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MONITORING OF INDOOR AIR IN A PASSENGER RAILWAY WAGONS

In low-energy and passive houses, about 80 % of the total energy is consumed for fresh air heating or cooling, the reason being the improved thermal insulation and air tightness of such a building. In fact, actual trend of building construction is to keep the windows closed. A similar situation is already encountered in some means of transportation, i. e. air-conditioned trains. Ventilation of the passenger space is assured mainly by a mechanical ventilation and, when the train stops, by a natural ventilation through door opening. In this paper we present some measurements of carbon dioxide concentration in a passenger railway wagon. Two types of passenger railway wagons were monitored. The first type was an “open” wagon (having rows of seats and a central corridor like in a passenger airliner) and the second one was a “closed” wagon (having a side corridor connecting individual compartments along the body of the train). By monitoring the carbon dioxide concentration it is possible to determine if adequate fresh air is being supplied to the space where the occupants have no possibility to intervene (windows being closed).

Key words: ventilation, measurement, carbon dioxide, passenger, wagon.

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ДОСЛІДЖЕННЯ ПОТОКУ ПОВІТРЯ У ЗАЛІЗНИЧНИХ ПАСАЖИРСЬКИХ ВАГОНАХ

У будинках з низьким енергоспоживанням та пасивних будинках близько 80 % загальної енергії споживається для підігрівання або охолодження припливного повітря залежно від пори року. Це зумовлено переважно підвищенням рівня теплоізоляції та герметичності таких будинків. Насправді сучасні тенденції будівництва таких споруд полягають у тому, щоб утримувати вікна закритими, подаючи натомість повітря за допомогою вентиляційного устаткування. Такою є ситуація в деяких транспортних засобах, а саме в поїздах, які оснащені кондиціонером. Вентилюють пасажирський простір переважно механічним способом і в момент зупинки поїзда – природною вентиляцією відкриванням дверей вагонів, крім того, там необхідно мінімізувати витоки тепла. У статті наведено результати вимірювань концентрації вуглекислого газу в залізничних пасажирських вагонах. Було досліджено повітряне середовище у двох типах залізничних пасажирських вагонів: перший тип був “відкритим” вагоном, який

мав два ряди сидінь з обидвох боків і центральний коридор між ними, а другий – “закритий” вагон з бічним коридором, що з’єднує окремі купе по довжині вагона. Вимірюючи концентрацію вуглекислого газу, можна визначити, чи постачається достатня кількість припливного повітря у простір, куди пасажири не мають можливості втрутитися (у випадку повністю закритих вікон). За результатами досліджень внутрішнього середовища в пасажирських вагонах, де було виявлено концентрацію CO_2 та враховуючи рівень температури повітря у вагонах, можна стверджувати, що якість повітря була незадовільною. У обох контрольованих вагонах концентрація CO_2 була більшою, ніж 1000 ppm. Пасажири в купе вагонів намагалися поліпшити стан повітря, відкриваючи двері від купе до коридору, навіть за рахунок втрати приватності. Це свідчить про те, що пасажири відчули симптоми втоми та погіршення якості повітря.

Ключові слова: вентиляція, вимірювання, вуглекислий газ, пасажир, вагон.

Introduction. In modern times, humans spend most of their time in closed spaces, whether they are buildings or means of transport. From the energy point of view, construction is a trend for building energy-efficient buildings [1]. Also in the means of transport is the effort to minimize heat leakage. In all cases, efforts are made to use energy efficiently. Modern buildings and vehicles are designed to provide fresh air in the required amount and quality (temperature and humidity). In order for the ventilation system to function according to predetermined parameters, natural ventilation is avoided. Buildings and means of transport shall be constructed with non-retractable windows to prevent natural ventilation [2] and thereby prevent the air-conditioning system from malfunctioning [3]. The constructors’ effort is to create an appropriate environment for people to stay, which requires a very demanding activity from multiple perspectives.

The objective of air quality monitoring in two types of railway air-conditioned passenger wagons was to obtain information about the air condition in simple spaces. From the perspective of air conditioning, a person’s large-wagon wagon with solid windows looks like a simple building. In monitoring air quality, we focused on the concentration of carbon dioxide, the source of which is the persons in the wagon. The result of monitoring can provide appropriate information for air conditioning designers in vehicles and buildings.

