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Control strategy to reduce carbon emissions in buildings – An analysis with MATLAB simulation

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Abstract - *This paper addresses the procedure of modeling the indoor situation in buildings in order to understand the behavior of key parameters which affect the thermal comfort of the occupants. The mathematical models of the indoor environment of a classroom have been designed with the concentration of carbon dioxide. Changes in this parameter over time have been simulated. Then, a new control strategy has been proposed in order to keep the carbon emissions under the appropriate conditions of the occupants. Through mathematical methods, some optimization methods has been proposed for Demand Controlled Ventilation using PID tuning in order to reduce energy consumption without affecting the permissible limits. Validation process of the model has been carried out by Mat lab/Simulink and the suitable results are shown.*

Key Words: *Building, mathematical model, carbon emissions, control strategy, Demand controlled ventilation.*

1. INTRODUCTION

Heating, ventilating with air-conditioning (HVAC) systems are multi-variables system, which are one of the major consumer of energy in buildings. These systems afford warmth and cooling, humidity control, indoor air quality, and offer comfort for the occupants. Despite great advances in HVAC systems but there are still wide fields of research, where, HVAC systems are constantly being developed in recent times, especially with the expansion of architectural buildings, and industrial renaissance taking place in the world. It is crucial to keep an eye on indoor air quality to maintain health condition indoor and to create proper stable environment for attaining the required work target.

The outside air must be modified before being sent indoor, though it is on expensive process but this process alters much indoor air quality. The indoor carbon dioxide concentration for ventilation is advised to maintain at lowest possible cost. A plan of action control to be set outside air being sent to the building on the basis of indoor CO_2 *concentration. Therefore the building will be properly aired. Mechanical ventilation system significantly others the indoor air condition. Most time ventilation system receives hugs amount of outdoor air usually on max occupancy valve. It leads to undesirable cost, Because most building does not have max occupancy level. Therefore it is inessential to conditioned all those amount outdoor air before being sent into the building. This leads to energy wastages* CO_2 *technology provides measures to control outside air to the indoor space which is based on actual ventilation rate* CO_2 *concentration.*

The energy required for air conditioning is reduced by combination of ventilation rate and number of known as measuring indoor CO_2 *concentration by a sensor and then a feedback signal is generated which controls the ventilation rate so that minimum amount of outside air is used to maintain an acceptable indoor air quality. Therefore we can conclude by mentioning that DCV (demand control ventilation) with PID tuning is used to save energy by reducing unnecessary amount of air which results from in appropriate ventilation rate.*

2. INDOOR AIR QUALITY

Workers & students 1/4th of their time spent in school &work. Therefore maintaining proper quality of indoor air in workplace & school is necessary outdoor air must be used to diffuse indoor air toxic waste & remove impurity.

The amount of CO_2 *in air is expressed in parts per million, PPM. Outdoor* CO_2 *level is around 400PPM. These levels depend upon ventilation traffic, industries, combustion and also climatic condition such as wind and temperature. An average adult contain 35000 to 50,000 PPM of* CO_2 *for breathing. Current ventilation guidelines, such as done by ASHRAE, advise that indoor* CO_2 *concentration not go beyond the outdoor concentration by more than about 650 ppm. Outdoor* CO_2 *concentration has noteworthy impacts on the indoor concentration. Hence, it is imperative to measure outdoor* CO_2 *levels to deal with indoor concentrations. Epidemiological research has initiated that indoor* CO_2 *concentration is an acceptable indicator to predict human health and performance. Many studies have found that higher* CO_2 *concentrations in schools are associated with increased student absence.*

Some studies have found that poorer student performance is associated with increased CO_2 *in classrooms. Some searches have confirmed that students performed their tasks at school less effectively when* CO_2*concentration was higher.*

3. MASS BALANCE MODEL OF INDOOR CARBON DIOXIDE

Conservation of mass forms the basis to model the dynamic change in CO_2 concentration. Then simulation of this process on software SIMULINK/MATLAB helps to provide the necessary environment to propose control strategies in order to adjust CO_2 concentration in accordance with the requirements of the occupants.
The mass balance of indoor CO_2 concentrations for the steady state can be determined for the ventilation rate used by the equation (1).

$$V_{indoor}\frac{d_{cin}}{dt} = G + Q_v C_{out} - Q_v C_{in} \text{.........} \quad (1)$$

Where:
V_{indoor} [m^3]: indoor space volume.
C_{in} [ppm]: indoor CO_2 concentration.
C_{out}[ppm]: outdoor CO_2 concentration.
t [s]: time.
G [m^3/s]: indoor CO_2 generation rate.
Q_v [m^3/s]: ventilation rate.

