Agronomy Research **11** (2), 463–470, 2013

Exploring the effect of carbon dioxide demand controlled ventilation system on air humidity

M. Reinvee*, J. Uiga, T. Tärgla, P. Pikk and A. Annuk

Institute of Technology, Estonian University of Life Sciences, Kreutzwaldi 56, EE51014 Tartu, Estonia; *Correspondence: mart.reinvee@emu.ee

Abstract. Earlier studies have indicated that elevated or inadequate levels of carbon dioxide (CO_2) in indoor air impairs users in the performance of decision-making. For this reason and also for potential energy consumption reduction carbon dioxide based regulated demand controlled ventilation (DCV) systems are used. Although DCV systems use less electrical energy than conventional ventilation systems, there is a problem in colder climates with the lowered humidity of air. It has been discovered in earlier studies that even brief exposure to relatively dry air has an impact on voice control parameters. In the current article, the humidity gains from ordinary usage of a faculty building, where a DCV system and room based temperature control is utilised, are examined. For that, the changes in the specific indoor humidity were compared to the changes in the specific ambient humidity.

Key words: CO_2 demand-controlled ventilation, absolute and relative humidity, indoor air-quality.

INTRODUCTION

Controlling outdoor air intake rates using a CO_2-based DCV is supposed to provide significant energy saving compared to systems that provide constant air-flow, since over-ventilation during periods of low occupancy can be avoided (Emmerich & Persily, 2001). However, CO_2–based DVC does not offer any possibilities to adjust relative humidity (RH). Due to the dependence of the specific humidity of indoor-air (SHI) to the specific ambient humidity (SAH) problems with too low or high indoor RH may be faced. This is caused by the fact that the cold ambient air, which is heated to a proper indoor temperature, contains a low amount of specific humidity. When heating that air, the humidity content is not changed, resulting in a low relative humidity. The dependencies between indoor and outdoor RH, when indoor factors are not taken into account, can be seen in Fig. 1.

Low relative humidity is an indoor air-quality parameter which affects humans in several ways. For example, it is a key factor in eye irritation, skin conditions, and also it affects various voice control parameters such as shimmer and jitter (Hemler et al., 1997; Wolkoff, 2012).

In addition, it has been found that environmental factors cause two-thirds of the impairments in the ability to produce voice sounds (Simberg et al., 2009). Most common environmental factors are working culture and indoor air quality (IAQ) (Rantala et al., 2012). Among lecturers these factors will be revealed in various voice symptoms such as voice tiredness, hoarseness and a need to clear the throat (Rantala et al., 2012). Although humidity related IAQ may not be immediately perceived because of sensory latency (Wolkoff et al., 2006) it has been proven that the human voice is particularly sensitive to decreases in relative humidity of inhaled air. Even a short provocation with dry air could cause a significant increase in perturbation measures (Hemler et al., 1997).

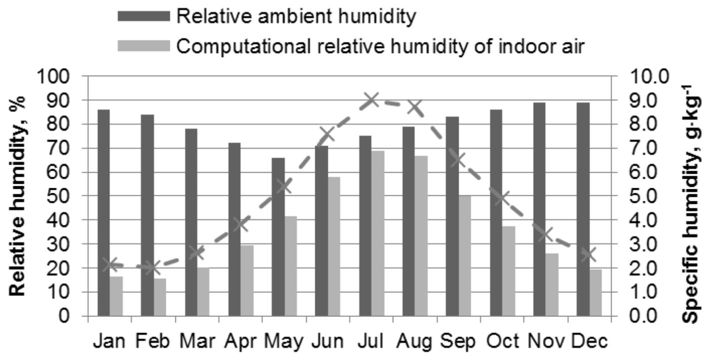

Figure 1. Average indoor (assuming an indoor temperature of 21 °C) and ambient humidity for the period 1970…2000 (Estonian Meteorological…, 2012; authors' calculations).

Current paradigm associates dry air with desiccation of the mucous membranes of the air ducts. As the mucous flow over the ciliary tract decreases or stops the resistance to infection diminishes (Kroemer & Grandjean, 2003). Therefore, the introduction of some sort of humidifier is suggested. One solution are portable humidifiers, however, although complaints about IAQ give reductions it is not effective for larger rooms (Hashiguchia et al., 2008).

In the currently valid European standard regulating indoor climate (EVS EN 15251, 2007), the humidification of indoor air is not obligatory in ordinary circumstances. For a renovated building, 25% is noted to be the lowest indoor RH, where the installed humidification systems should start working (EVS, 2007). That only applies for buildings, where air-humidification systems have been installed or are planned to be installed. Currently there is no valid governmental regulation for regulating indoor climate parameters in the analysed building type.

