Achievement of Thermal Comfort in the Building Through Interaction with External Factors

Nurin Zecevic 1, Ejub Dzaferovic 1, Azrudin Husika 1, Amira Salihbegovic 2

1 Mechanical Engineering Faculty, University of Sarajevo, Vilsonovo setaliste 9, 71000 Sarajevo, Bosnia and Herzegovina
2 Faculty of Architecture, University of Sarajevo, Patriotske lige 30, 71000 Sarajevo, Bosnia and Herzegovina

nurin.zecevic@gmail.com

Abstract. Building envelope has significant role in the building sector. It represents immediate interaction between outside and inside environment. In dependence of its characteristics and opposed requirements, it affects on achievement of the thermal comfort of inside area and closer environment. Existing standards in the building sector dictate air tightness of an envelope, limiting air infiltration with the aim to save energy, but also influence on the inside environmental quality in situation when optimal air quality cannot be achieved due to the insufficient ventilation of the room. Besides that, building envelope in dependence of its characteristics, under the influence of Sun light, can less or better absorb heat flux and cause the temperature rise on the surface of the building. Specific characteristic of material to absorb and retain solar thermal heat, in urban environments, contributes more and more to the presence of the phenomenon known as urban heat island. For interaction of the building envelope with the environment factors, the building of Mechanical Engineering Faculty was chosen as a case study, on which the measurement of the envelope surface temperature was performed with the aim to empirically confirm presence of higher temperatures on building envelope. At the same time, the measurement of indoor air quality parameters, as carbon dioxide concentration, inside air temperature and relative humidity was performed, to estimate ventilation efficiency of inside area. Results of the measurement have shown the presence of relatively high surface temperature on the building envelope, which is the in accordance with the earlier research about the existence of higher surface temperatures in dependence of its characteristics and environment. Measurement of indoor air quality parameters showed higher carbon dioxide concentrations, especially in winter semester, which values exceeded by 60 % of recommended ones. Higher carbon dioxide concentrations are result of insufficient ventilation of the room, and it is indicator that optimal cooling system with frequent ventilation is necessary criteria that needs to be fulfilled to achieve quality inside environment from the aspect of the comfort, productivity and health of users. In the recent years, there has been noticed evident increase of the outside temperature, especially in urban area due to the construction and characteristics of applied materials in buildings, resulting also in the climate change. It is necessary to emphasize that planners and designers in the conceptual stage of construction or renovation of the buildings, incorporate solutions and decisions about the materialization of the envelope, which will affect on the reduction of urban heat island, considering as one of the energy efficiency measures.
1. Introduction

The choice of material is one of the most complex questions with which is designer concerned. “The question of material as foundation of architecture” has more significance today, due to the wide range of materials and higher awareness about environmental influence of building materials [1]. One of the main criteria on which should be paid attention during the selection of material is influence of materials on environment and on the health of people, because building can in dependence of its material characteristics affect on comfort of inside area and closer environment. Very often in densely built cities, where due to the specific characteristics of building materials to absorb and retain heat, the appearance of Urban Heat Island (UHI) is noticed, phenomenon that is present when the air temperature in urban area is higher than in suburban or rural area. Beside horizontal surfaces like flat roofs, pavements, streets, vertical surfaces or facades that make large part of cities, also affect on environmental conditions due to the direct contact with the surrounding area.

The surface temperature of the building is affected by different factors, as outside air temperature, Sun light, wind and relative humidity, urban components (vegetation, pavement and traffic), inside conditions, orientation, characteristics of materials behind façade etc. Different combinations of these factors, together with specific characteristics of façade (density, specific heat capacity, emissivity, absorption etc) can lead to greater or lesser amount of the heat accumulated in an envelope and as result can have higher surface temperature [2,3]. Due to the thermal mass of usual dark and massive building materials, façade of the building can emit the heat after sunset, specially if there is a weaker wind, it can result with the increase of average air temperature within the city for about 5°C and decrease of the cooling effect of local outside temperature. Without night cooling, human thermal comfort is prolonged, and continuous nights with higher air temperature have serious affect on human health, higher energy consumption for building cooling during summer time, especially in the area where are greater needs for cooling [4,5].

