Theoretical and experimental investigation of ventilation rates and their relation with IAQ and thermal comfort in university classrooms during SARS-COV-2 pandemic

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Abstract. During the pandemic of Covid-19, ventilation rate of buildings and especially in spaces with high occupancy like classrooms, presents high research interest. The ventilation strategies, combined with the use of masks, contribute to the decrease of the infection risk of Covid-19. Also, ventilation improves Indoor Air Quality (IAQ), contributing to the good health of the users and potentially influences their thermal comfort. In the proposed work, the experimental investigation of the ventilation's adequacy in naturally ventilated classrooms located at the University of Western Macedonia, in Kozani, Greece, took place. Measurements include thermal comfort parameters, as well as IAQ ones, namely carbon dioxide (CO_2), volatile organic compounds (VOCs), aldehydes and ozone (O_3). The air exchange rates were determined according to the tracer gas decay and equilibrium analysis methods, using CO_2 as tracer gas, while simulations analysis using appropriate computational approaches was applied. The results between tracer gas method and simulation analysis were compared, allowing the validation of the adopted models. Given that for both approaches natural ventilation proved to be inadequate, different simulated scenarios of ventilation, including natural and mechanical configuration, were investigated; the relation of ventilation rates to IAQ and thermal comfort was investigated. Moreover, the infection risk, given the determined or simulated IAQ, was assessed, according to relevant approaches.

1. Introduction

The Covid-19 pandemic that we have been experiencing for the last years, has led to the revision of the ventilation requirements for the residential buildings, especially as regards building units that show severe overcrowding like educational facilities (Award et al., 2022). The ANSI/ASHRAE Standard 62.2 (ASHRAE, 2022), as well as the European CEN EN 16798-1 Standard (CEN, 2018) are the most common reference texts which offer guidance on ventilation airflow rates. However, the appearance of Covid-19 led to the revision of the international ventilation standards (REHVA 2020; WHO, 2021), as concern the minimum air changes rates that are needed according to building type. These new ventilation conditions can change the sensation and comfort of the building users with regard to thermal conditions and indoor air quality (IAQ).

Building ventilation is an important mean, in order to ensure adequate IAQ and avoid health problems (WHO, 2010; Awbi, 1998). Ventilation can be provided by natural (passive) or mechanical supply and/or exhaust systems. Natural ventilation, is the result of pressure difference, mainly referring to wind-induced, buoyancy-driven or a combination of them (Zhang et al., 2021) depending on climate, building design and human behavior, while mechanical systems refer to the use of fans; fans can either be installed directly in windows or walls, or installed in air ducts for supplying air into, or exhausting air from, a room (WHO, 2009). Mix mode (hybrid) configurations are also referred to, indicating the coupling of mechanical and multiple passive ventilation (Zhang et al., 2021). Air ventilation rate per hour is used to check the air renewal in a given place (ACH). Experimental measures and numerical simulation models are two of the most commonly used methods to predict ventilation performance for buildings (Lin et al., 2021). The most common experimental methods to calculate ACH is the tracer gas and blower-door methods. The first method uses concentrations of gases such sulfur hexafluoride (SF_6) and carbon dioxide (CO_2) as tracers to predict the ACH, while the blower door method is a steady-state method, which can be implemented by fan pressurization in a range of pressure differences, usually in steps of 10–60 Pa (ASTM, 2018). On the other hand, the numerical simulation models include multi-zone airflow model, regional model and computational fluid dynamics (CFD) model. Multi-zone airflow model is believed to be the best choice for predicting ventilation performance on the building scale, while CFD model is most widely used to describe the airflow in a zone with high accuracy (Chen et al., 2010).

Except from the ventilation, IAQ attracts the scientific interest during pandemic of corona virus, as poor IAQ may cause various respiratory diseases, allergic diseases and cancer (Habil et al., 2015; Mentese et al., 2020). The main parameters related to IAQ are mainly the building and finishing materials, occupant activities and outdoor air quality which can be correlated with the ventilation. As concern the main air pollutants that are monitored at the residential settings, volatile organic compounds (VOCs), particulate matter (PM), carbon dioxide (CO_2) and monoxide (CO), ozone (O_3), nitrogen oxides (NO_X) and radon (Rn) are referred to (WHO, 2010).