Materials and Methods. The carbon dioxide concentration and the indoor air temperature were monitored in two types of air-conditioned rail passenger wagons. The first measurement was carried out in a passenger compartment with 11 sections, each with six seats. The second measurement was carried out in a 76-seat passenger-sized passenger car. The monitoring was in May during normal operation. The first measurement took place in one compartment with six seats and lasted 37 minutes. The second measurement was carried out in a passenger car and lasted for 1 hour and 47 minutes. The number of passengers in the wagon varied during the measurement. The measurements were recorded: carbon dioxide concentration, indoor air temperature and outdoor air temperature.

The measuring devices. During the indoor air quality monitoring, the ZG106 CO_2 Monitor was used. It is a portable carbon dioxide sensor in the air with a record of measured CO_2 concentration and air temperature in the internal memory. The measured values are recorded automatically after 30 minutes each 24 hours. In our case, the record was made manually every 5 minutes. The device works by the NDIR method and is designed to measure the temperature and CO_2 concentration of the room. The CO_2 concentration range is from 0 to 3.000 ppm. Accuracy of CO_2 concentration is ±50 ppm. The influence of temperature on the measurement is ±2 ppm per 1 °C. The temperature range is from 0 to 50 °C. The accuracy of the temperature measurement is ±1 °C.

Characteristic of the experimental space. Indoor air quality monitoring was conducted in two different rail wagons. The first measurement was carried out in a railway wagon for 66 passengers in a closed compartment for 6 passengers.

Fig. 1. Sensor ZG106 CO_2 Monitor [4]

Fig. 2. Schematic of the seating arrangement in a rail car with a coupe [5]

At the time of the experimental measurement, the train was almost always fully occupied. In the six local coupe there were 4 to 6 people. The heating wagon was provided with an electric heater. The interior volume of the wagon compartment was approximately 11.5 m^3. The window in the coupe was unpretentious.

Fig. 3. View of the wagon. Left – Section (Source: Coupé) [5];
Right – Personal Grand Prix Wagon (Author: Marek Bičan (2009) [6])

The second measurement was carried out in a passenger-sized passenger car designed for 76 passengers. At the start of the experimental measurement, the wagon was fully occupied. During the monitoring, all windows were closed in the wagon. The ventilation was provided by the ventilation and air conditioning system. The interior volume of the passenger wagon was approximately 126.5 m^3.

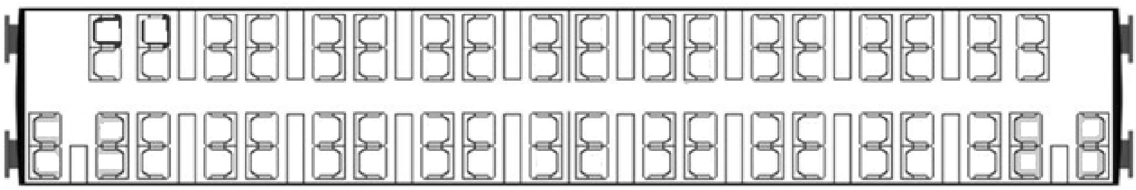

Fig. 4. Schematic of the seat arrangement in a passenger car [7]

In both cases, it was a rail wagon with its own air conditioning system to replace the worn out air and to heat or cool it. The air capacity of the plant is 2000–2800 m^3 / h [8].

Result and discussion. During the monitoring of a railway passenger car, the ZG106 CO2 Monitor [4] measured: indoor air temperature and concentration of carbon dioxide. Outdoor air temperature and outdoor relative humidity were determined from Weather Underground's hydrometeorological data [9]. The weight of the persons was estimated. The data found is documented in Tables 1 and 2.

During the monitoring of the indoor environment in the passenger compartment (coupe), the outside was partly cloudy. By measuring carbon dioxide concentrations, it was found that when the train was in motion, the carbon dioxide concentration was less than when the train stood at the station. The measured minimum carbon dioxide concentration was 1160 ppm and a maximum of 1495 ppm. The average carbon dioxide concentration was 1305 ppm, which corresponds to a value that shows signs of fatigue, decreased concentration on exercise, and a feeling of exhaust air.