Considering the relation between building materials and health aspect, existing global standards in building sector dictate air tightness of the building, limiting air infiltration with the aim to save energy. Very often these measures are contradictory in situation when with the achievement of energy savings and decreasing carbon foot, there is negative affect on health and productivity of users. Users when feel uncomfortable in the room, will do all necessary activities to achieve comfort, which can result with the higher energy consumption, especially because existing standards for ventilation are minimal recommendations that can not result with the optimal air quality [6]. Pollution of indoor air is considered as one of the first five enviromental risks for users health [7], where influence of unhealthy environment and low air quality is reflected by health problems as asthma, allergies, respiratory diseases, neurological problems, lower concentration and productivity [8,9]. Children in educational institutions are especially sensitive on air pollution because they inhale higher air volume relative to their weight, so concentration of pollution substances can result with larger load on child’s organism [8,9].

Term „health building“ has emerged as a reaction to the Sick Building Syndrome (SBS), with the aim to build a building, where users are minimally exposed to the inside pollution, where the thermal comfort and quality inside environement are provided, and where is the minimum risk of enviromental contamination. Interest in designing and building of healthy building has risen recent years due to the greater needs of users for pleasure with the enviroment where they work and live. There is delicate balance for every designer to ensure that the building satisfies energy requests, but it should not be achieved under the cost of ignoring human needs and enviromental degradation [10]. Simply, energy declaration without declaration related to the inside quality enviroment does not make sense [11].
2. Methodology
As a case study for interaction of the building envelope with the environment factors, the building of Mechanical Engineering Faculty in Sarajevo was chosen. Mechanical Engineering Faculty represents a typical compact architecture of public educational buildings, with typical geometrical form. Total height of the building is 26 m, with rectangle basis and seven floors. Constructive system of the building is consisted of concrete pillars and external walls made of brick, thickness 26 cm, with thermal insulation EPS 10 cm and bright colored finishing silicate plaster. The building is south oriented to the Vlsonovo walkway, characterized by avenue of trees and busy street.

At Mechanical Engineering Faculty, measurement of surface temperature on the façade was performed with the aim to compare and analyze measured values with data from macrolocation or more precise nearest meteorological station Bjelave and to examine if there is a presence of higher temperature values on the building envelope from the UHI aspect.

Also, measurement of indoor air quality parameters, as carbon dioxide concentration, inside air temperature and relative humidity, was performed with the aim to examine if there is presence of higher carbon dioxide concentration as side effect of implemented energy efficiency measures at Mechanical Engineering Faculty. Results of the measurement are compared with permissible values and researches of other authors about the influence of carbon dioxide concentration on the health and productivity of users in educational buildings. Measurement of indoor air quality parameters was performed in two classrooms and one office, but in this article only measured values from one classroom will be analyzed. Orientation of the classroom is east. Classroom has sunshading protection in the form of manually operated portable panels and ventilation is natural. Average number of students in one group was in the range 20-39 during measurements.

3. Measurement
For the measurement of temperature on the façade of the building, used are sensors from company Gemini Data Loggers (UK) Ltd. “Data logger system Tinytag Plus Intrinsically Safe duo channel device for measurement of temperature and relative humidity TGIS-1580”, mounted on all four sides of the building and in chosen offices. Measurement has lasted from July 2015 till September 2017.

Measurement of IAQ parameters for classroom 403 was performed in winter and summer semester of 2016, where measurement in winter semester has lasted from 14th November till 9th December 2016. In summer semester, measurement in the classroom 403 has lasted from 8th -29th May 2017. The aim of performed measurements in two semesters was to compare measurement results in summer semester when the classroom is more ventilated with the results of winter semester when it was heating season and the classroom is less ventilated. Used equipment for measurement of IAQ parameters is OPUS 20-TCO logger, which was mounted in chosen rooms 1.1 m above floor and 1 m far from occupants. Sensor measured values every 10 seconds, and reading of the values was every 60 seconds. According to the standards for educational buildings with natural ventilation, recommendation is that maximum carbon dioxide concentration should not exceed 1500 ppm or according to the standard EN 15251 it should not exceed 800 ppm above outside carbon dioxide concentration level [12,13].

