Determination of optimal air exchange rate to provide optimal IAQ

Anatolijs Borodinecs[1,*], Jurgis Zemitis[1], Andris Kreslins[1], Baiba Gaujena[1]

[1] Riga Technical University (RTU), Institute of Heat, Gas and Water Technology, Riga, Latvia

[*] *Corresponding email: anatolijs.borodinecs@rtu.lv*

SUMMARY

This paper is devoted to the analysis of indoor air quality in buildings depending on ventilation volume. In the scope of this paper the main problems of indoor air quality in airtight buildings were identified and easily implemented calculation methods of predicting dynamically changing indoor air contaminant levels as well as relative humidity is provided.

The proposed calculation method takes into account parameters of outdoor air, internal CO_2 and moisture production, buildings volume and air exchange rate.

The paper also presents the results of monitoring of indoor air quality specifics of apartments, offices and classrooms in Latvia and compares the obtained results with the calculated ones.

The results shows that proposed method is accurate in predicting CO_2 level and could be used for evaluation of CO_2 level while the prediction of relative humidity still opposes some problems.

KEYWORDS

Ventilation, indoor air quality, CO_2 concentration, humidity, prediction

1 INTRODUCTION

As the issued directive no. 2010/31/ES on the energy performance of buildings is binding for all member states of the European Union there needs to be paid increasingly more attention to energy effectiveness of buildings. This regulation states that starting from the year 2021 all new buildings will need to be nearly zero energy. Thus meaning that the buildings will need to comply to today's standards of low energy houses and therefore will be similar to them from engineering point of view. As seen from the experience of these buildings the needed low level of energy consumption can only be achieved by complex solutions including - increased building envelopes thermal conductivity by applying thicker insulation, usage of low-e coated passive windows, passive solar energy use as well as higher air tightness to reduce air infiltration. The last means that there will be necessity for mechanical ventilation as no longer air will be able to penetrate through building envelope and by only using controlled ventilation we obtain possibility to regain energy from the exhaust air to supply air through heat exchanger.

The existing data of built low energy and passive houses shows the energy consumption for ventilation takes significant part (up to 25%) in total energy consumption. So there exist good opportunity for energy savings in ventilation systems. But it should be taken into account that extremely low ventilation rates lead to inappropriate indoor air quality and sick building syndrome. To prevent this it is necessary to incorporate into existing national building codes requirements for ventilation to ensure appropriate IAQ not specific air exchange rates.

For example, in Latvia (LBN 231-03, 2003) require a minimum of 5 l/s of fresh air per person if it is the only pollutant in the room or determines the necessary air exchange according to occupied space type and area (LBN 211-08, 2008). However it would be more accurate to assess the necessary volume of fresh air to provide appropriate IAQ, as this is the main purpose of ventilation. The main characteristics that define IAQ are CO_2 level and relative humidity. Both of these indicators are mainly related to human beings while the air pollution can also be caused by ozone from printers/copy machines, cooking fumes and emissions from building materials and described using total volatile organic compound value. All these characteristics describing IAQ are affected by air exchange rate, indoor pollutants, parameters of outdoor air and room specifications. It is therefore necessary to at first determine the threshold values of the CO_2 concentration level and relative humidity to choose the exact ventilation rate for each given situation.

The existing researches (Olli, 2008) on indoor air quality have shown that optimal CO_2 concentration in indoor air is up to 1000 ppm. Although data (ASHRAE, 2007) on CO_2 impact on human health has shown that negative impact on breathing only occurs when CO_2 concentration is above 5000 ppm. The evaluation of indoor air quality in Netherlands (Wim Z. and Gert B., 2008) has shown that allowed CO_2 concentration level is 1000 ppm with a maximum value of 1200 ppm.

According to the regulations (ASHRAE, 2007) relative humidity should be maintained between 30% and 60% for indoor environments. Long periods of relative humidity below 30% can cause drying of the mucous membranes and discomfort for many people while relative humidity above 60% for extended time periods promotes indoor microbial growth. At the same time relative humidity should be below 40-45% for at least one month a year to ensure drying out and killing of dust mites.