Table 1

Data found when monitoring the first closed coupe wagon

time (h: min)	Number of persons (-)	Total weight of persons (kg)	Air temperature in the coupe (°C)	Concentration of CO_2 (ppm)	Outdoor air temperature (°C)	Relative humidity of the outside air (%)	remark
10:53	5	425	20.8	1380	14,0	41	closed door
11:00	5	425	22.3	1255	14,0	41	closed door
11:05	5	425	22.9	1280	15,0	41	closed door
11:07	4	340	23.1	1390	15,0	41	closed door
11:10	4	340	23.32	1400	15,0	41	closed door
11:15	4	340	23.6	1185	15,0	48	open door
11:18	5	450	23.7	1250	15,0	48	open door
11:20	6	530	23.8	1260	15,0	48	open door
11:24	6	530	23.9	1495	15,0	48	open door
11:30	6	530	24.0	1160	15,0	48	open door

During the monitoring of the indoor environment in the passenger car, the weather was clear outside. By carbon dioxide measurements it was found that before the stop the air was fed at a higher speed than at the normal train speed. 76 people were traveling in an open wagon, of which approximately 46 children were 12 years of age.

Table 2

Data found when monitoring the second open wagon

time (h: min)	Number of persons (-)	Total weight of persons (kg)	Air temperature in the coupe (°C)	Concentration of CO_2 (ppm)	Outdoor air temperature (°C)	Relative humidity of the outside air (%)
17:13	76	4104	23.6	1635	21.0	32
17:20	76	4104	24.1	1680	21.0	32
17:25	76	4104	24.1	1660	21.0	43
17:30	76	4104	24.7	2210	21.0	43
17:35	76	4104	25.2	1660	22.0	43
17:40	76	4104	25.3	1550	22.0	31
17:45	76	4104	25.4	1550	22.0	31
17:50	72	3804	24.4	1500	22.0	43
17:55	72	3804	25.4	1635	22.0	43
18:00	74	3954	25.6	1530	21.0	43
18:05	74	3954	25.6	1530	21.0	43
18:10	74	3954	25.6	1450	21.0	43
18:15	74	3954	25.6	1205	20.0	43
18:20	74	3954	25.4	1140	20.0	43
18:25	74	3954	25.4	1175	19.0	43
18:30	74	3954	25.6	1155	19.0	43
18:45	74	3954	25.4	1205	19.0	43
18:50	74	3954	25.4	1235	19.0	43
19:00	74	3954	25.3	1190	19.0	43

In the passenger car, a minimum carbon dioxide concentration of 1140 ppm and a maximum of 1660 ppm was measured over an hour and 47 minutes. The average calculated carbon dioxide concentration was 1468 ppm, which corresponds to a value that shows signs of fatigue, decreased concentration of activity and a feeling of exhaust air.

From the collected data of the indoor environment in the monitored railway wagons, it can be stated that in the passenger compartment the interior air temperature gradually increased. The concentration of carbon dioxide was also increased.

Table 3

Effects of carbon dioxide concentration on human health

350–400 ppm	concentration in the external environment
do 1000 ppm	level without an unpleasant feeling
1000–2000 ppm	symptoms of fatigue and decreased concentration, feeling of exhaust air
1200–1500 ppm	the recommended maximum level of CO_2 in indoor areas
2000–5000 ppm	headache occurs
over 5000 ppm	decreased concentration, fatigue, headache

The sudden drop in carbon dioxide concentration at 11:10 am was caused by opening the door to the coupe. From the observation of the course of indoor air temperatures and carbon dioxide concentrations, it is possible, based on experience from similar measurements, to find that people have opened the door to the coupe due to the increasing air temperature and not because of the increase in carbon dioxide. In the next timeframe we can see an increase in carbon dioxide concentrations even though the door from the coupe to the corridor has been constantly open. It can be assumed that if the door was continuously closed to the coupe, the carbon dioxide concentration would reach much higher values.