3.1. Analysis of the temperature oscillation on the envelope of the building and comparance with values from the meteorological station
Measured temperature values on the façade of Mechanical Engineering Faculty and from meteorological station Bjelave are shown in Table 1, based on which the comparation was made from the aspect of average, minimum and maximum monthly temperatures. Displayed temperature values are sum of average monthly temperatures from the east, south and west side of the building, as sides that are mostly exposed to the Sun. For comparation, measured values from the year 2016 are used.
because the measurement was performed during the whole year, while the measurement in 2015 has lasted from July till the end of December 2015, and in 2017 the measurement has lasted from January till September 2017.

**Table 1.** Monthly temperature values from façade of Mechanical Engineering Faculty and meteorological station Bjelave (2016).

| Month/year | Average temperature | Minimum temperature | Maximum temperature |
|------------|---------------------|---------------------|---------------------|
| 2016       | Façade  | Bjelave  | Façade  | Bjelave  | Façade  | Bjelave  |
| I          | 0.8     | 1.2      | -12.7   | -2.4     | 17.8    | 4.8      |
| II         | 8.5     | 7.4      | -3.7    | 3.5      | 24.4    | 12.4     |
| III        | 7.8     | 6.1      | -1.5    | 2.2      | 30.2    | 11.1     |
| IV         | 15.3    | 12.9     | 0.4     | 7.0      | 34.4    | 20.7     |
| V          | 16.0    | 13.9     | 2.0     | 8.4      | 35.6    | 20.5     |
| VI         | 22.3    | 19.5     | 9.8     | 13.9     | 38.6    | 26.7     |
| VII        | 24.2    | 21.1     | 11.7    | 15       | 41.7    | 28.9     |
| VIII       | 21.5    | 18.6     | 7.1     | 13.4     | 39.4    | 25.8     |
| IX         | 18.3    | 15.6     | 4.7     | 10.6     | 37.0    | 22.7     |
| X          | 11.6    | 9.8      | -0.1    | 6.2      | 30.6    | 14.9     |
| XI         | 7.4     | 6.1      | -5.5    | 2.3      | 24.5    | 10.8     |
| XII        | 0.4     | -0.9     | -10.6   | -4.4     | 16.6    | 3.3      |
| Avg.       | 12.8    | 10.9     | 0.13    | 6.3      | 30.9    | 16.9     |

In 2016, average measured temperature at façade was higher for 2.0 °C compared to the temperature value of meteorological station Bjelave. From the aspect of minimum temperature, temperature on the façade was lower for about 6.2 °C than at meteorological station and from the aspect of maximum temperature, surface temperature was for 14 °C higher than temperature value at Bjelave.

![Figure 1](image-url)

**Figure 1.** Measured maximum temperature values of façade and the office of Mechanical Engineering Faculty and meteorological station Bjelave (2015-2017).

At Figure 1 are shown temperature values measured on the south façade of Mechanical Engineering Faculty, inside air temperature of the office and values from meteorological station Bjelave. The measurement period includes values from July 2015 till September 2017. Because south
façade is the most exposed to the Sun light, average maximum temperature on the south façade was higher for about 20 °C than at meteorological station Bjelave for the measurement period 2015-2017 or in 2015 it was higher for 19.3 °C, at 2016 for 21.2 °C and in 2017 for 20.3 °C.

For more precise comparison of temperature values and estimation of the presence of higher temperature on the façade, official document of meteorological station Bjelave with extreme highest temperature of specific month was used. Depending on the year, from the document are extracted days that were extreme hottest for chosen months July, August and September and their maximum temperature values were compared with ones measured on the façade of Mechanical Engineering Faculty. In Table 2, measured values for Mechanical Engineering Faculty are shown, as extreme hottest days for July, August and September in 2015, 2016 and 2017.

Table 2. Measured temperature values on south façade and in office of Mechanical Engineering Faculty per characteristic days (2015-2017).