2 MATERIALS/METHODS

Theoretical method to determine dynamically changing contaminant concentration in indoor air

To theoretically predict the dynamically changing indoor air quality parameter levels based on air ventilation rate, pollution rate and outdoor air parameters a theoretical model was developed which is based on mass and energy balance. The calculation methods to obtain the equitation describing CO_2 concentration in indoor air at any given time moment can be expressed by equations 1 - 5:

$$\frac{dM_{CO2}}{dt} = CO_2 outdoors + CO_2 produced - CO_2 exhausted \quad (1)$$

Expressing the necessary values by room and air parameters we can obtain following:

$$\frac{V * dc_{in}}{dt} = n * V * c_{out} + n_{pers.} * q - n * V * c_{in} \quad (2)$$

Dividing both sides by V, assuming that $(c_{in} - c_{out}) = y$ and integrating the obtained equitation by time from $t=0$ to $t=t$ yields:

$$\int_{y(0)}^{y(t)} \frac{dy}{((n_{pers.} * q)/V) - n * y} = \int_0^t dt \quad (3)$$

This results in:

$$\frac{((n_{pers.}*q)/V)-n*y(t)}{((n_{pers.}*q)/V)-n*y(0)}=-nt \quad (4)$$

By replacing the *y* with the initial equitation and knowing that at the starting time *t=0* the CO_2 concentration in room will be C_0 we can obtain the following final equitation for dynamically changing CO_2 concentration in indoor air:

$$c_{in}(t)=c_{out}+(c_0-c_{out})*e^{-n*t}+(1-e^{-n*t})*+\frac{n_{pers.}*q}{n*V} \quad (5)$$

Where V – room volume, m^3; n – air exchange rate, c_{out} – outdoor air CO_2 concentration, kg/m^3, $n_{pers.}$ – number of persons in room; q – CO_2 production by one person, kg/h, c_{in} – indoor air CO_2 concentration, kg CO_2/m^3.

Similar equitation's has been provided in existing researches by Koiv (2007). Analogous it is possible to determine the relative humidity in indoor air by calculating the absolute humidity:

$$G_{in}(t)=G_{out}+(G_0-G_{out})*e^{-n*t}+(1-e^{-n*t})*+\frac{G_{prod.}}{n*V} \quad (6)$$

Where V – room volume, m^3; n – air exchange rate, G_{out} – moisture in outdoor air, kg H_2O /m^3, G_{in} – moisture in indoor air, kg H_2O/m^3, G_0 – initial moisture in indoor air, kg H_2O /m^3, $G_{prod.}$ – produced moisture, kg H_2O /m^3.

Measurements of CO_2 and RH in buildings

For the purpose of practical evaluation of IAQ and to verify the precision of the developed theoretical model, measurements in two apartments, two offices and a classroom where done and result where analyzed. The ventilation systems in apartments and offices where hybrid type with natural air supply through windows and construction gaps and with mechanical exhaust from kitchens and bathrooms, while in classroom it was mechanical during classes and additional ventilation by opening of windows during breaks.

During measurements windows remained closed in apartments and offices to obtain constant air exchange rate and the number of people in rooms was registered for each half an hour. For classroom number of students was registered for each class as well as timing of window opening. The measurements in apartments were done in periods from 12.02.2011 till 15.02.2011 and from 04.04.2011 until 07.04.2011, the office buildings where measured from 16.02.2011 till 18.02.2011 and from 29.03.2011 until 01.03.2011 while the classroom from 19.11.2011 till 21.11.2011.

For indoor air quality measurements the data loggers with the following parameters were used: temperature: -20^0C to 70^0C ($\pm 0.35^0C$); relative humidity: 10% to 90% (±2.5%); CO_2 level: 0 to 2500 ppm (±50 ppm or 5% of reading).

3 RESULTS

An example of results for theoretically predicted and measured levels of CO_2 in office building is shown in Figures 1 while Figures 2 shows the relative humidity.