Estimation of infection risk from Covid-19 is connected with the assessment of ventilation rate and IAQ. The Wells–Riley equation is the most common model for quantifying the risk associated with airborne transmission of respiratory diseases (Riley et al. 1978). Relative works investigate the ventilation rate and infection risk of school buildings (Park et al., 2021; Xu et al., 2021), universities (Li et al., 2021), offices (Dai and Zhao, 2020) and health care facilities (Li and Tang, 2021) during the pandemic period, while some of them assess the effect that wearing of mask has to the spread of the corona virus (Dai and Zhao, 2020; Park et al., 2021; Li et al., 2021).

Thermal comfort is “that condition of mind which expresses satisfaction with the thermal environment“(ASHRAE, 2020). Specific standards like ISO7730 (CEN, 2005), ANSI/ASHRAE 55 (ANSI/ ASHRAE, 2020) and EN 15251 (CEN, 2012) have been developed including methods to predict thermal comfort. Two main approaches appear in these standards, the PMV approach (based on Fanger’s model), as well as an adaptive one which has application in naturally-ventilated buildings where heating and cooling systems are off.

The investigation of indoor environmental parameters (IEQ) of educational buildings, and especially universities, presents high interest (Papadopoulos et al., 2022; Akanmu et al., 2021; Zuhaib et al., 2018), as the maintaining of comfort and healthy indoor climate can positively affect the occupants’ learning performance and participation in the educational procedure (Astolfi and Pellerey, 2008; Corgnati et al., 2007). After the appearance of the Covid-19, these types of buildings gather even greater research interest, especially for the new conditions of ventilation that are formed due to the intense crowding that is observed (Gil-Baez et al., 2021; Di Gilio et al., 2021; Park et al., 2021). These new ventilation conditions can influence the IAQ, as well as the thermal comfort of the students (Miranda et al., 2022; Torriani et al., 2023). Measure of CO_2 concentration is a good and cheap indicator for IAQ and ventilation (Rueda López et al., 2021). Also, it is notable to assess the increase of the energy consumption that will be demonstrated after the increasing of the ventilation rates (Schibuola and Tambani, 2021).

Simulation models give the opportunity to investigate different ventilation scenarios and to simulate chemical exposure, while also including the energy consumption factor (Connolly et al., 2022).

Scenarios of different type of ventilation mechanical, natural or mixed configuration can be implemented, involving different ventilation rate (Tian et al., 2020). Also, numerical approaches can be used to investigate the transport of the aerosol, like Covid-19, generated by an infected person and the spread of it (Picard et al., 2022).

In the present work, the experimental investigation of the adequacy of ventilation in naturally ventilated classrooms located at the University of Western Macedonia, in Kozani, Greece, took place. Measurements include thermal comfort parameters as well as IAQ ones, namely carbon dioxide (CO2), volatile organic compounds (VOCs), aldehydes and ozone (O_3). The air exchange rates were determined according to the tracer gas decay and equilibrium analysis methods, using CO_2 as tracer gas, while simulation analysis was also applied. Moreover, the risk of airborne infection to Covid-19 was estimated for different scenarios of wearing a mask or not using the Wells-Riley model.

2. Methodology

2.1. Description of the investigated building

The building under investigation is that of the School of Mechanical Engineering of the University of Western Macedonia, located at center of Kozani. The climate of Kozani is characterized as the coldest one, regarding Greece (Kozani is ranked on D climate zone according to the Greek version of the EPBD (TEE, 2010)), because of its location and altitude (710m); rainfall is generally moderate, summers are mild and snowfall is frequent in the winter months. The occurring meteorological parameters during the campaign, have been obtained from a meteorological station installed by the research. Two different classrooms of the building have been chosen for the present measurements campaign; Both are located on the ground floor. More specifically, one amphitheater with total surface area 128.5 m^2 and capacity of 120 people and one classroom with total surface area 50.9 m^2 and capacity of 60 people, have been selected. Both classrooms are heated through conventional heating appliances, hot water radiators, while ventilation is performed naturally through the opening of the windows and doors. Natural ventilation was achieved through the windows lying on tilt position. The amphitheater has three windows, with dimensions of 1.35mx1m (height x weight), while the classroom has one window, with dimensions of 1.35mx1.5m.

