Measurements of carbon dioxide concentration and temperature in dormitory rooms in Poland and Spain – a case study

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Abstract. Main parameters of a microclimate that could influence people behaviour and comfort are: temperature, carbon dioxide level, relative humidity, noise and lighting intensity during the day and evening. During analysis of energy efficiency the most important factor is temperature and many researches concentrate only on this one, however it is necessary to maintain a proper indoor air quality. In this paper we show results of measurements conducted in selected dormitory areas in Poland and Spain, using an instrument TSI 9565, as a part of the research project “The possibility of the renewable energy sources usage in the context of improving energy efficiency and air quality in buildings and civil constructions”. Buildings differed not only in climatic data but also in their construction (heat transfer coefficient values, materials), air change rates (ACH), density of occupation etc. Moreover data obtained during our research was compared with a theoretical model of changes in CO2 in time. In case of three tested rooms, CO2 concentration was in a recommended range during all measurement period, while in one house even an initial value was too high. Temperature was found between 19.0°C and 24.4°C.

1. Introduction

The quality of indoor air (IAQ) in buildings is considered in terms of health and thermal comfort of the occupants. It is shaped by both physical and chemical parameters influencing indoor conditions in a different way and range. The human thermal comfort is mostly understood as the situation in the room, where the person does not feel warm or cold, which means that he is in a state of the sustainable heat balance. A thermal comfort is a connection between an individual sensation and a few objective influences on the environment, that is why in the case of crowded rooms, a definition of thermal comfort poses a problem [1]. The comfort depends on many factors, which can be divided into two main groups: the environmental and individual parameters. The environmental factors include: air temperature, air velocity, relative humidity, background radiant temperature and an asymmetry of the temperature distribution, while in the group of individual factors it is necessary to note: a metabolic rate, an acclimatization (the ability of thermoregulation) and a clothing insulation [1]. Requirements for the indoor air quality are regulated by specific national legislations - standards and regulations. In Poland main information about the IAQ are shown in [2,4,5]. The regulations underline that...
ventilation and air conditioning systems should be designed to provide adequate the indoor environmental quality, including the optimal air exchange, its purity, temperature, relative humidity and a speed of air stream in the rooms. In public buildings in rooms for a permanent and temporary residence of people the amount of outdoor air delivered should be at least 20 m³/h per one person, while in case of operation of air-conditioning systems or mechanical ventilation without the possibility of opening windows, the flow is set as minimum 30 m³/h for each user [5]. Carbon dioxide (CO₂) concentration is a parameter commonly used as an indicator of the IAQ in buildings. Peoples are the main source of this pollution but it is also influenced by factors as the room ventilation or indoor temperature. CO₂ itself is not harmful potentially, however its excessive exposure is found to cause headaches, fatigue and lower performance at work. According ASHRAE standard this concentration should not exceed 2500 ppm, being 1000 ppm recommended upper limit[6]. Indoor temperature directly influences the human physical and psychological health, sense of comfort, as well as his comfort feeling. The indoor temperature is the end result of combination many factors, like radiation temperature of walls and ceilings, heat transfer through the elements of the building, internal heat gains etc. These gains can be from natural sources: gains from people or pets, as well as artificial ones connected with a work of ventilation, air conditioning or heating system. ASHRAE recommendation is an operative temperature between 20-23.5°C in winter and between 23–26°C in summer.

This work studies the IAQ and thermal comfort in dormitory rooms located in different climate zones, Poland and Spain, through measurements of parameters, such as CO₂ concentration, indoor temperature and VOC concentration. Experiment is a part of the research project “The possibility of the renewable energy sources usage in the context of improving energy efficiency and air quality in buildings and civil constructions” conducted in different types of buildings. We focused our research presented in this paper on the living quarters, where people spend most time of their life, so their microclimate is extremely important for their health and well-being. Previous tests were conducted in the public buildings located in these countries with high occupancy and ventilation, how was published in [7,8]. In the mentioned studies, it was shown that time variation of carbon dioxide follows an analytical expression given in those references. Current research focuses on the microclimate in dormitory rooms located in the same zones, but with the low occupancy and ventilation air flow. The aim of this work is to detect differences in behaviour with the climatic zone for these conditions and to check if the theoretical model of previous works continues working on these states. The whole project results allow to deliver general conclusions about parameters of microclimate depending on variables.