| Day/ year | Daily maximum temperature (°C) | 7:00 | 14:00 | 21:00 |
|-----------|-------------------------------|------|-------|-------|
|           |                               | Façade | Office | Façade | Office | Façade | Office |
| 2015      |                               |        |       |       |       |        |       |
| 18.7.     | 37.3                          | 21.8   | 30.8  | 48.1  | 34.0  | 27.7   | 32.6   |
| 30.8      | 35.7                          | 20.1   | 30.4  | 43.6  | 34.5  | 25.7   | 32.2   |
| 18.9.     | 38                            | 18.5   | 28.3  | 46.9  | 32.6  | 24.3   | 29.6   |
| 2016      |                               |        |       |       |       |        |       |
| 13.7.     | 35.3                          | 20.6   | 28.3  | 42.7  | 30.4  | 28.7   | 30.0   |
| 5.8.      | 33.2                          | 17.9   | 30.4  | 44.6  | 33.1  | 25.3   | 32.3   |
| 14.9.     | 29.0                          | 14.9   | 26.3  | 42.2  | 29.6  | 19.6   | 27.9   |
| 2017      |                               |        |       |       |       |        |       |
| 22.7.     | 35.0                          | 20.7   | 40.1  | 33.6  | 30.4  | 26.9   | 33.6   |
| 10.8.     | 38.2                          | 22.6   | 46.2  | 37.9  | 33.1  | 30.8   | 36.4   |

For analysis, according to the data from meteorological station Bjelave for 2015, 18th July 2015 was officially the hottest day for month July in 2015, with measured maximum temperature for that day of 37.3 °C. Measurement values from façade and meteorological station are divided by hour, at 7:00, 14:00 and 21:00 in accordance with the document of meteorological station Bjelave.

On the Figure 2 oscillations of temperature values on the surface of façade and in the office of Mechanical Faculty, for selected day 18th July 2015, are shown. During the night, average measured temperature on façade was 22 °C. From 7:00 in the morning, temperature on south façade gradually starts to increase by 2-4 °C per hour. At 11:00, temperature on the façade was 41 °C, while at 14:00, temperature reached 48 °C, which is higher for 11 °C than measured maximum temperature of that day. From 15:00, temperature on the façade starts to gradually decrease, first three hours for about 5-9 °C and then 2 °C per hour. At 21:00, measured temperature on the façade was 28 °C.

In the office, during the night period, average air temperature was 31 °C and with the increase of outside temperature, surface temperature of external wall also was increasing. In the period when the highest temperature values were measured on the surface, temperature in the office was 34 °C. At the end of day, with the decrease of outside temperature, decrease of inside temperature was noticed. At 21:00, measured temperature in the office was 32.6 °C. One of the reasons of higher temperature was
due to the start of vacation from the middle of July, when office is not being used and ventilated. Also, office in which the measurement was performed, has large transparent area with inside sunshading device, which further affects on greater absorption of the Sun energy and rising of the inside temperature.

As it is earlier mentioned, envelope of the building represents physical boundary and immediate link between inside and outside environment, that in dependence with its specific characteristics influences on achieving thermal comfort inside of the building and at closer outside environment. Due to the more frequent insulation of the buildings, energy savings are achieved, but also these measures of purposely limiting air infiltration affect also on indoor air quality. At 2011, on Mechanical Engineering Faculty were implemented energy efficiency measures, as thermal insulation, energy efficiency windows and new condensing boiler. The measure which was not included in the Project of energy efficiency was optimal system of cooling, where most classrooms and offices rely on natural ventilation. The aim of the measurement of indoor air quality parameters (IAQ) was to estimate if there are side effects of implemented energy efficiency measures, due to the insufficient ventilation.

3.2. Measurement of the IAQ parameters in the classroom of Mechanical Engineering Faculty

In the classroom 403, measurement of IAQ parameters was performed in winter and summer semester, with the aim to compare measured values in summer semester when the classroom is more ventilated, with the winter semester when natural ventilation does not represent ideal solution. At Figure 3 are shown measured values of IAQ parameters for the classroom 403 in winter semester, and at Figure 4 are shown measured values of IAQ parameters for summer semester.

Measured values were affected by the number of occupants, duration of the class, break, season, use of electric equipment, outside climatic conditions and frequency of natural ventilation of the room. Based on the Figure 3 for winter semester, curves that represent a carbon dioxide concentration have more sharp character, characterized by constant increase of concentration during the lecture, which peak on the graphic mostly reached over 1600 ppm, and in some cases it reached the value 2400 ppm. Lower values are reached during the period of longer breaks or after the end of class.
Curves on the Figure 4 for summer semester, have more looser character than ones for winter semester, which peak averagly reached the value from 1200 ppm. Lower values are reached by ventilation of the room during lectures, break and after the end of class.