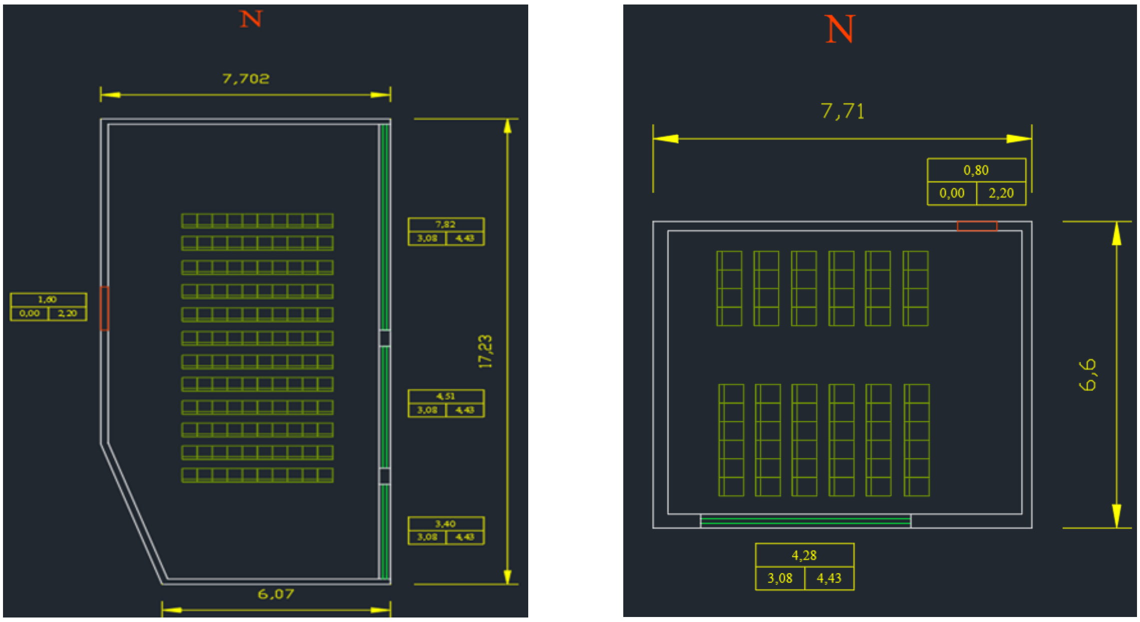

Figure 1. Layout of the Amphitheater (left) and classroom (right)

2.2. Experimental measurements set-up

The measurement campaign, based on ISO 7726 (ISO, 2001) and ANSI/ASHRAE Standard 55 (ANSI/ASHRAE, 2020), lasted 11 days (12/10/2021-22/10/2021) for the parameters of thermal comfort, while for the IAQ parameters, the passive samplers for chemical compounds were placed for a period of 5 days (18/10/2021-22/10/2021). The environmental parameters of air temperature (T_{air}), relative humidity (RH) and CO_2 concentration, were measured using Hobo MX1102A and Hobo U12-012 coupled with Telaire 7001. For air velocity, a 3D anemometer was used, while for the radiant temperature, the thermocamera FLIR TG165 was used. The above parameters were measured at a height of 1.1 m, based on the recommendation of ISO 7726 (ISO, 2001). special care was taken in order to ensure that the instruments would not disturb any class activities. Furthermore, the equipment was placed in the centre of the room and away from heat sources. The obtained meteorological parameters through the respective meteorological station, concern air temperature (°C), relative humidity (%), wind speed (m/s), barometric pressure (mbar) and wind direction. The time interval for all the environmental parameters, indoor and outdoor ones, are about 1-min, expect for radiant temperature which was monitored only in the day when PMV values where calculated. The characteristics of the installed instruments are presented in Table 1. As concern IAQ parameters, Radiello passive samplers for VOCs, BTEX and O_3 were used.

Table 1. Measuring quantity, instrument indication

Measuring Quantity	Instrument Type	Accuracy	Range
T-RH-C_{CO2}	Hobo Onset MX1102A	±0.21°C (T), ±2% (RH), ±50ppm (CO_2)	0-50 °C (T), 1-95% (RH), 0-5000ppm (C_{CO2})
T-RH-C_{CO2}	Hobo Onset U12-012	±0.5°C (T), ±5% (RH), ±50ppm (CO_2)	-20 to 70 °C (T), 5-95% (RH), 0-2500ppm (C_{CO2})
T-RH-C_{CO2}	Hobo Onset Talaire 7001	±0.5°C (T), ±5% (RH), ±50ppm (CO_2)	-20 to 70 °C (T), 5-95% (RH), 0-5000ppm (C_{CO2})
Wind Speed	Gill Instruments 3D Anemometer	±1.5% RMS	0-50m/s (u)
T-RH	DeltaOhm Hygrotransmitter HD9009TR	±0.5°C (T), ±5% (RH),	-40 to 80°C (T), 0-100% (RH)
Wind Speed	Thies CLIMA 4.3515.30.000	±0.5m/s (u)	0.5-40 m/s (u)
Wind Direction	Thies CLIMA 4.3127.40.000	±4°	0-360°