CO_2 based DCV systems are not widespread, and there are no studies concerning the change of the SHI after renovation in order to establish the quality of indoor air in terms of the humidity content. Therefore, this article focuses on the effect of DCV to the SHI. In order to establish the possible effects the temperature and the RH were measured in classrooms and offices of the Institute of Technology of the Estonian University of Life Sciences.

MATERIALS AND METHODS

For analysing, the deviations of indoor RH from the ambient RH the values of specific humidity of indoor and ambient air were compared. In order to achieve that goal, temperature and RH measurements were taken with a measurement interval of 5 minutes. The devices utilised for the measurements are listed as follows: Extech

Instruments CO210; Velleman DVM171THD; Comet S3120 temperature and relative humidity dataloggers and Ahlborn ALMEMO 2690-8 datalogger.

For calculating the specific humidity the principles described by Krüger (2001) were used

$$q = \frac{x_{H_2O} \cdot M_{H_2O}}{x_{H_2O} \cdot M_{H_2O} + (1 - x_{H_2O}) \cdot M_{dry}} \cdot 1000, \quad (1)$$

where q – specific humidity of air g kg^{-1}; x_{H_2O} – volume mixing ratio of water; M_{H_2O} – molar mass of water, $M_{H_2O} = 18.01534$ g·mol^{-1}; M_{dry} – molar mass of dry air, $M_{dry} = 28.9644$ g·mol^{-1}.

The volume mixing ratio of water was calculated by formula (Krüger, 2001)

$$x_{H_2O} = \frac{P_{H_2O}}{P}, \quad (2)$$

where P_{H_2O} – partial pressure of water hPa; P – air pressure hPa.

The partial pressure of water was found by (Krüger, 2001)

$$P_{H_2O} = \frac{e(T) \cdot RH}{100}, \quad (3)$$

where *e(T)* – vapour pressure of water hPa; *RH* – air pressure hPa.

The calculation methodology for finding the vapour pressure of water at different temperatures is described by Lowe & Ficke, 1974 and by Krüger, 2001

$$e(T) = a_0 + T \cdot (a_1 + T \cdot (a_2 + T \cdot (a_3 + T \cdot (a_4 + T \cdot (a_5 + T \cdot a_6))))), \quad (4)$$

where *e* – vapour pressure of water kPa; *T* – temperature °C; $a_0 \ldots a_6$ – constants given in the original document (Lowe & Ficke, 1974).

Based on previous equations and assuming room temperature 21°C, SHI should be > 3.8 g kg^{-1} to guarantee > 25% RH.

The parameters of ambient air were gathered from the Estonian Meteorological and Hydrological Institute as hourly averages of the Tõravere measurement point. The measurement point of Tõravere was chosen as the location of the data due to its proximity to the faculty building. What is more, since there are no official weather measurements made in Tartu itself, a comparability of the calculations, by using approved measurements, was expected to be reached. Specific ambient humidity (SAH) was only given as hourly averages; therefore the SHI was also calculated as hourly averages, although the measurements were made in 5 minute intervals.

From the collected data the Pearson's correlation coefficients were calculated to investigate the dependencies between SAH and SHI. The results describe linear relationships between ambient and indoor specific humidity and therefore, for the purposes of this paper, show how SHI is related to SAH. In order to examine, whether the difference between night and daytime usage is statistically significant, average deviations of SHI from SAH were calculated. For this purpose the following formula was utilised

$$D = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)\,, \tag{5}$$

where D – deviation g kg^{-1}; n – number of measurements; x_i – value of SHI, g kg^{-1}; y_i – value of SAH, g kg^{-1}.

The measurement data was collected from different locations (rooms), during various periods (Figs 2–4). The rooms were selected according to the location and the type of usage. The periods of measurements were in winter, spring and summer assuming similar behaviour in temperature and RH for spring and autumn. The locations are described as follows:

A. Room 020 with a surface area of 51 m^2 is located on the basement floor of the building. The room is mostly empty and therefore the average internal heat gain, which describes the heat gain from sources like human activities, electrical appliances, etc. is the lowest.
B. Room 108 with a surface area of 16.3 m^2 is used as an office by one person. The busiest usage period usually falls between 8:00 to 16:00.
C. Room 202 with a surface area of 102 m^2 is a lecture hall and is used frequently between 8:00 and 16:00 in lecturing periods.
D. Room 228 with a surface area of 34 m^2 is a common room for employees. It is used for preparing coffee and meals, meaning that this room has short periods of intense usage.
E. Room 416 with a surface area of 16.5 m^2 is an office room it is also mostly occupied from 8:00 until 16:00 during semester time.

