THE ROLE OF MICROCLIMATE IN THE FORMATION OF INDOOR AIR POLLUTION

by

Oskars KALVA *

Faculty of Geography and Earth Sciences, University of Latvia, Riga, Latvia

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Indoor air quality plays a key role in assessing people's quality of life, as a large proportion of people spend up to 22 hours a day indoors and people are exposed to indoor air almost all day long [1]. People in developed countries spend much more time indoors. Recently, employers are paying more and more attention to ensuring the well-being of employees, as it affects the quality and productivity of their work [2, 3]. Ensuring an appropriate working environment on the part of employers ensures both sustainable social and economic links. Well-being can be affected by various parameters of the indoor environment, in addition to the microclimate, they can be: lighting, noise level, and various odors. However, one of the primary indicators of comfort or discomfort in an indoor environment is thermal comfort or discomfort [4].

Gas stations were chosen as place for measurements because they are considered dangerous for several reasons: gas station territory is potentially hazardous with a high environmental risk and explosion hazard. Working shifts and nights is also considered undesirable for human health as it disrupts the biological rhythms in the human body [5]. In such circumstances, the indoor microclimate and air parameters play a very important role, as spending long hours in inappropriate microclimatic conditions is likely to lead to various long-term health problems for the workers.

Key words*: indoor microclimate, air pollution, aerosol pollution, gas stations*

Introduction

Both indoor air and its quality and composition are closely related to outdoor air. Indoor air is not only polluted by emissions from factories, vehicle exhaust and various mixtures of chemicals that spread abroad but is also polluted by the various particulates and dust that enter the premises from the indoor ventilation, heating, and insulation systems through which this air flows until it enters the indoor environment. The quality of the indoor environment is also influenced by the size of the premises, the number of people employed in the specific premises, as well as the methods and equipment used in the work process [6, 7].

Indoors, people are exposed to relatively even level of pollution at all times, as ventilation systems compensate for the increased levels of pollution, even when the warm season is on, and the rooms are more heavily ventilated and exposed to emissions from the outdoor

*Author's e-mail: oskars_kalva@inbox.lv

environment. During the ventilation process, polluted air is removed from the room and clean air enters. In addition, the operation of ventilation systems helps to reduce the concentration of dust and humidity in the room. It is possible that during the warm seasons, the amount of pollution in the indoor environment is higher due to purely technical reasons, both because of the increased mobility of people and the exchange of outdoor air, and because during the warm season, condensing systems work more intensively and can emit additional pollution [8, 9].

There are many negative effects on human health that are caused by poor quality of indoor air, microclimate and air quality have a direct impact on the health, comfort, and productivity of employees. The reason why these environmental quality indicators are not always given due attention is that unfavorable indoor air conditions have long-term consequences for human health and are not immediately apparent [10, 11]. However, epidemiological studies in Europe in recent years have shown that air pollution is associated with increased mortality and the prevalence of various diseases like respiratory and cardiovascular diseases, the impact of air pollution is also associated with the development of neurodegenerative diseases in different age groups [12]. This is due to rapid industrialization. In the context of the urban environment, road transport is one of the main distributors of various sources of pollution, such as nitrogen dioxide, benzene, polycyclic hydrocarbons [13].

Parameters such as actual air temperature, relative humidity, absolute humidity, maximum and minimum humidity, maximum and minimum air temperature are used to characterize the indoor microclimate. It has been found that a stronger correlation between indoor and outdoor air can be observed under the same climatic conditions when the outdoor temperature is higher. To better define indoor and outdoor climate commitments, various modeling techniques are performed that include both outdoor environmental conditions, such as solar radiation levels, and information about indoor microclimate. However, this type of modeling has revealed specific influencing parameters or conditions, as there are various additional correlations between the parameters in both the outdoor and indoor environments that make it difficult to directly identify features and effects. Determining indoor ambient temperature and microclimate parameters is additionally important, as it is associated with huge energy consumption. The 40% of global energy is consumed to provide an indoor microclimate. Energy is used to provide heating, air conditioning and ventilation. The indoor environment is being studied to create workspaces in which employees are provided with the best possible microclimate and environmental conditions, while reducing excessive energy consumption. In any type of research on the level of well-being and comfort of employees, it is very difficult to find the most suitable indoor environment, as the feeling of comfort for everyone may manifest itself in different environmental factors [14, 15]. Although a huge amount of energy is invested in the operation of air conditioning and ventilation systems, studies show that about 35% of employees are not satisfied with the thermal conditions of their workplaces [16]. The quality of the indoor environment varies indoors, for example, people are exposed to much higher concentrations of pollution in production facilities. Employees are often exposed to pollution for more than 40 hours a week. Workplaces where overtime is most often allowed are usually associated with manufacturing and industry so in reality employees spend even more than the allowed 40 working hours in the most potentially polluted places [17].