3. Results/Discussion

3.1. Experimental assessment

3.1.1. Ventilation Rate

For the estimation of the ventilation rate of the classrooms (ACH), the tracer gas approach is used (ASTM, 2018). In the present work, the CO_2 that was generated from the occupants has been used as a tracer gas, while the steady-state (constant concentration) and decay methods have been adopted (ASTM,2019), discussed in detail below. The steady-state or equilibrium method can be used when the concentration of the tracer gas becomes constant during the occupancy period. Since this method is a single zone method, it can only be used to estimate ACH on a building with a uniform CO_2 concentration. On the other hand, decay or step-down methods can be used when a space is vacated after occupancy, or if there is a stepwise decrease in occupancy. The estimation of ACH is made measuring the rate of the reduction of the tracer gas concentration over a certain period. Below are presented the equations of both models:

$$Q_S = \frac{10^6 G}{C_{in} - C_{out}} \quad (1)$$

where: Q_s: Ventilation rate of the space [L/s], G: CO_2 generation rate [L/s], C_{in}: Steady-state concentration CO_2 in the zone [ppm], C_{out}: Outdoor CO_2 concentration [ppm]

$$Q_D = \frac{V}{\Delta t}\ln\frac{(C_1 - C_{out})}{(C_0 - C_{out})} \quad (2)$$

where: Q_D: Ventilation rate of the space [L/s], V: Volume of the space [m^3], C1: Maximum CO_2 concentration in decay period Δt [ppm], C0: Minimum CO_2 concentration in decay period Δt [ppm], Cout: Outdoor CO_2 concentration [ppm], Δt: Time period [hours]

In the left diagram of Figure 2, CO_2 concentration in the Amphitheater is presented for a typical day, indicating selected periods of constant values that were used to for calculating ventilation rate with the steady-state method. In the right diagram of Figure 2, the application of decay method during the evacuation of the classroom by the students is presented.

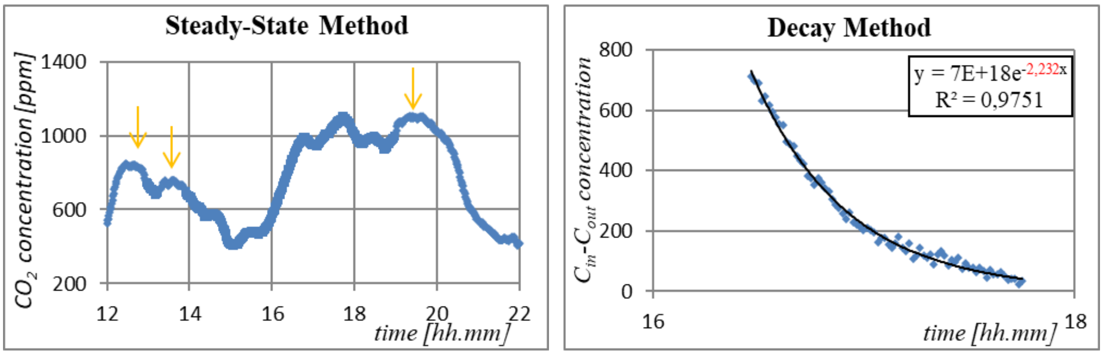

Figure 2. Charts describing the application of adopted tracer gas methods

The mean ventilation rate for each classroom, method and day are presented in Figure 3. The results, throughout the complete measurement campaign, are below the desired levels set by the standards for the Covid-19 period (6 h^{-1} for classrooms) (REHVA, 2020), for both classrooms. For the amphitheater, the average ventilation rate, is 2.2 h^{-1} and 1.7 h^{-1} for the steady-state and decay method respectively, while for the classroom 3 h^{-1} and 2.8 h-^{1}. The results vary between days, but also between models, due to factors that are difficult to predict, such as the external weather conditions, the degree of windows opening, as well as the case of the door of the classrooms being open, the exact number of students, but also the appropriateness of the time intervals chosen to calculate the ventilation values. The steady-state method tends to include more uncertainties in the present work, as the periods of constant CO_2 concentration are limited due to the presence of the natural ventilation. Moreover, the variation in the number of students during the lecture period can lead to fluctuations of CO_2 concentration, while the constant value that was selected for the generation rate (G) may add more uncertainties, as it can be different for every student, because it depends on the metabolic rate and anthropogenic characteristics (Batterman, 2017). For the specific estimation, an average value for adult at a normal activity in the office (sitting, writing, or reading) of 0.0052 L/s was adopted (Krawczyk et al., 2016).