All of the locations have the lowest usage during summertime, when there's a break between semesters.

RESULTS AND DISCUSSION

The graphs describing the measurement results and calculated SHI and SAH are presented in figures (Figs 2–4).

Measurements conducted in springtime (16.04.2012–25.04.2012) are presented in Fig. 2 and Table 1. Results indicate that the correlation between SHI and SAH is > 0.95 – in other words very strong. As expected the measurements showed that if the room occupancy is higher, then a stronger correlation between SHI and SAH will exist. In case of DCV, the room's air exchange rate is more intensive if the CO_2 level is higher. After the CO_2 level exceeds the set point the DCV activates. The ventilation process continues until the CO_2 level drops. As a result, SHI is strongly affected by the SAH. For example, SHI of room 020 is constantly higher than SHI in other rooms (Fig. 2 & Fig. 4). This means the belief that a human presence in the room would raise the humidity in the long run is disproved in case of CO_2–DVC.

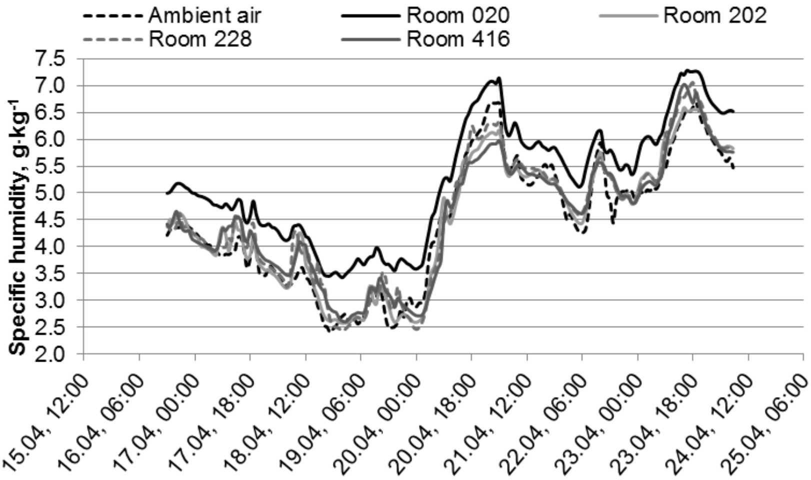

Figure 2. Calculated hourly average specific humidity during 16.04…24.04.

Measurements conducted in summertime (25.07.2012–02.08.2012) are presented in Fig. 3. During this period, the occupancy of the rooms and the whole house is at its lowest and therefore the ventilation system was turned off. The air exchange between indoor and outdoor is expected to occur only due to infiltration and air leakages. Thus, the convergence of SHI and SAH will happen after a delay, which can be seen in the figure below. As expected the correlations between SHI and SAH are lower, than < 0.9 and correlations during the day and night-time are roughly the same.

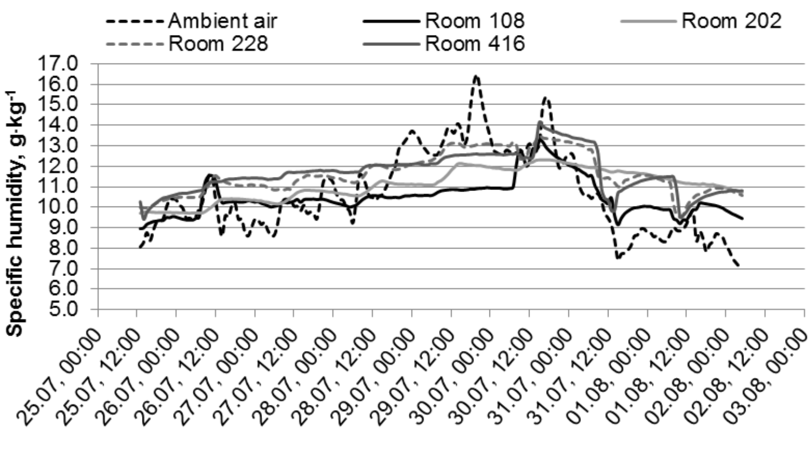

Figure 3. Calculated hourly average specific humidity during 26.07…02.08.

The measurements conducted in wintertime (17.12.2012–28.12.2012) are presented in Fig. 4. The occupancy of the rooms occurs mainly from 08:00 until 16:00 o'clock and therefore a continuously working ventilation system can be assumed. In the room 020 the space is ventilated, but it is running at a lower rate. However, after December 21st the building was empty due to Christmas holidays and the ventilation system was turned off – the effect is also seen in Fig. 4 and Table 1.