When students enter to the classroom, indoor CO_2 concentration will begin to increase until the amounts of CO_2 resulted from the students and amounts present within the air delivered from ventilation system to the space become in balance state. This state is called the equilibrium point. At this case, there is no change in CO_2 concentration which is shown in equation (2):

$$V_{indoor}\frac{d_{cin}}{dt} = 0 \text{ .... } (2)$$

Then, equation can be written as follows:

$$Q_v C_{in} = G + Q_v C_{out} \text{ ....}(3)$$

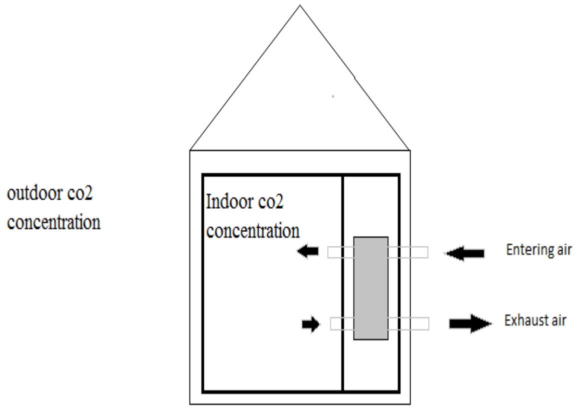

Figure - 2 Indoor mass balances

By rearranging equation (3) the carbon emissions in a building can be calculated as shown in the equation (4)

$$C_{in} = \int \frac{G + Q_v C_{out} - Q_v C_{in}}{V_{indoor}} dt \text{..................}(4)$$

4. TRADITIONAL BASE/FORCED VENTILATION MODEL

Traditional base/forced strategy operates according to the existence of occupancy, so that when there is occupancy, forced ventilation will be used regardless of occupancy size, while base ventilation is used only when there is no occupancy. Hence, the criterion in this strategy is not the occupancy size, but it is the existence of occupancy. This strategy means if there is occupancy, the ventilation rate is the forced rate. On the other hand, when there is no occupancy, the ventilation rate is the base rate. As shown in Figure 3 , the model has been designed so that when there is occupancy, the signal passing through switch (1) is 1. In this case, the signal passing through switch (2) is the forced rate. As long as there is occupancy, the ventilation rate is the forced rate. On the other hand, when there is no occupancy, the signal passing through switch (1) is 0. In this case, the signal passing through switch (2) is the constant rate.

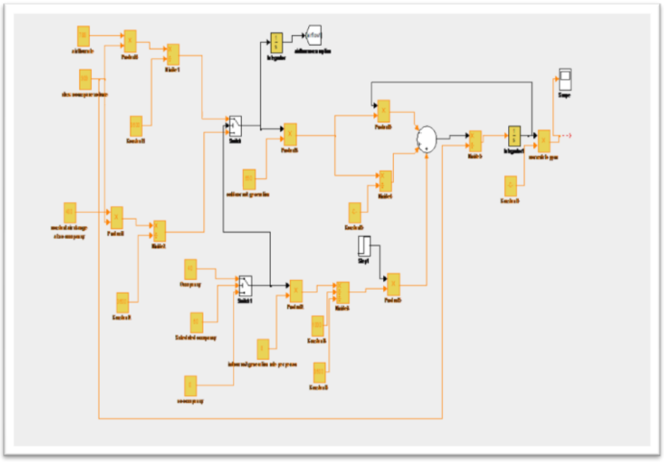

Figure 3 Traditional base/forced ventilation model

4 DEMAND CONTROLLED VENTILATION (DCV) MODEL USING PID TUNING

To save energy, HVAC control system uses CO_2 concentration to automatically change the ventilation rate so that indoor CO_2 concentration remains at or below a maximum level. (DCV) using PID control strategy controls the ventilation rate according to the building occupancy (CO_2 concentration resulted from occupants). By this way, if the building is only 60% full, then only 60% of the design-rate ventilation air will be used, not 100% as is used in traditional mechanical ventilation systems.

CO_2 sensors are the technology available to operate (DCV) strategy. Sensors continuously measure indoor CO_2 concentration. Then based on measuring, the ventilation rate is modified when indoor CO_2 concentration reaches a pre-defined level. This level represents differential between indoor and outdoor CO_2 concentration.

The average of target indoor CO_2 concentration (set point) used in the model is 800 ppm. This strategy has been applied by using PID controller which operates as follows: When the differential between indoor CO_2 concentration measured and set point is in the range [-50→50], there is no signal control. In this case, switch (2) allows only the constant rate to pass, . On the other hand, when the differential between indoor CO_2 absorption measured and set point exceed this range, there will be a feedback signal. In this case, switch (2) allows the forced rate to get ahead of until the differential becomes again within the range.