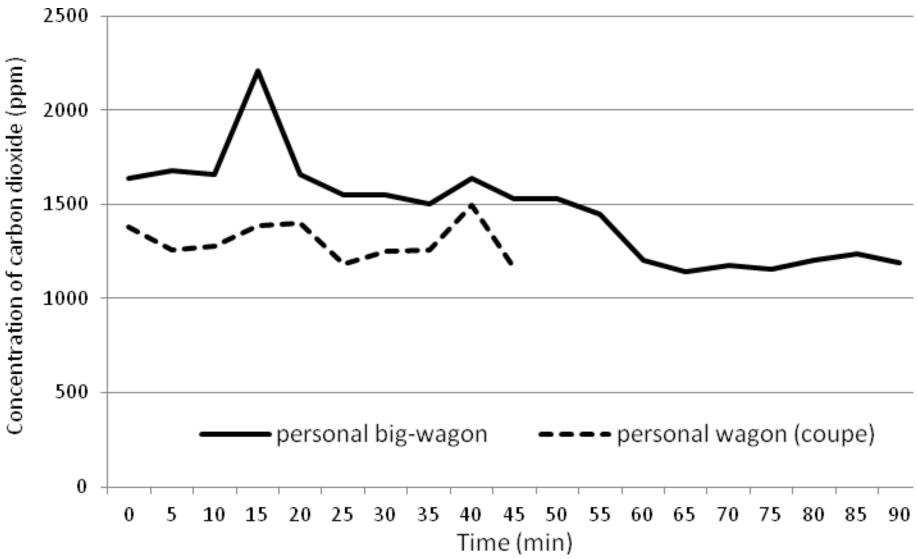

Fig. 5. The measured indoor concentration of carbon dioxide

In the passenger car, all seats were occupied. There were 76 people in the wagon, of which 46 were children. The children sat together in one half of the wagon. In the second half of the wagon were adults and children. At the beginning of the measurement, the device was placed in the first half of the wagon between the children. At 11:25 am the device was moved to the second half of the wagon between adults. The air temperature in the wagon was approximately constant (about 25.5 °C). In the first 60 minutes of monitoring, the carbon dioxide concentration averaged 1633 ppm. In the next 47 minutes, the concentration dropped to an average of 1186 ppm. The decrease in the concentration was due to decreased activity of the children. It is known that increased activity (interview, games, etc.) also increases the production of carbon dioxide.

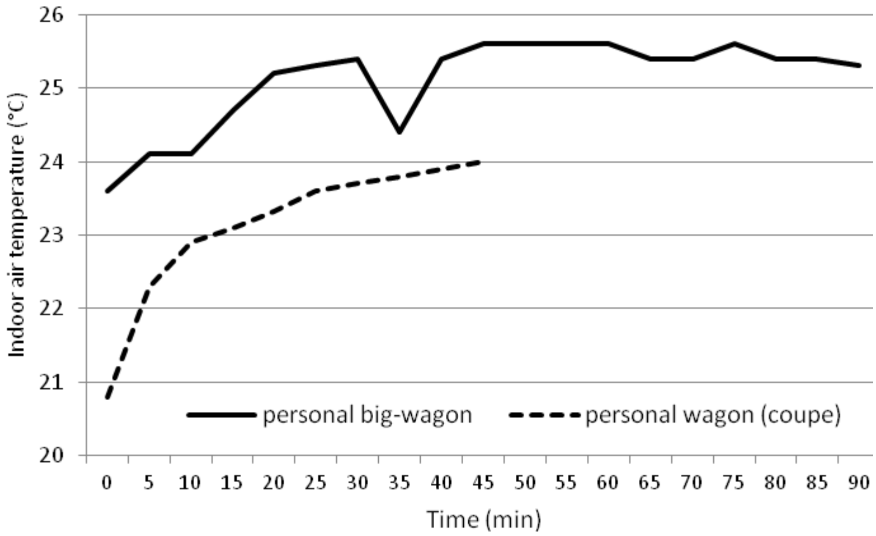

Fig. 6. The measured indoor air temperature

According to the manufacturer's technical parameters of the ventilation device [8], the volume flow rate for the passenger compartment is approximately 2000 m^3/h. If the given value is determined by the number of seats in the wagon, it is 30.3 m^3/h per person. If fresh air at 30 m^3/h per person was supplied to the individual compartments, a given amount of air would be sufficient to provide the required air quality with a carbon dioxide concentration of about 1000 ppm. However, if circulating worn air is mixed into the fresh air, it can be assumed that a given amount of air will be insufficient in terms of CO_2 concentration. Similarly, for the passenger large-wagon according to [8], the volume flow is approximately 2800 m^3/h. If this value is determined by the number of seats in the wagon, it is 36.8 m^3/h per person.

Conclusion. From the monitoring of the indoor environment in the passenger rail car, when the CO_2 concentration and the indoor air temperature were detected, it can be stated that the air condition was inadequate. In both monitored wagons, the CO_2 concentration was greater than 1000 ppm. In the passenger wagon with sections, the average CO_2 concentration was 1305 ppm and the average air temperature was 23.1 °C. In the passenger car, the average CO_2 concentration was 1468 ppm and the average air temperature was 25 °C. Passengers in the passenger compartment were trying to improve the air condition by opening doors from the coupe to the alley, even at the cost of loss of privacy, which suggests that passengers experienced symptoms of fatigue and deterioration in air quality.

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