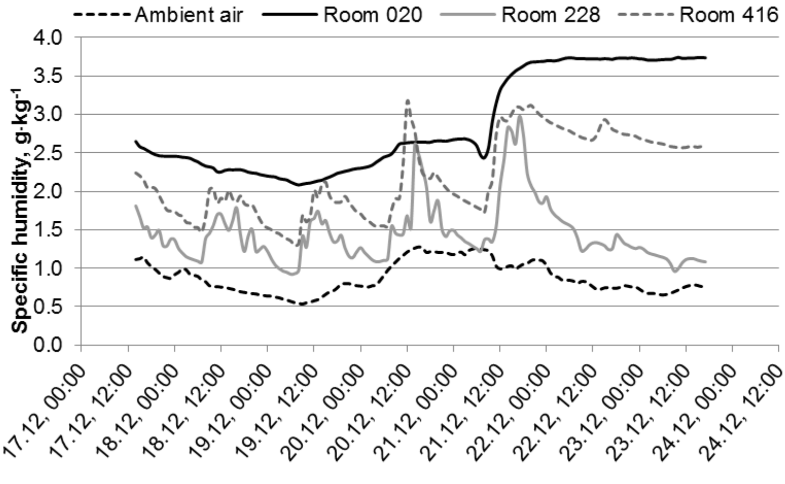

Figure 4. Calculated hourly average specific humidity during 17.12…23.12.

The relationship between SAH and SHI is summarised in Table 1.

Table 1. The correlations between ambient and indoor specific humidity

Measurement period	Location	Correlation		Average deviation, g kg^{-1}	
		08:00–16:00	16:00–08:00	08:00–16:00	16:00–08:00
16.04–24.04	Room 020	0.994	0.990	0.758	0.756
	Room 202	0.979	0.985	0.160	-0.023
	Room 228	0.969	0.977	0.233	0.052
	Room 416	0.968	0.969	0.226	0.013
25.07–02.08	Room 108	0.763	0.698	-0.131	0.039
	Room 202	0.494	0.483	0.378	0.741
	Room 228	0.861	0.814	0.804	1.251
	Room 416	0.789	0.774	0.784	1.309
17.12–21.12	Room 020	0.844	0.967	1,510	1.502
	Room 228	0.732	0.556	0.687	0.416
	Room 416	0.620	0.670	1.165	0.876
21.12–23.12	Room 020	0.063	-0.521	2.353	2.862
	Room 228	0.115	0.727	1.308	0.627
	Room 416	-0.321	0.311	1.894	1.920

From the table above (Table 1) we can follow that in frequent occupancy periods (16.04…24.04 and 17.12…21.12) room's SHI average deviation is greater during day time which indicates SHI gain from human activity. There are mixed results from periods when the ventilation system was turned off and as a human presence was not monitored no conclusions can be drawn.

The effect of portable humidifiers on the room's SHI

Long–term averages in Fig. 1 revealed that from November to March undesired (< 25%) indoor RH is expected in the Estonian climate. Based on analysis it can be concluded that factors which include human activity (evaporation, moisture of overcoats, etc.) has some effect on SHI (see average deviations in Table 1), however, the outcome is not sufficient to meet desired (> 25% RH) IAQ as CO_2–DVC do not preserve a room's humidity level.

Use of portable humidifiers is one potential solution to increase the humidity level in the air. In a short experiment, the indoor air temperature and humidity in two rooms were measured. In the bigger room (113.6 m^3) two air humidifiers were used, while in the smaller room (52.1 m^3) no humidifiers were installed. The nominal power of a humidifier was 38 W and during eight hours 2 dm^3 of water was evaporated into the air. The occupancy of the rooms was equal during the measurement period. The result is that RH of the air in the humidified room increased by a maximum of 12% (Fig. 5).

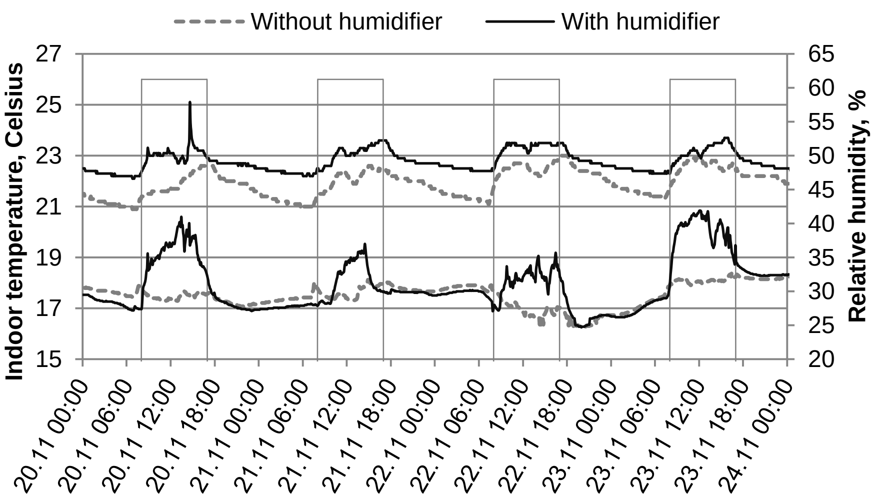

Figure 5. The effects of humidifiers on the indoor air.