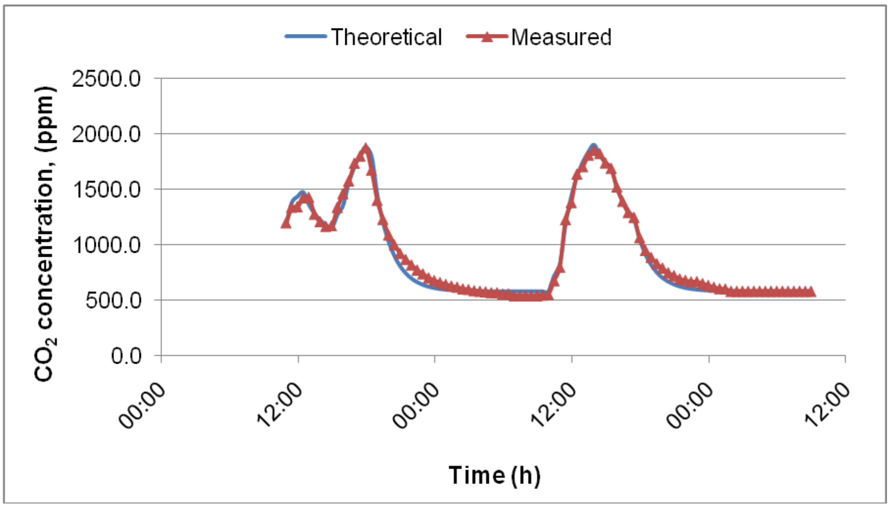

Figure 1: Theoretically predicted and measured CO_2 concentration in office

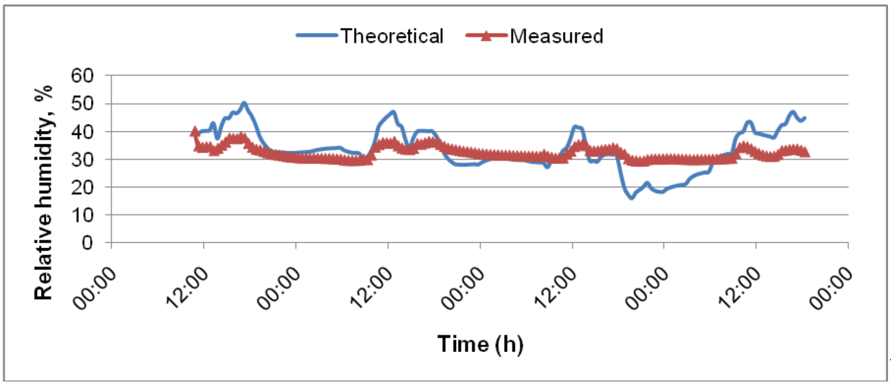

Figure 2: Theoretically predicted and measured relative humidity in office

The calculated precision of developed method for CO_2 concentration prediction can be seen in Table 1 while Table 2 shows the size of errors for relative humidity prediction and the prediction accuracy in percents.

Table 1: Accuracy and mean error for CO_2 concentration prediction

Measurements	Mean error of predicted CO_2 concentration (ppm)	CO_2 prediction accuracy (%)
Apartment 1	111±16,6	93,4±1,2
Apartment 2	118±18,7	89,9±1,6
Office 1	38±7,2	95,5±0,8
Office 2	84±15,0	92,6±1,0
Classroom	64±16,2	93,4±1,4

Table 2: Accuracy and mean error for relative humidity prediction

Measurements	Mean error of predicted RH (%)	RH prediction accuracy (%)
Apartment 1	5,2±0,7	88,2±1,6
Apartment 2	4,4±0,6	89,5±1,3
Office 1	4,0±0,4	86,6±1,4
Office 2	5,0±0,6	84,4±1,7
Classroom	4,6±0,5	87,6±1,6

4 DISCUSSION

Analysis of obtained results

As it can be seen from the obtained results, proposed theoretical method of predicting CO_2 level as function of indoor pollutants, outdoor air parameters, air exchange rate and room specifications gives accurate results with the average precision of 93.0%. The main cause of error could originate from not knowing the actual air exchange rate. The rate was assumed using available data from existing researches (Howard-Reed et al. 2002) and was not calculated or measured thus making the comparison between prediction and measurement uncertain. For the residential building assumed air exchange rate was 0.5 ach while for the office 0.7 ach. The classroom has constant air exchange of approximately 2.5 ach with increase to 5.0 ach during time when windows are opened. Another source of error is caused by the difficulties to determine the actual volume of air in the room due to furniture and equipment which takes up the free space.

Results show that developed method gives better results in office and classroom cases due to fact that there are fewer variables because number of people as well as their activity level is more constant compared to apartment where people walk back and forth more intensively. Nevertheless the figures showed that given method precisely predicts the rate of change in CO_2 concentration and gives precise prediction values which presumably would be even higher if measurement would be performed in more controllable conditions.

The results show that this type of theoretical method is not as accurate for predicting relative humidity. The average prediction accuracy is 87.3% and as seen from figure 2 the fluctuation rate of change in relative humidity is not predicted too precisely. The actual measured relative humidity level is more stable and does not change as widely as predicted. This could be explained by several following reasons.