A separate type of pollution is particulate matter (PM) pollution, such as from cigarette smoke, but similar pollution is from gas emissions. This is the case at gas stations, where this type of pollution, as well as fuel fumes, escapes into the air all the time. As a result, employees are constantly exposed to unhealthy working conditions. The PM is one of the biggest pollutants from health and environmental perspectives both indoors and outdoors. Long term exposure to PM pollution is associated with different health problems, such as asthma and cardiovascular disease [18, 19]. The ingress of PM into indoor of gas stations is facilitated by the continuous flow of people in the shop during the day which increases air migration through the air [20]. Outdoor air quality in many of the most developed countries has improved significantly over the past fifty years. Pollutants of the outdoor environment are an important influencer of air quality, but with decreasing ambient pollutant levels, the role of pollutants that are formed indoors, is becoming relatively more important for humans in these premises. In addition to pollutants from the outdoor environment, indoor emission sources can degrade air quality as much and even more. Sources that produce indoor air pollution include cooking and cleaning, in addition to emissions from indoor components like building materials, personal care products, consumer electronics [21-24].

Since indoor air and environmental parameters are directly related to outdoor environmental factors, the outdoor environment, and processes specific to gas stations must first be known, because they were chosen as the plots for this study. Gas stations are generally considered to be environmentally hazardous objects with characteristic of air and soil pollution. Air pollution occurs during fuel or gas refueling, when mixtures of different gases escape into the air [25]. The main air pollution at gas stations is the gases produced during the combustion process, especially when burning fossil fuels such as gasoline, diesel, and liquefied petroleum gas. Combustion waste is ash and flue gas. When flue gases are emitted into the air, they contain various oxidation products such as water, NO_x, CO_2, SO_2, as well as substances resulting from incomplete combustion. These substances are called volatile organic compounds. Combustion also releases compounds that do not decompose, such as metals. All these combustion components pollute the environment and have a major impact on air quality. It is possible to make the combustion process more environmentally friendly. This can be done either by cleaning the flue gases, or by improving the combustion efficiency with catalytic converters, or by increasing the combustion temperature, but such methods are limited, and the only way to eliminate the problem of air pollution from combustion products is the introduction of renewable energy resources. Such an action would make the issue of the environmental quality of gas stations irrelevant, as oil products and fuel would be replaced [26, 27].

The aim of the study is to assess whether and how the indoor microclimate and its changes affect the air quality in these premises. During the development of the research, it is planned to understand what are the conditions that affect the indoor microclimate and how it will affect, for example, the formation of aerosol pollution.

Methods

The direct measurement method was used to measure changes in indoor humidity and temperature at gas stations. In the period from September 3, 2018 until April 9, 2019 measurements were performed at four gas stations, at each station over a period of 6 days, 22 hours, and 40 minutes, with a measurement interval of 5 minutes. The PCE Temperature and Humidity Datalogger was used to obtain the data on relative air humidity and temperature changes in premises. This device works with precision of ±0.4 ºC and ±3.0% relative humidity. This device collects instantaneous data, which after the end of the measurement cycle can be easily exported to data analysis programs, in this case IMB SPSS statistics 22 was used for data analysis. Cyclic measurements at each station were repeated four times to obtain a total of 16 independent data sets. In this way, it was planned to obtain the widest possible overview of the variability of indoor environmental indicators, so that it will be possible to see some seasonal trends and sharper differences in parameters.