2. The material and methods
In order to verify the influence of individual air parameters on the user comfort and well-being, this paper was designed to investigate the indoor air quality of the premises in Poland and Spain and compare it elaborately. The following air parameters were measured: carbon dioxide concentration, atmospheric pressure, room temperature, relative humidity and volatile organic compounds. All IAQ parameters were recorded using instrument TSI 9565 (Figure 1) 1.0 m above the floor. This equipment’s characteristics is showed in a Table 1. Values were recorded every minute during 2 hours, whereas in figures regarding the carbon dioxide level we show average values for each 5 minutes, to compare them with results of simulations.
Table 1. Basic parameters of the IAQ meter.

| Parameter     | Range                        | Precision             |
|---------------|------------------------------|-----------------------|
| Temperature   | between -10 and +60 °C       | ± 0.1 °C              |
| Carbon dioxide| between + 0 and + 5000 ppm   | ± 50 ppm (± 3%)       |
| Humidity      | between 5 and 95%            | ± 3%                  |
| Pressure      | between -3757 and +3757Pa    | ± 1 hPa               |
| VOCs          | between 10 and 20000 ppb     | ± 10 ppm              |

In Spain, the measurements were conducted in 2 places. First one was student’s residence of School of Engineering Sciences of Belmez (University of Cordoba) (Figure 2). The residential complex built in 2010 consists of a few modules and offers the accommodation and services to the university community. The apartment used for tests (Room A) was component from living room, 5 bedrooms, 3 bathrooms and halls. In the residence the air HVAC system is installed, as multiplies in the common areas. Walls and roofs were constructed under Spanish law and heat transfer coefficients were 2-3 times higher than in Poland. In the building new double-glasses windows were mounted. Second tested room (Room B) was a twins hotel room located in a historic building in the old town area in Cordoba (Figure 3). Heating and air-conditioning was in this case organized as a central air system. Windows were old. In Poland, first tested place (Room C) was a new residential building in Niewodnica (Figure 4), constructed under Polish law from 2014. All windows were triple-glasses. Water heating system with panel radiators was used in the building and there were no air-conditioning system. A second tested area was a double room (Room D) in an old hotel constructed in 1960s (Figure 5) that was modernized a few years ago. Retrofitting included a replacement of windows and modernization of the façades. In all tested rooms there was natural ventilation with low Air Changes by Hour (ACH), varying between 1.2-1.5 h⁻¹. Description of buildings and basic parameters concerning the measurements are presented in the table 2.
Table 2. Basic parameters of rooms.

| Number of a building | Location | Number of people during the test | Volume [m³] | Volume per user [m³/capita] | Air Changes by hour (h⁻¹) |
|----------------------|----------|----------------------------------|-------------|-----------------------------|--------------------------|
| 1                    | Room A in Students’ residence located at a rural site (Spain) | 5           | 80                       | 16.0                      | 1.3                      |
| 2                    | Room B in a hotel located in a city centre (Spain) | 2           | 41                       | 20.5                      | 1.5                      |
| 3                    | Room C in as single family house located at a rural site (Poland) | 6           | 75                       | 12.5                      | 1.2                      |
| 4                    | Room D in a hotel located in a city centre (Poland) | 2           | 38                       | 19.0                      | 1.3                      |

The measurements of indoor air quality were performed in public utility rooms in September, when heating and air-conditioning systems were not working.

Moreover we compared results of tests with simulation using CO₂ concentration model delivered and described in Krawczyk et al.[8]. The following mathematical relations were used in calculations [8]:

\[
\text{Air Changes by hour (h⁻¹)} = \frac{\text{Volume per user [m³/capita]}}{\text{Number of people during the test}}
\]
where: ACH – the air change rate [1/h], t – time [h], P – pressure [Pa], \( C_{CO_2in} \) – carbon dioxide concentration in indoor air [ppm], \( C_{CO_2out} \) – carbon dioxide concentration in outdoor air [ppm], V – the volume of indoor air [m³], g – \( \mu CO_2 \) gains from a person [g/(h per)], N – number of people occupied a room in this instant t, T – temperature [K], R – constant, \( \mu CO_2 \) – the molar mass of carbon dioxide.

Analysis were carried out using E-LAB_6 application, which had been created within VIPSKILLS project [9] and allowed to find a distribution of the carbon dioxide in specific rooms with longer times of usage of rooms.

3. The results

3.1. Outdoor parameters

During measurements parameters were recorded twice (Table 3): before and after tests in buildings, however no significant difference in values was found and it is possible to set them as constant values.

For estimation of the average values we took into account 15 minute measurements. To avoid mistakes first 5 minutes after the equipment was turned on was excluded as stabilization time. Average values shown in Table 3 were used for simulations conducted according to Equation 1.