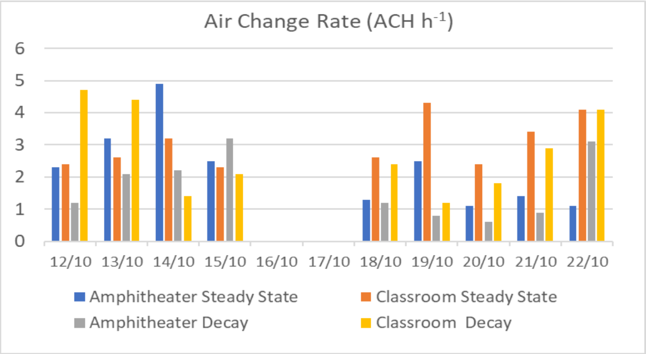

Figure 3. Air change rate per classroom and method for the whole measurement campaign

3.1.2. *Indoor Air Quality (IAQ)*

The indoor air pollutants were measured using diffusive air samplers placed approximately at the height of breathing zone at the amphitheatre. The monitoring of VOCs, aldehydes and O_3 was carried out with the use of Radiello passive samplers. VOCs were chemically desorbed by the passive samplers with CS_2. Analysis was performed at GC-FID Agilent Technology 6890N using 2-fluorotoluene as internal standard. Aldehydes were desorbed with HPLC grade acetonitrile by the passive samplers and analysis was performed at Agilent HLPC 1100 Series. O_3 concentrations were analysed with UV-VIS spectrophotometry, using a RAYLEIGH UV-1601 spectrophotometer.

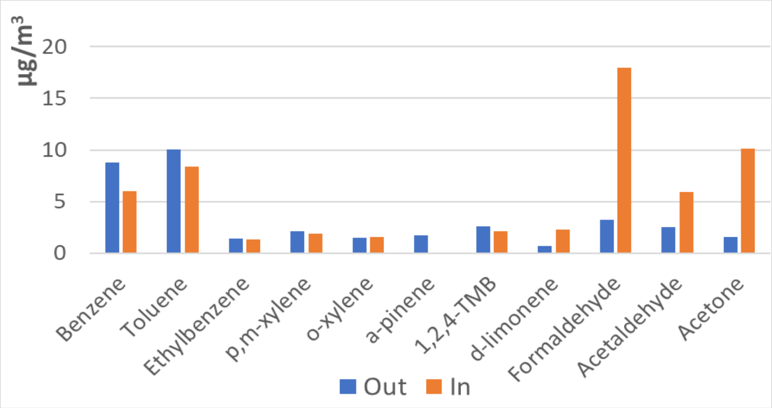

Figure 4. Concentrations of Volatile organic compounds and aldehydes

Figure 4 presents the concentration of VOCs and aldehydes; no elevated indoor concentrations were observed, while the I/O ratio is greater than unity for carbonyl compounds and less than, or equal to, unity for most VOCs. Regarding the O_3 concentration, it was lower inside (12.27 $\mu g/m^3$) than outside (45.30 $\mu g/m^3$), confirming that the main source of ozone inside the buildings is the external environment. These results confirm the positive impact that ventilation has on IAQ, as well as its contribution towards the ensuring of a healthy environment in the period of Covid-19.

3.1.3. *Infection Risk*

The probability of infection risk for different type of mask and degree of ventilation rate was calculated using the Wells-Riley model (Riley et al., 1978). This steady-state model can provide a rather simple and easy-to-implement evaluation method of the airborne infection risk. the Wells-Riley relation is presented in equation (3) equation, while equation (4) represents the modified Wells–Riley equation, having integrated mask filtration efficiency factor:

$$P = 1 - e^{\frac{-Iqpt}{Q}} \quad (3)$$

$$P = 1 - e^{\frac{-Iqpt(1-n_I)(1-n_S)}{Q}} \quad (4)$$

where P is the probability of infection risk; I is the number of infectors; the variable p is the pulmonary ventilation rate of susceptible people (m^3/h); p = 0.3 m^3/h when people are sitting or participating in light activity indoors (Duan, 2013). Q is the room ventilation rate (m^3/h); q is the quantum generation rate by an infected person (h^{-1}); t is the exposure time (h); and η_I, η_S are mask efficiencies for the infected person and susceptible person, respectively.