To determine the indoor air parameters at the gas stations, four gas stations from one company, located in Riga in Pardaugava region, were selected for the work, fig. 1. Stations for this paper were named as gas station X (56º54'44.926; 24º7'23.312), gas station Y (56º54'34.434; 24º5'4.014), gas station Z (56º55'39.391; 24º6'24.864), and gas station Q (56º56'4.302; 24º0'23.27).

Four gas stations of one company were selected, as this is the largest fuel representative in Latvia, thus the company provides the highest possible working environment parameters, which allows to assess the overall situation more objectively with its possible negative effects, as it is expected that the responsible staff have made every effort to eliminate any undesirable factors that could have an additional influence on the fact that gas stations are potentially hazardous locations. Exactly these four stations of Pardaugava region were selected, because each of them differs with its outdoor environmental parameters, which are determined both by the location of the stations in the context of the urban environment and the traffic intensity in the specific place. The choice of stations emphasizes the difference in outdoor environmental parameters, as outdoor environmental parameters play a major role in the quality of the indoor environment.

Figure 1. Station location in Riga, Latvia

To select a period from each station for the correlation analysis, the fact that employees report more about bad feeling at work was taken into action. Employees of station X, station Y and Q believe that a worse feeling is observed in the cold season. Employees of station Z mentioned that the worse feeling was developing in the warm season, therefore the measurement period from the cold season was chosen.

The measuring equipment at the stations was installed behind cash desk, as these are the places where employees spend the longest part of the working day.

The program IMB SPSS statistics 22 was used to analyze the obtained data. The analysis of the main components (PCA) was performed for such parameters as average, maximum, minimum relative humidity outdoors, average, maximum, minimum relative humidity indoors, average, maximum, minimum air temperature outside, average, maximum, minimum air temperature indoors, number of visitors.

Pearson correlation was performed in the SPSS program to assess whether correlations are formed between indoor humidity and temperature in the outdoor environment. Pearson correlation data were obtained for a one-week measurement cycle at each station, as well as for all averages for all measurements. The correlations between indoor and outdoor air temperature, as well as between indoor and outdoor relative humidity, are only shown in the point graphs.

Plume Labs Flow was used to gain insight into aerosol contamination in station premises. With accuracy of 90-95% this device collects data of $PM_{2.5}$ and PM_{10}.

Results and discussion

First stage analysis - microclimate

The first air quality measurements were performed in year of 2018 and 2019 to analyze the microclimate and its changes indoors at gas stations. As mentioned above, the data for analysis were selected from the winter season, because during this time station staff complained much more about the discomfort that could be related to the instability of the microclimate and the increase in the number of aerosols at certain times.

The analysis of the main components shows that there is correlation between such parameters as the maximum indoor air temperature, the average indoor air temperature, and the number of visitors, fig. 2. More customers mean more food ordered and cooking equipment working more intensively, which both increase the average air temperature and at some point, produce maximum temperatures. These could also be considered as the conditions in which the most aerosol particles enter the gas station premises, as the highest air activity is between the indoor and outdoor environment, which takes place through the station door. However, such a relationship between these parameters can be observed only when the differences in microclimatic conditions between the indoor and outdoor environment are not too high, otherwise the changes in air temperature would be much more affected not by the amount of heat generated by cooking equipment but by the parameters from outdoor environment. Also, with a higher flow of customers, the need to operate more cooking equipment (ovens, grills) increases, which could also increase the concentration of aerosols in the air.

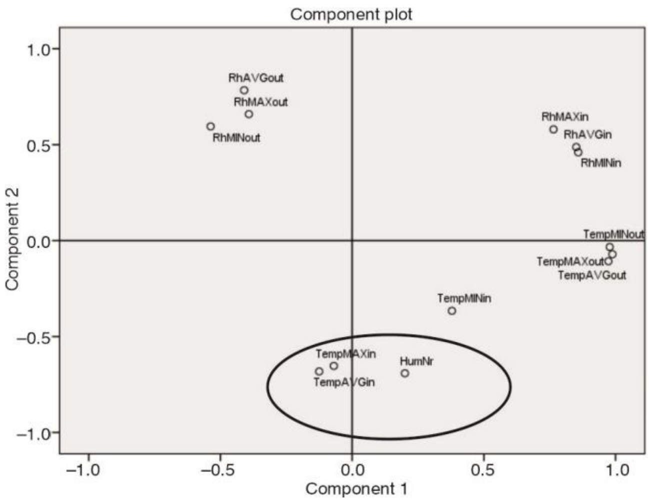

Figure 2. The PCA analysis of all measurement data of the main micrometeorological components for all stations (printout from IBM SPPS)