The SHI of the two rooms was equal in the beginning of the day, but raised 1−2 g kg^{-1} after the start of the humidifiers (Fig. 5). The result is sufficient to conclude that in rooms where a CO_2–based DCV is utilised, the humidity of the rooms could be increased by installing small humidifiers for only a short period. Having concluded that, it has to be noted, that the energy spent on humidifying the 113.6 m^3 room is 0.61 kWh and with the Estonian price for electricity 0.14 EUR kWh^{-1} the financial spending is 0.07 EUR during 8 hours. This means that in the case of large buildings the humidification of individual rooms is costly and needs to be thoroughly considered.

CONCLUSIONS

In this article, analysis was conducted on how the specific outdoor humidity (SAH) affects the indoor specific humidity of indoor–air (SHI) level of a building where a CO_2 based demand controlled ventilation is installed and operated.

In the case of CO_2–DVC the raise of SHI level during routine building usage is insufficient for desired IAQ, thus even more sophisticated ventilation control, which would allow preserving a room's humidity level, should be used in the Estonian climate. Moreover usage of portable humidifiers in order to ensure proper IAQ raises serious questions about the energy efficiency of CO_2–DVC. A short investigation into raising the relative humidity indicated that offices that are used full–time gained a 12% rise in relative humidity compared to a similarly occupied room without a humidifier installed. Nevertheless, humidifying the indoor air comes with cost. For a 113.6 m^3 room electrical energy consumption of 0.61 kWh during an eight–hour period was observed.

Further research should be done to investigate the role of air exchange rate and set point of CO_2 level, also further studies should monitor human presence.

REFERENCES

Emmerich, S.J & Persily, A.K. 2001. *State-of-the-Art Review of CO_2 Demand Controlled Ventilation Technology and Application*. U.S. Department of Commerce, Boulder, 43 pp.

Estonian Centre for Standardisation (EVS). 2007. EVS–EN 15251–2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

Hashiguchia, N., Hirakawaa, M., Tochiharaa, Y., Kajib, Y. & Karak, C. 2008. Effects of setting up of humidifiers on thermal conditions and subjective responses of patients and staff in a hospital during winter. *Appl. Ergonomics.* **2**, 158–165.

Hemler, R.J.B., Wieneke, G.H. & Dejonckere, P.H. 1997. The effect of relative humidity of inhaled air onacoustic parameters of voice in normal subjects. *J. Voice.* **3**, 295–300.

Kroemer, K.H.E. & Grandjean, E. 2003. *Fitting the task to the human*, Taylor & Francis, London, 416 pp.

Krüger, B. 2001. Air humidity calculation. http://www.cactus2000.de/js/calchum.pdf

Lowe, P.R. & Ficke, J.M. 1974. *The computation of saturation vapour pressure*. Envoronmental Prediction Research Facility, Monterey, CA, 27 pp.

Rantala, L.A., Hakala, S.J., Holmqvist, S. & Sala, E. 2012. Connections Between Voice Ergonomic Risk Factors and Voice Symptoms, Voice Handicap, and Respiratory Tract Diseases. *J. Voice.* **6**, 819.e 13–819. e20.

Simberg, S., Santtila, P., Soveri, A., Varjonen, M., Sala, E. & Sandnabba, N.K. 2009. Exploring genetic and environmental effects in dysphonia: a twin study. *J. Speech Lang. Hear. Res*. **62**, 153–163.

Wolkoff, P., Wilkins, C.K., Clausen, P.A. & Nielsen, G.D. 2006. Organic compounds in office environments – sensory irritation, od or, measurements, and the role of reactive chemistry. *Indoor Air.* **16**, 7–19.

Wolkoff, P. 2008. 'Healthy' eye in office–like environments. *Environ. Int*. **8**, 1204–1214.

Wolkoff, P. 2012. Indoor air pollutants in office environments: Assessment of comfort, health, and performance. *Int. J. Hyg. Envir. Heal.* In Press.