In this study it was assumed that each classroom has one infector student (I=1), the time of exposure is about 2 hours (duration of the lecture), while the quantum generation rate of COVID-19 (q) is 48 h^{-1} according to the literature (Buonanno et al., 2020). The ventilation rate was considered to fluctuate between 0.5-6 h^{-1} based on the measurement values, as well as on the guidelines limits. Three different scenarios were investigated. The first does not concern the use of mask, the second refers to the use of basic surgical mask, while the third with the use of FFP2/KN95 mask.

The estimated association between the infection probability and ventilation rate for the different scenarios is shown in Figure 5. The results indicate that wearing a mask plays an important role in reducing the infection risk, particularly in low ventilation rates. Also, the lower volume of the classroom increases the infection risk about 2.5% for first and second scenario, making ventilation needs stricter. The type of mask is playing a key role in the spread of the corona virus, as high protect masks FFP2/KN95 reduce the infection risk under 1%. Ventilation rate- lower than 2h^{-1} increases the infection risk significantly. The campaign findings are in agreement with the ones of the literature referred to in the introduction.

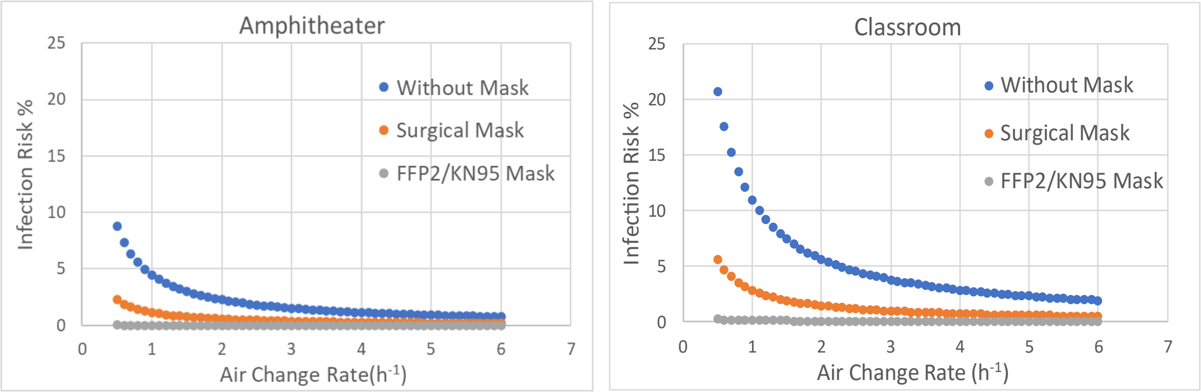

Figure 5. Estimation infection risk of Covid-19 for three different scenarios

3.1.4. Thermal Comfort

Fanger model was used to predict the thermal comfort of the classrooms. The Predicted Mean Vote index (PMV) and the Predicted Percentage Dissatisfied index (PPD) (Fanger's thermal comfort indices) were calculated according to the relations proposed by EN ISO 7730, Annex D (CEN, 2005). Calculation was implemented for each specific period the classes were crowded. The PMV was estimated from measured thermal comfort parameters (air temperature, radiant temperature, air velocity and relative humidity) along with physical parameters of metabolic rate and clothing. Metabolic rate was calculated according to the EN ISO 7730, Annex A (CEN, 2005) was adopted for sedentary activity, while clothing was recorded during the point-in-time survey. In Table 3, the values of PMV and PPD for the 21/10/2021, are presented, noting that only in that day the students filled the questionnaire about their perception of thermal comfort and their clothing level.

Table 3. Mean values of thermal comfort parameters

Classrooms	Period	PMV	PPD	TSV
Amphitheatre	09:15-10:30	-0.25 ± 0.40	9.63 ± 6.01	0.38 ± 0.79
	11:15-12:15	-0.20 ± 0.34	8.17 ± 3.03	0.33 ± 1.05
Classroom	09:15-10:30	0.19 ± 0.22	6.71 ± 2.98	0.47 ± 0.94
	19:00-20:00	0.21 ± 0.25	7.15 ± 3.52	0.5 ± 1.10

As can be seen in Table 3, PMV values for both classrooms were inside the comfort range of (-0.5,0.5) proposed by the ANSI/ASHRAE Standard 55 (ANSI/ASHRAE 2020). As regards the European Standard EN15251 (CEN, 2012), all values lie within the indicated limits category II (-0.5, 0.5). Also, thermal sensation vote (TSV) of the students, resulting from the analysis of the questionnaires is presented in Table 3. It should be mentioned that the questionnaire was prepared and used for the scope of the presented research, namely the investigation of the actual comfort sensation of students for the time they fill, based on ANSI/ASHRAE Standard 55 (ANSI/ASHRAE, 2020). Alongside questionnaire including anthropometric information for each person, namely gender, height, weight and of course their clothing, was used, as this information was important for the calculation of PMV. A total number of 106 questionnaires was collected; the average values of TSV laid within the relevant range of $-1.5 \leq TSV \leq 1.5$ for all the periods showing that thermal comfort is satisfied (ANSI/ASHRAE 2020). Fanger model and questionnaire analysis results indicate that thermal environment is quite acceptable, despite the fact that windows are open. However, the results cannot be representative of the thermal comfort of the students in general, since the measurements were carried out in a period when the outdoor temperature is not particularly low.