According to the correlation data, highest correlation between the relative humidity outside and the relative indoor humidity can be seen at the gas station X, tab. 1. This is due to the very warm weather during this period (September 3-10, 2018), the average daily outdoor temperature was 19.09 ºC, so the station door could be set to open during the day, so there could be a direct air exchange between indoor and outdoor air. There is also a high correlation between relative indoor humidity and outdoor temperature, as well as indoor and outdoor air temperature. These relationships can also be explained by the high outdoor temperature mentioned above. This means that in such conditions a very active aerosol transport could be observed at the station. This is in line with studies in China, which have collected data on the formation and accumulation of aerosols, which have confirmed that it is human activity and industrialization that are causing more and more pollution from various aerosols in both outdoor and indoor environments [28]. In the case of gas stations, special mention should be made of particles resulting from the operation of the vehicle's engine.

Table 1. Pearson correlation data for station X in the period September 3-10, 2018

	Temperature outdoors	Relative humidity outdoors	Temperature indoors	Relative humidity indoors
Temperature outdoors	1	**0.802****	0.429**	**0.568****
Relative humidity outdoors	**0.802****	1	0.206**	**0.767****
Temperature indoors	0.429**	0.206**	1	0.360**
Relative humidity indoors	**0.568****	**0.767****	0.360**	1

Note: ** – statistically substantial correlation (p<0.01)

Gas station Z has the highest correlation between relative indoor humidity and outdoor air temperature, as well as between indoor air temperature and outdoor air temperature, tab. 2. As the outdoor air temperature was relatively low at 6.44 ºC in this measurement period (from November 4-11, 2018), the temperature correlation expressed in this case is not related to the direct air exchange between the indoor and outdoor environment, as it was at gas station X in which case the station door could be set to open mode. In the case of gas station Z, the relatively small size of the station, 68.7 m^2, could play a major role, which means that the entry and exit of each customer from the station premises affects the indoor environment much more than at the larger station. As the premises are narrower and the distance to the cash register area from the door is small, the door sensor responds to their movements or presence near the door. If customers actively move around the station premises, the door stays open automatically, so outdoor air may enter the station for a long period of time.

Table 2. Pearson correlation data for station Z in the period November 4-11, 2018

	Temperature outdoors	Relative humidity outdoors	Temperature indoors	Relative humidity indoors
Temperature outdoors	1	0.272**	**0.438****	**0.745****
Relative humidity outdoors	0.272**	1	0.347**	0.208**
Temperature indoors	**0.438****	0.347**	1	0.104
Relative humidity indoors	**0.745****	0.208**	0.104	1

Note: ** – statistically substantial correlation (p<0.01)

The correlation analysis of the gas station Y shows that a strong correlation is visible between the relative humidity outdoors and the indoor humidity, as well as between the relative indoor humidity and the outdoor air temperature, tab. 3. The average air temperature was only +9.41 ºC, which is not very high, so it is doubtful that at some point the station door could have been set to open. However, as the service station is a highly visited station, visited by an average of 1250 people per day during the period under review, so the door has been intense in any case. If looking from a side of indoor microclimate, then the indoor temperature and microclimate in station Y was the most stable of all stations. Another factor that should be mentioned is that this station, like the station Q, has 3 air conditioners, as well as more ventilation hatches, which means that with the correct parameters operational installation is possible to obtain a much more stable environment.