In winter semester, students rarely go out of the classroom during the break because classrooms are warmer than the hall, which results with the lower decrease of carbon dioxide concentration for about 50 ppm. Average increase of the carbon dioxide concentration during the lecture was 293 ppm and decrease 88 ppm. In summer semester, increase of carbon dioxide concentration till the middle of lecture was 147 ppm and the decrease till the end of class was 220 ppm, vica versa compared to the winter semester. In winter semester, it took about six hours from the end of class, that the
concentration of carbon dioxide drops by 1052 ppm, to an acceptable concentration of 720 ppm. Usually it is achieved in the late evening hours. In the summer semester, from the end of last class, it took about 2.5 hours for the carbon dioxide concentration to fall by 450 ppm, to a value from 600 ppm.

Measurements from second classroom and office were not detailed and wider analysis. Measurement in the office showed that the maximum carbon dioxide concentration has exceeded the recommended values per 45 % and for the period of three weeks, average maximum carbon dioxide concentration was in the range 1596-2600 ppm. For the classroom 401, first measurement period was characteristic for analysis. After the end of class on Friday, in very short period, air temperature has decreased by 15 °C and relative humidity increased from 17 % to 50 %. At 22:00, measured air temperature was 2.9 °C and 0.9 °C at 06:00 of the following day. Average air temperature during the first measurement period was 1.4 °C, relative humidity 60 % and average carbon dioxide concentration during the weekend was 610 ppm. On Monday, at beginning of the first class, the air temperature was 9.1 °C and after two hours, temperature raised to 24.1 °C and relative humidity fall from 68.8% to 31.7%. The cause of very low air temperature and high relative humidity is due to the left opened windows at the end of class on Friday.

4. Results and discussions

Measured temperature values on the façade of Mechanical Engineering Faculty for period 2015-2017 and values of chosen specific day in July of 2015, have shown higher temperatures on the façade compared to the ones from meteorological station Bjelave. One of the reason of higher temperatures on the façade is due to the characteristics of external wall, because brick has thermal capacity to storage the heat. Energy accumulated inside of external wall during the middle of day, is being released back during the night in the form of heat, warming the area inside of the building and closer environment. According to the [14], it is one of the main impacts of UHI in urban area. Researching results [2] have shown that temperature on the façade behind plaster, with polystyrene insulation as it is a case at Mechanical Engineering Faculty, compared with the uninsulated massive wall made of brick, can be very high due to the lower thermal mass although the color of façade was bright. Simulation results of insulated façade show that temperature of dark colored insulated façade can reach 60°C, which is indicator that the choicement of the façade color has significant influence on the temperature of the façade, but also influence on closer environment.

Comparing maximum values of carbon dioxide concentration in winter and summer semester, it can be concluded that maximum values in winter semester has exceeded the limit of recommended values by 60 %. In summer semester, although there was a rise of carbon dioxide concentration during the class, due to the frequent opened windows and natural ventilation, that value decreased two times more compared to the increase of same. Windows are rarely open during winter period due to the higher temperature differences and because thermal comfort represent priority in comperance with indoor air quality. Natural ventilation during winter period does not represent ideal solution for ventilation, causing possible discomfort by introducing colder outside air. In summer semester, measurement was performed in May, when outside air temperatures were more comfortable and do not have such a great impact on overheating of the classroom. With natural ventilation, it is possible to achieve optimal air temperature and to change stale air by introducing fresh outside air. Because concentration of carbon dioxide is related to the ventilation efficiency, with the implementation of energy efficiency measures, it is necessary to develop optimal cooling system, especially when there are higher outside air temperatures. Beside the cooling system, it is recommended to ventilate the room early morning or late at night, when outside air temperatures are lower and to provide adequate sunshading system.
5. Conclusions

Based on temperature measurements on the façade of Mechanical Engineering Faculty, the presence of higher surface temperatures during summer period was observed, that can have possible influence on increase of ambiental air temperature. Every year a rise of outside air temperature is evident, especially in urban area due to the global warming and specific characteristics of applied building materials. It is necessary to emphasize that designers and planners in conceptual phase or during renovation of the building, incorporate solutions and decisions that will decrease the affect of Urban Heat Island. According to the research of other authors, measurements that lead to decrease of UHI are considered energy efficiency measures, because one of consequences are greater needs for cooling, due to the higher outside air temperature in urban area.