3.2. Simulation Analysis

As mentioned above, ventilation rate for the amphitheater was also calculated using the CONTAM simulation program. CONTAM is a multizone network software tool, developed at the National Institute of Standards and Technology (Dolis and Polidoro, 2020). Firstly, a pseudo-geometry of the investigated amphitheater, as well as of the surrounded rooms was created. Then flow paths like windows, doors or cracks that connect each zone together or with the outdoor environment were created too. Weather data is also necessary for the simulations, as CONTAM calculates the airflows between rooms (and outdoor) by taking into account the wind pressure on the building envelope through the use of pressure coefficients with wind velocity and direction, the air pathways (Picard et al., 2022). The needed meteorological data were taken from the meteorological station used in the measurement campaign, while the pressure coefficients were taken from the Air Infiltration and Ventilation Center (AIVC) database (Orme et al., 1998). Values of indoor air temperature, based on experimental measurements are also used as input data.

The simulation scenarios included the business-as-usual scenario, referring to the conditions of the experimental analysis (scenario 1), an increased ventilation rate scenario, referring to the windows being completely open (scenario 2), as well as an mechanical ventilation scenario achieving the indicated by the standard ventilation rates (scenario 3). In table 2, the experimental as well as simulated ventilation rates are presented. The results for scenario 1 are more close to the ones for the decay method, rather than the steady state ones, considering the potential effect of uncertainties that has been discussed above. It should also be noted, that during the simulation, the door of the amphitheater was consider closed, so cross ventilation wasn't present. This may add some additional uncertainties to the simulation results, as the door of the investigated amphitheater, by actual operation, stayed open periodically. Moreover, for the case of completely open windows (scenario 2), ventilation rate increases significantly, satisfying the requirement for 6 h^{-1} (REHVA, 2020), while the fluctuation of ventilation rate between the days becomes higher, compared to the basic simulation scenario, as the dimension of the openings has been increased and the influence of the outdoor conditions is higher. The effect of increased ventilation rate on thermal comfort will need to be assessed. Finally, mechanical ventilation achieves the desired ventilation rate.

Table 2. Estimated Ventilation Rate (h^{-1}) for experimental and simulation analysis

	18/10	**19/10**	**20/10**	**21/10**
Decay Method	1.20 h^{-1}	0.80 h^{-1}	0.60 h^{-1}	0.90 h^{-1}
Steady-state Method	1.30 h^{-1}	2.50 h^{-1}	1.10 h^{-1}	1.40 h^{-1}
Current Operation (Scenario 1)	0.85 h^{-1}	0.89 h^{-1}	0.95 h^{-1}	0.90 h^{-1}
Windows Full Open (Scenario 2)	7.16 h^{-1}	7.46 h^{-1}	8.00 h^{-1}	7.58 h^{-1}
Mechanical Ventilation (Scenario 3)	6 h^{-1}	6 h^{-1}	6 h^{-1}	6 h^{-1}

CO_2 concentration is commonly used as a surrogate indicator for assessing IAQ and ventilation efficiency (Hui et al., 2008). High CO_2 concentration is a critical issue for educational environment due to high occupancy and lack of ventilation (Liu et al., 2019; Merabtine et al., 2018). The new ventilation strategies that are applied, after the appearance of pandemic of Covid-19, can change the high concentrations of CO_2. Figure 6 presents the CO_2 concentration of amphitheater during the measurement campaign at 21/10/2021, as well as regarding the simulation scenario 1; that is the day thermal comfort was assessed too (section 3.1.4).

As it can clearly be seen, the simulation results are very close to measured ones for scenario 1 (Figure 6). Some difference may occur due to the accuracy of the measurement instrument and to different the generation rate that students have, as in simulation scenarios a common value of generation rate was considered (as mentioned above). The experimentally observed increasing of CO_2 at about 16:00 wasn’t predicted on a simulation level, this behavior can be considered momentarily, mainly attributed to some change in the number of occupants. The inadequate ventilation rates of the experimental case / simulation scenario 1, lead to high CO_2 concentration rates during the occupant period. On the other hand, the CO_2 concentration of the scenarios 2&3 (Figure 7) doesn’t exceed the 600ppm due to high ventilation rates.