Table 3. Pearson correlation data for station Y in the period September 28, 2018 to October 5, 2018

	Temperature outdoors	Relative humidity outdoors	Temperature indoors	Relative humidity indoors
Temperature outdoors	1	**0.607****	0.112	0.238**
Relative humidity outdoors	**0.607****	1	0.089	**0.509****
Temperature indoors	0.112	0.089	1	0.283**
Relative humidity indoors	0.238**	**0.509****	0.283**	1

Note: ** – statistically substantial correlation ($p<0.01$)

The correlation analysis performed for gas station Q in the measurement period (from October 7-14, 2018) shows that there is a correlation between indoor and outdoor air temperature, as well as between the relative humidity outside and the temperature inside, tab. 4. During the measurement period, the average outdoor air temperature was +11.85 ºC, however, station Q could be one of the most dynamic gas stations in Latvia in terms of the number of customers (because this is the nearest to National Airport), so the operating mode of the door is always very intensive. An additional factor influencing why the outdoor air temperature and humidity of this station can affect the indoor air is that station Q is a station with both a main entrance and an additional entrance from the car park, thus allowing outdoor air to flow. This means that in such conditions very active aerosol transport could be observed at the station, but not so much accumulation of these substances.

Table 4. Pearson correlation data for station Q in the period October 7-14, 2018

	Temperature outdoors	Relative humidity outdoors	Temperature indoors	Relative humidity indoors
Temperature outdoors	1	**0.664****	**0.546****	0.096
Relative humidity outdoors	**0.664****	1	0.391**	0.137
Temperature indoors	**0.546****	0.391**	1	0.321**
Relative humidity indoors	0.096	0.137	0.321**	1

Note: ** – statistically substantial correlation ($p<0.01$)

If compare the obtained results for all stations, then it is visible that in general it is difficult to observe pronounced mutual correlations. This can be explained by the fact that although the measurement periods in all stations were performed in the cold season, the outdoor conditions were different in each case, which clearly causes differences in results even with the same room parameters and station structure. However, it should mention that at the beginning of the study these four gas stations were selected precisely because of their different parameters of the premises (area, structure). Therefore, the differences in measurement results between stations also seem natural. This means that to accurately assess the indoor environmental parameters of an objects and their effects - air temperature, relative humidity, as well as other related indicators such as the number of aerosols indoors, the results will be much more accurate if that object is evaluated. The accumulated data shows that the generalization of the results is not always applicable to all objects, because although the dimensions of the premises in the objects are similar, there is a possibility that different technological solutions are used in each of them, such as ventilation and air conditioning which may affect the measurement results.

Second stage analysis – air pollution

In January of 2022 (from January 3-9, 2022), test measurements were performed to determine the concentration of aerosols in the premises. Station X was chosen as a sample plot, where employees worked with FLOW equipment during the day. The $PM_{2.5}$ and PM_{10} values were measured as well as hourly average values of air temperature and relative humidity were also recorded with a PCE temperature and humidity datalogger, figs. 3 and 4. Data on air temperature and relative humidity outdoors were used to compose the data of the day with meteorological conditions. At present, only indicative measurements have been taken to understand the accumulation trends of aerosol contaminants. The results of measurements show that higher (highest PM_{10} values in morning hours were 20 μg/m^3), but not critical aerosol pollution was observed at the times when station has the highest customer activity, mainly in

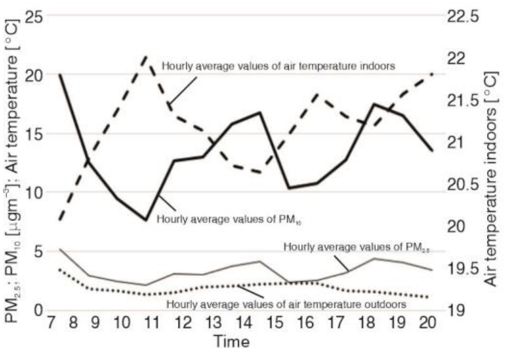

Figure 3. Hourly PM_{10} and $PM_{2.5}$ concentration, air temperature indoors, and outdoors on January 4, 2022, Example of station X,