Significance of measurement of IAQ parameters in the classroom of Mechanical Engineering Faculty is reflected through indicating and raising awareness about the influence of implemented energy efficiency measures on indoor air quality, which further reflects on productivity, health and well being of users. Aspect of indoor air quality should be in the focus of interest, because people spend most of their time in the building and they are in the direct contact with inside ambiental conditions. Measurements that are performed at Mechanical Engineering Faculty are indictor of energy efficiency measures influence on inside ambiental conditions from the aspect of carbon dioxide concentration, because measurements did not include efficient system of cooling or raising awareness about frequent ventilation of the room caused by higher air tightness of the building. Measurement results of classroom 401 have shown that human factor has significant influence on “efficiency” of energy efficiency measures, causing higher energy consumption, presence of discomfort and unadequate inside conditions.

Aim of the research was to show how measurements of parameters inside of the building and on the envelope are interrelated. On one side, there is façade that with in dependence of its materialization and specific characteristics influences on closer environment, especially from the perspective of Urban Heat Island. On the other side, there is influence of the same envelope on inside conditions from the aspect of comfort and health. Due to the increased air-tightness of the buildings, heating season has decreased, but there are greater needs for cooling and frequent ventilation of the building as one way to achieve indoor air quality. Building envelope at the same time represents physical barrier and bond for achievement of inside and outside comfort, requiring interplay and interaction of different factors from technical, energy, environmental and human aspect. During designing process, by respecting the principles of sustainability and aiming to achieve success of implemented energy efficiency measures, it is necessary to pay attention not to endanger productivity and health of users and their close surroundings, because then energy efficiency measures are considered as counterproductive.

References
[1] D.M. Roodman and N. Lenssen, “A Building Revolution: How Ecology and Health Concerns Are Transforming Construction”, WorldWatch paper 124,1995.
[2] R.. Van Dijk, “Adaptables, An Adaptive Façade for the Future”, Faculty of Architecture at Delft University of Technology, 2008.
[3] M.H. Din, H. Dzinun, P. Mohanadoss, S. Chelliapan, Z.Z. Noor, D. Ossen and K. Iwao, “Investigation of Heat Impact Behavior on Exterior Wall Surface of Building Material at Urban City Area”, J Civil Enviroment Engg 2:11, DOI: 10.4172/2165-784X.1000110, 2012.
[4] A.Z. Ramirez and C.B. Munoz, “Albedo Effect and Energy Efficiency of Cities”, Sustainable Development – Energy, Engineering and Technologies – Manufacturing and Enviroment, In Tech, ISBN: 978-953-51-0165-9, 2012.
[5] P. Osmond and J. Fox, “Building cool cities for hot future”, The Conversation, 2016
[6] G. Lowitz, “Managing Carbon-Dioxide Risk: What You Should Know”, ONSET HOBO, 2015
[7] United States Environmental Protection Agency (EPA), “Why Indoor Air Quality is important to Schools”, n.d.

[8] G. Kats, “Greening America’s Schools: Costs and Benefits”, A Capital E.Reports, 2006.

[9] M.J. Mendell and G.A. Heath, “Do Indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature”, Indoor Air 2005, pp. 27-52, 2005.

[10] Z. Bako-Biro, N. Kocchar, D.J. Clements –Croome and H.B. Awbi, “Ventilation rates in schools and pupils performance”, Building and Environment 48, pp. 215-223, 2012

[11] W.B. Olesen, “Revision of EN 15251: Indoor Enviromental criteria”, International Centre for Indoor Enviromental and Energy, Department of Civil Engineering, Technical University of Denmark, n.d.

[12] Dž. Bijedić, “Holizam umjesto optimizacije: Integralni pristup u arhitektonskom stvaralaštvu”, Arhitektonski fakultet Univerziteta u Sarajevu, Sarajevo, 2012.

[13] U. Desideri and S. Proietti, “Analysis of energy consumption in the high schools for a provience in central Italy”, Energy and Buildings 34, pp. 1003-1016, 2002.

[14] V. Echarri, A. Espinosa, C. Rlzo, “Thermal Transmission through Existing Building Enclosers: Destructive Monitoring in Intermediate Layer versus Non-Destructive Monitoring with Sensors on Surface”, Sensors 2017, 17 (12), 2848, 2017