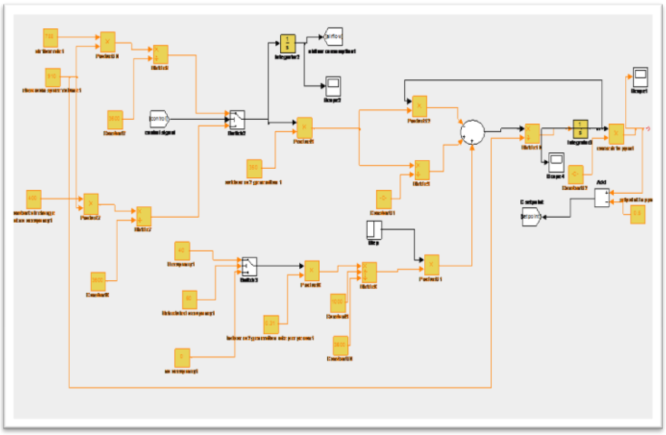

Figure 4 Demand controlled ventilation (DCV) with PID controller

5. DESIGN OF SHEDULED OCCUPANCY MODEL AND ENERGY SAVINGS MODEL

The Scheduled occupancy is simulated by considering the phase represents the time before occupancy, period represents the whole day (24 hours) by taking the Amplitude = 1. And width as period

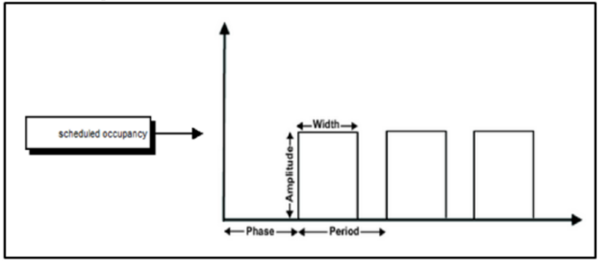

Figure 5: Scheduled occupancy model

The comparing between air consumptions shows that (DCV) strategy operates according to the occupancy size (indoor CO_2 concentration), not just according to the existence of occupancy, as it is in base/forced strategy. This leads to savings in air consumption. Where, percentage of savings can be calculated as follows:

Percentage of savings = (air flow consumption for traditional strategy - air flow consumption for DCV strategy) / air flow consumption for traditional strategy

Hence, it is possible to calculate the amount of savings in energy consumption when using (DCV) strategy. By the imposition that amount of air savings must be heated or cooled by the different between indoor and outdoor temperatures during winter or summer, respectively, the energy needed for this process can be calculated

$$E = \rho_{air} . c_{p\ air} . V_{air} . |\Delta T| \quad \text{.....................} (5)$$

Where:

E [J]: heat (energy).

ρ_{air}[kg/m^3]: density of air.

c_{pair}[J/kg.K]: specific heat capacity of the air V_{air}[m^3]: air volume.

|ΔT|: the difference between indoor and outdoor temperatures in absolute value.

The below shown figure (5) gives the simulink model of energy savings

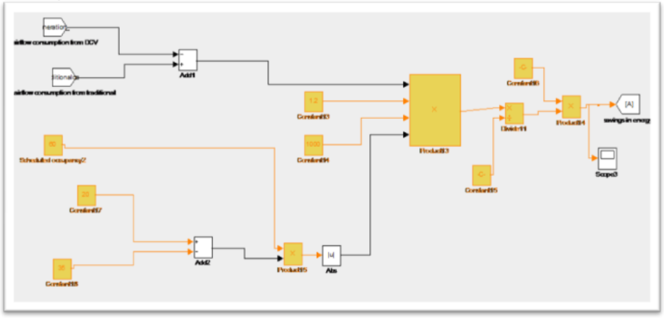

Figure 6 Energy Savings model

6. SIMULATION RESULTS

The figure 7 indicates the percentage of carbon emissions in the indoor airspace by using the traditional approach for the occupancy of 34 students and the figure 8 shows the airflow consumption using the traditional controller. From this it shows that by using the traditional approach the carbon percentage is of 0.87 % which in advance increase in the occupancy may leads to brutal health hazards as discussed from figure 1. So in order to decrease the percentage of carbon emissions in the indoor space of a classroom now a DCV using PID fine-tuning is adopted. By this the amount of percentage has been gradually reduced to 0.12% which is indicated in figure 9.and the equivalent airflow consumption is shown in figure10. Consequently the total amount of carbon emissions has been condensed to a great extent by using Demand controlled ventilation (DCV) and the respective energy reserves in carbon emissions and airflow consumption is shown in figure 11 and 12.

