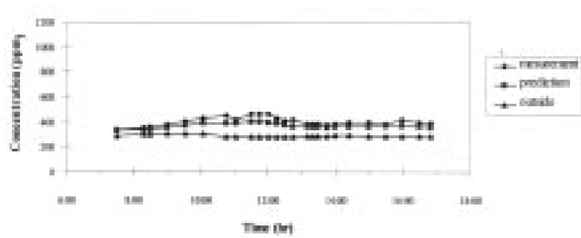

Figure 10: Predicted and Measured $CO_2$ Concentration on the 20th floor.

## CONCLUSIONS

From the results of comparison between predicted and measured value of $CO_2$ concentration in PTT building, we may conclude that equation (1) could be used to predict $CO_2$ concentration in an office building within a reasonable accuracy. On the 5th floor where the predicted result is not as good as on the other floors, the trend of the curve indicated that the predicted curve reflects the trend of actual measurement.

By using equation (1) together with the ability to analyze air flow in building, it enables us to predict C(t) quite closely and also sheds some light to the mechanism of pollution transport between floors. Benefit of using the technique in the design of ventilation system is obvious, for example, in PTT building;

* On the upper floor, the value of C(t) is quite low, the building operator may turn off some of the exhaust fans to save energy without affecting the indoor air quality.

* Pollution from the upper floor of PTT building is transported to the lower floor through elevator shafts and stairwells. The value of C(t) at the lower floor is quite high. The designer and the building operator should be aware of this fact.

## REFERENCES

(1) ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, Ga.

(2) Meckler, M.(1993), Carbon Dioxide Prediction Model for VAV System Part-Load Evaluation. Heating/Piping/Air Conditioning, January.