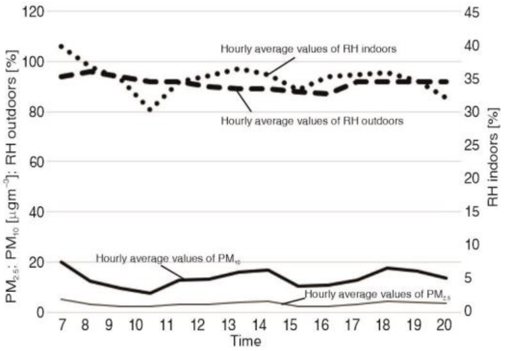

Figure 4. Hourly average PM_{10} and $PM_{2.5}$ concentration, relative humidity (RH) indoors, and average relative humidity outdoors on January 4, 2022, Example of station X

morning and evening hours, when the clients also bought the locally prepared food. These are also the moments when there is a decrease in temperature and an increase in relative humidity during the winter season, which occurs because of more intensive air flow through the store door. In addition, increased customer activity in these areas is leading to more active air circulation from the outdoor environment. At those times, cooking equipment is also operated, which, as the results show, emits additional aerosol pollution which occurs in the indoor environment. To make sure that there was indeed more customer traffic in the store at the specific times when higher aerosol concentrations were observed, a recording from the station's video surveillance system was also checked, confirming that customer traffic was indeed more intense at those times. In the winter season, there is a clear correlation between changes in the microclimate and changes in indoor aerosol concentrations this is confirmed by the observed changes in PM_{10} values. Regarding to $PM_{2.5}$ values, it is visible that these values are quite constant and are much less affected by external factors. The average daily temperature outside was +2.13 ºC, which is much less than in a store where the heating system is set to +21 ºC.

The small size of the stations X is a factor of which, when the flow of customers is activating and the doors remain open for a longer time, cold and humid outdoor air enters the station. At this point, there is an interaction between the microclimate and aerosol concentrations in the air, if the increase in $PM_{2.5}$ concentration at higher customer flows can be explained by the increased operation of cooking appliances at these times, then the increase in PM_{10} values can be explained by aerosol transport from the outdoor environment. The graphs, figs. 3 and 4, show that at times when customer activity is lower, ventilation systems do their job and air quality improves at these times. These results are in line with other studies on the indoor distribution of $PM_{2.5}$, which show that indoor cooking is one of the main sources of $PM_{2.5}$. Particularly high levels of PM are emitted when gas appliances are used for cooking, so $PM_{2.5}$ can be up to twice as high as when cooking on electric appliances [29, 30].

To obtain more accurate and much more analyzable data, it is necessary to perform long-term measurements, the best way to do that is to install several measuring devices, which would help to assess the situation at each station more accurately, when all employees working in one shift would be equipped with measuring devices. In this case, it would be possible to determine more precisely when the concentration of aerosols in the room increases. This study should be continued throughout the year to monitor the actual impact of outdoor air on the indoor environment. It is now clear that such regularities can be assessed in rooms with relatively active indoor and outdoor air circulation, otherwise if the transport of substances is not active, the indoor situation will be more stable and directly dependent on technological equipment (ventilation and conditioning) activities, of course, without excluding the effects that can be caused by the equipment used in the room, as well as the possible fumes of objects and materials which are located in these premises.

Conclusions

Preliminary results show that the indoor microclimate is exposed to the effects of outdoor climate, meteorological conditions, indoor parameters, variability in the number of customers, as well as the complex influence of all these parameters, the connection between indoor microclimate and accumulation of aerosols in building is also visible. Further research is required in this regard across Latvia and EU.

During cold season bigger indoor microclimate inconsistencies and deviations from the permissible norms were observed in all gas stations, which indicates that it is difficult to maintain the station microclimate in a state when only ventilation equipment is operating, but air conditioning equipment is switched off. This could indicate that more aerosols are accumulating in the room during the winter season, but this hypothesis needs to be tested with measurements that will be carried out as the work progresses.

Higher aerosol pollution was observed when the fast-food preparation equipment was operated indoors, as the ventilation systems are not able to remove solid particles from the room immediately. This means that it is very difficult to maintain and ensure even and stable microclimate conditions as well as constant air quality in facilities such as gas stations where people are actively moving between indoor and outdoor environments. It is influenced by many factors, the determining factors of which are the climatic indicators in the outdoor environment, as well as the activity of customers and the intensity of operation of technological equipment at these times.

Infiltration from the outdoor environment through the station door is a significant source of PM10 pollution.

Assessing the effect of the microclimate on PM, it is visible that PM2.5 values are more uniform and their concentration in the room is less dependent on the effects of the influence of outdoor environment.

Active flow of people has a significant effect on PM10 values and their concentration in the air can increase by 50% due to the flow of people.

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