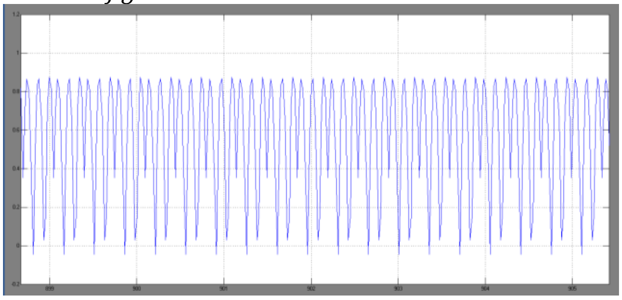

Figure 7 Volume of carbon emissions in a classroom using traditional approach

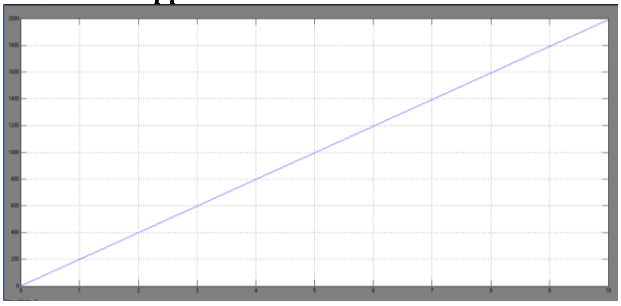

Figure 8 Air flow consumption using traditional approach

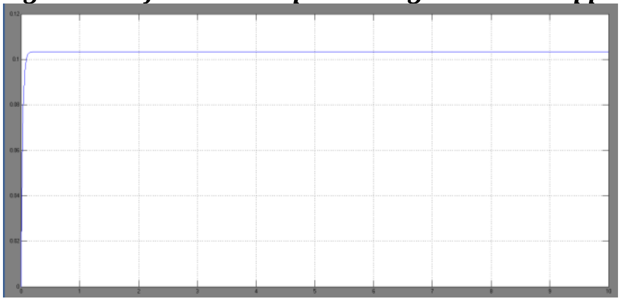

Figure 9 Volume of Co2 concentration after using Demand controlled ventilation with PID tuning

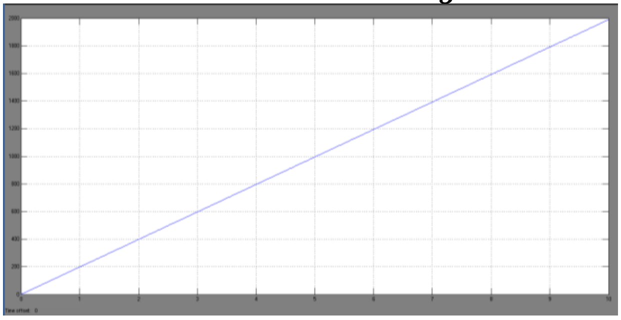

Figure 10 Airflow consumption using Demand controlled ventilation

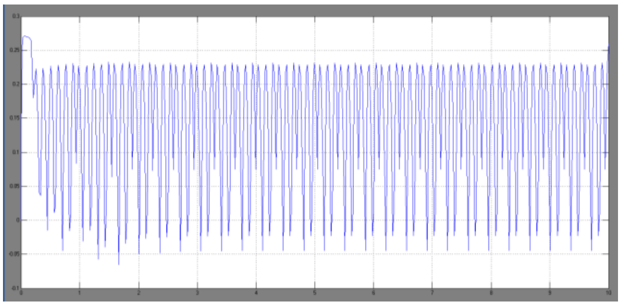

Figure 11 Energy savings in carbon emissions

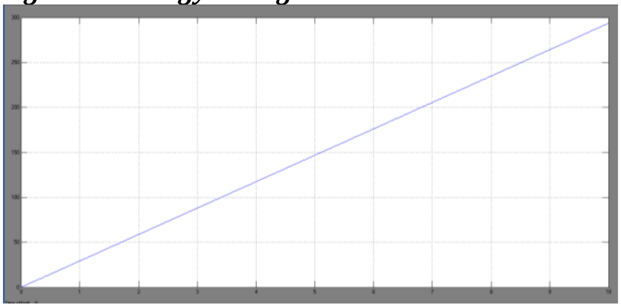

Figure 12 Savings of energy in airflow consumption

7.CONCLUSION

The basic physical processes within classroom with different sizes of occupancy have been modeled using MATLAB/SIMULINK software.

In order to achieve this task, the outdoor boundary conditions had précised. Modelling the concentration of carbon dioxide is done on the basis of the principle of conservation of mass i.e mass model of carbon emissions, where, the main flows of air to and from the building have been modeled with the quantity of carbon dioxide carried by these flows. Then two different control strategies have been modeled: earliest is the traditional strategy, while the succeeding is demand controlled ventilation (DCV) using PID tuning. DCV strategy adjusts itself and use fresh air only when the concentration of carbon dioxide reaches to the limit values. This control shows the best way of reducing the carbon emissions when compared with traditional controller and this way lead to investments in energy needed for air conditioning.

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