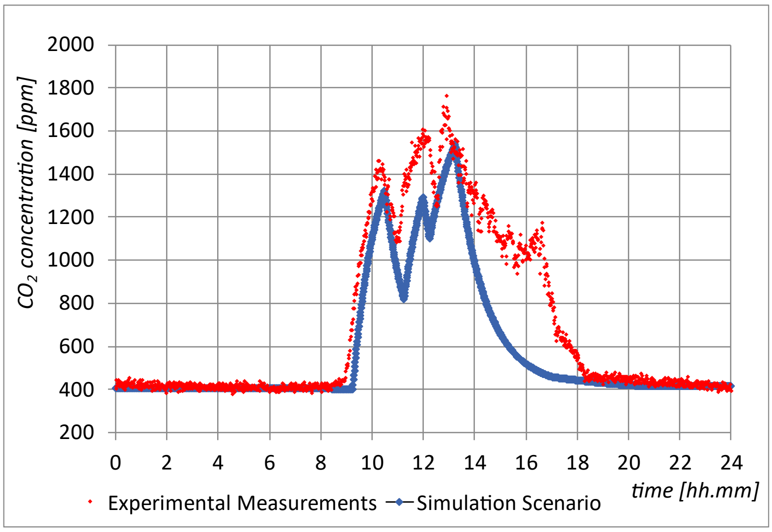

Figure 6. CO_2 concentration for experimental measurements and simulation scenario

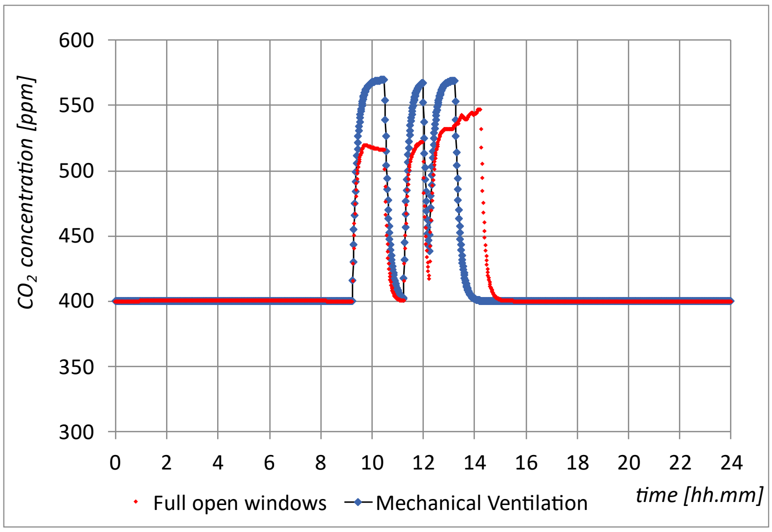

Figure 7. CO_2 concentration for simulation scenario of full open windows and mechanical ventilation

4. Conclusions

The present investigation presents interesting data regarding the new operating conditions of educational spaces, after the emergence of Covid-19. The results of tracer gas method (steady-state and decay method), as well as of simulation analysis, indicate that the natural ventilation of both classrooms investigated is inadequate and below the new desired levels that have been set by the standards for the Covid-19 period. The simulation analysis provides more stable results compared to the tracer gas method. As results indicate, higher ventilation rates as well as wearing of masks can significantly reduce the infection risk of covid-19. The impact of increasing the ventilation rate is positively reflected in the IAQ, while the thermal environment for both classrooms is acceptable, despite the potential effect of weather conditions due to natural ventilation. Simulation scenarios show the impact that ventilation has on CO_2 concentration.

Future work could extend the measurement campaign throughout the winter period, in order to identify potential effect of colder temperatures on the estimated ventilation rates, both also to assess the impact of natural ventilation on IAQ and thermal comfort; the thermal comfort effect can be assessed by simulation approaches also. The use of air cleaning devices and their inclusion in relevant research works, can also provide useful findings, towards the decrease of ventilation requirements, while maintaining high IAQ. Energy issues should not be neglected.

The proposed work aims at presenting the potential of combined use of experimental and simulation approaches, towards the integrated consideration of IEQ and energy aspects for burdened indoor air cases, as the University ones, through the Covid-19 pandemic.

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