First of all it is difficult to assess the exact internal moisture load as the sources in building are more diverse (people, showers, cooking, plants, construction ect.) than compared to the lone source of CO_2 which is people. Also the data stated in the literature on moisture generation vary in the sources and disparity can be as high as ten times (Michael and Achilles, 2004).

The second source of error occurs due to changing moisture content in outside air. The obtained data only provides values for outside relative humidity and temperature with tree hour intervals.

The most significant cause of error could be the reason that the objects in the room also affect the moisture content of air, which in the developed method has not been taken into account. As the existing studies (Iain and Max, 2007) shows, the majority of the moisture, which is released into the room across short time periods at first is absorbed on the surfaces and absorbent materials, and only then released into the air. Thus stabilizing the moisture content in the air and the calculation method must take into account the average amount of moisture released during the day or even week rather than the momentary rate of release. The exact amount of absorbed moisture is difficult to determine and it varies in each individual case depending on the objects in the room and their materials. For example, in offices that has a lot of plain paper and wooden tables the percentage of absorbed moisture will be much higher compared to empty apartment. This means that the method of calculating the relative humidity should be supplemented by a variable, which would describe the moisture absorption capability of the room. For example the Environmental Protection Agency's indoor humidity assessment tool uses a capacitance term to allow only 5% to 10% of moisture flow inside into the air and assumes the other 90% to 95% is absorbed by building contents.

Application of the developed method

The provided IAQ parameter prediction method can be used in cases of demand controlled ventilation, which can ensure optimal air change rates for an airtight building. The usual control parameters for demand controlled ventilation in buildings are CO_2 level, temperature, presence of people, RH and cooking fumes. As of now installation of indicators to automate the ventilation system are necessary but they cost extra money and can possibly be avoided if a precise air flow profile is predesigned by pollutant prediction.

On the other hand, when designing ventilation systems for low-energy houses, one should keep in mind that by installing very good heat recovery, which is a must in these types of houses, you do not save much energy by small decrease of air flow. Therefore you can afford higher ventilation rates without a big energy penalty and should always place healthy indoor environment above small money saving.

5 CONCLUSIONS

The proposed method gives accurate results for predicting indoor air quality parameters. The average precision for CO_2 concentration prediction is 93.0% while for relative humidity 87.3%. Precision for predicting relative humidity can be improved if absorption and desorption processes are taken into account and average moisture gains for prolonged periods are used. Further case studies to express the absorption factor for each given situation as single non-dimensional value must be done.

The application of given method can be used to determine the optimum air exchange rate in new low-energy buildings to provide the necessary indoor air quality by using the minimal volume of fresh air to reduce total energy consumption.

6 REFERENCES

ASHRAE. 2007. *ASHRAE Standard 62.1-2007*, Ventilation for acceptable indoor air quality, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Howard-Reed C., Wallace L. A., and Ott W. R. 2002. The Effect of Opening Windows on Air Change Rates in Two Homes. Journal of the air & waste management association 52(2), pp. 147-159.

Iain S. W and Max H. S. 2007. Humidity Implications for Meeting Residential Ventilation Requirements. Environmental Energy Technologies Division, pp. 1-19.

Koiv Teet-Andrus. 2007. Indoor climate and ventilation in Tallinn school buildings. Proceedings of the Estonian Academy of Sciences: Engineering. Vol. 13, Issue 1, pp. 17-25.

LBN 231-03. 2003. Latvian Building Code. Heating and ventilation of residential and public buildings.

LBN 211-08. 2008. Latvian Building Code. Multi-storey residential buildings.

Michael A. K. and Achilles N. K. 2004. A New Look at Residential Interior Environmental Loads. ASHRAE Thermal IX Conference Clearwater Beach, Florida, pp. 1-10.

Olli S. 2008. Ventilation Strategies for Good Indoor Air Quality and Energy Efficiency. International Journal of Ventilation, Vol. 6, No. 4, pp. 297-306.

Rasmus L. J. and Camilla B. 2008. Necessary Air Change Rate in a Danish Passive House, In: *Conference proceedings of 12th International Passive house Conference 2008,* Nuremberg, pp. 516.

Wim Z. and Gert B. 2008. Sustainable schools: Better than traditional schools? In: *Proceedings of Indoor Air 2008,* Copenhagen, on CD, pp. 8.