### Table 3. Parameters of outdoor air

| Number of building | Location                | CO₂ concentration (ppm) | Average temperature (°C) | Average relative humidity (°C) | Average atmospheric pressure (hPa) |
|--------------------|-------------------------|-------------------------|--------------------------|-------------------------------|-----------------------------------|
| 1                  | Spain – the rural area  | 387                     | 19.8                     | 43.9                          | 958                               |
| 2                  | Spain – the city centre | 396                     | 22.4                     | 45.0                          | 965                               |
| 3                  | Poland- the rural area  | 380                     | 15.6                     | 64.0                          | 1000                              |
| 4                  | Poland - the city centre| 399                     | 16.2                     | 60.3                          | 1009                              |

3.2. Indoor air parameters

During the study, the concentration of carbon dioxide, indoor pressure, indoor air temperature, relative humidity and volatile organic compounds were measured. Values of carbon dioxide changes obtained are shown in Figures 6-9. In this paper we show results of measurement conducted 120 minutes. In case of the dormitory and the house, buildings were used in mornings by part of habitants and measurements started at 5 p.m. when all users came into buildings. To avoid mistakes, first 5 minutes after the equipment was turned on was excluded as stabilization time. In both hotels measurements were carried out when habitants arrived to the rooms, without previous ventilation etc. All values were recorded every minute and the average value was calculated every 5 minutes. In Figures 6-9 a blue line represents results of measurement while a red one shows results of simulations obtained using VIPSKILLS tool [9] delivered based on formula (1).
A good agreement between measured concentrations and values obtained from simulation is obtained. This shows that equation (1) is a good model also for conditions with low occupancy and ventilation, where gains from internal sources (persons) and external contributions are similar.

At the beginning of measurements CO₂ concentration was in a range 460-900 ppm. In Poland, initial CO₂ concentrations are very similar for both rooms 620 ppm. Significant differences in this initial values are found in Spain. While in the students residence (Room A) the initial concentration is 460 ppm, in the Spanish hotel (Room B) 900 ppm was recorded. This fact is due to the worst ventilation in this old hotel. During the entire measurement time, CO₂ is very near recommendation limit of 1000 ppm [6], for all locations. The highest value 1305 ppm was registered in Polish house, after 2 hours.
The growth rate of CO$_2$ during this time was different in both countries. An increase of carbon dioxide was the slowest in Spanish hotel (90 ppm during 2 h), while the faster in Polish house (615 ppm per 2h). This growth rate is bigger for those rooms where occupancy is higher and depends on volume per user (Table 2). Highest growth rate were found in the Spanish residence (Room A) and the Polish hotel (Room D) with a volumes per user 16.0 and 12.5, respectively. Lowest ones were found in the other rooms, Spanish hotel (Room B) and Polish house (Room C) with values 20.5 and 19.0, respectively. However, for similar volume per user, growing of CO$_2$ concentration is lower in Spain. The main factor of this difference is the different temperature between both countries by climate conditions.

Indoor temperature during measurements was in range 21.9-24.0°C in Spain and 19.0-20.4°C in Poland (Figure 10), that was connected with outdoor temperature for both locations. During tests increase in temperature was low: from 0.5°C in hotels to 2.0°C in residential buildings. Bigger temperature growths were in Spain, due mainly that law regulations are not so strict and heat transfer coefficients of wall and roof are 2-3 times higher than in Poland, so indoor temperature more dependent on external conditions. In all rooms indoor temperature was nearly in recommended range and differences between values from regulations (in Poland 20°C, Spain 21-23°C) and recorded ones are acceptable.

![Figure 10. Indoor temperature variation during measurement time.](image-url)
A level of volatile organic compounds (VOCs) was in a range between 13 and 1650 ppb as showed in Figure 11. In accordance to this figure, it can be observed that this distribution in residential building 3 (Room C) in Poland is medially three times higher than in the residence hall in Spain (Room A). The lowest values were found in a hotel room in Poland. In both buildings located in Spain VOC concentration was similar, while in case of Polish object significant difference was noted. Values of VOC concentration between 60-200 ppb are considered good in a point of view of the IAQ, whereas 200-660 ppb is considered as moderate conditions when some ventilation is necessary and finally values between 660-2000 ppb indicate poor IAQ with intensified ventilation recommended [10]. According this classification, only building 4 (Polish hotel) is acceptable, Spanish buildings are moderate whereas Polish house needs a special attention and improvements.

4. Summary and conclusions

We presented results of measurements conducted in four buildings: the students residence, the single family house and hotel rooms located in Poland and Spain. In all cases, the occupancy was low and ACH was between 1.3 -1.5 h⁻¹.

This paper has shown that time variation of CO₂ concentration in these conditions could be simulated by the analytical expression (Equation 1). This variation depends of the volume per user and for similar values of this parameter, Poland showed a high growing due to the different temperature. Values of CO₂ concentration were always near to ASHRAE recommendation, only in the Polish house (Room C) this proper value was exceeded appreciably with 1305 ppm.

Indoor temperature was higher in Spanish buildings by virtue of external conditions. Higher heat transfer through the envelope in Spanish building resulted in stronger influence on outdoor conditions in this country. Moreover infiltration of outdoor air, that temperature was higher in Spain also weighed. All temperature values were near of national regulations.

Finally, the level of VOC concentration was in a range between 130 and 1650 ppb. From the point of view of the IAQ, only the hotel in Poland (building 4) is considered as good. Spanish buildings 1 and 2 are classified as moderate ones and a special ventilation is necessary for Polish house (building 3).
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