The influence of the vertical temperature gradient on working conditions in industrial halls heated with radiant tubes. Case Study

Influența gradientului vertical de temperatură asupra condițiilor de lucru în hale industriale încălzite cu tuburi radiante. Studiu de caz

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DOI: 10.37789/rjce.2023.14.3.10

Abstract. *The article analyses the variation of the vertically temperature gradient, in an industrial space heated with radiant tubes. Data monitoring was done with a workstation equipped with 5 high-performance temperature sensors. The temperature measurement was carried out in 5 distinct points inside/outside the production space, selected in different hypotheses, and a thermovision camera was used at the floor level. The values of the indoor air temperature measured at the level of the ankles, at the level of the work plane and at the level of the head of the people in the productive space fall within the normal limits.*

Key words: temperature gradient, working conditions, industrial halls, radiant tubes

1. Introduction

The heating of industrial spaces generally raises problems in the choice of the heating system [1] due to high energy consumption (over 50% of global energy consumption is due to industrial sector) [2]. For this reason the interest in radiant heating systems has increased in recent years, as these systems have been shown to be energy efficient compared to hot air heating systems [3].

For industrial buildings and the heating systems that serve them, the energy efficiency of the system must be correlated both with ensuring working conditions and with ensuring inside parameters specific to technological processes [4], [5], [6], [7], [8], [9], [10], [11]. On the other hand, only the thermal justification for a heating system related to industrial buildings is not enough to decide whether an investment is economically efficient. Practically, from an energy point of view, the options for choosing the heating system can be compared based on the following criteria [5]:

- annual cost;
- updated total costs;
- payback.

Thus, in order to evaluate the provision of working conditions from the point of view of thermal comfort, the study carries out the verification by in situ measurements of the air temperature at 4 representative heights for the activity carried out in the production hall (at the level of the floor, the ankle, the work plane and at human head level) considered for the case study. The obtained experimental data were monitored and collected for a period of 5 days (February 2023).

2. Description of the space where the temperature is monitored

The monitored production space with an area of 573m^2, and a free height of 5.33m, is set up in a hall with a metal structure, side closures from 40mm sandwich panels, no false ceiling, roof closures from 60/100mm sandwich panels, PVC windows with insulating glass 4x18x4 (52.5 sq m), finished concrete floors without insulation (directly on the ground). The monitored production space (the wing building J1) has a common wall to the North with the wing building H1 production space, it has a common wall with the production space J2 and has 2 external walls to the East towards the inner courtyard and to the West towards the wing building D.

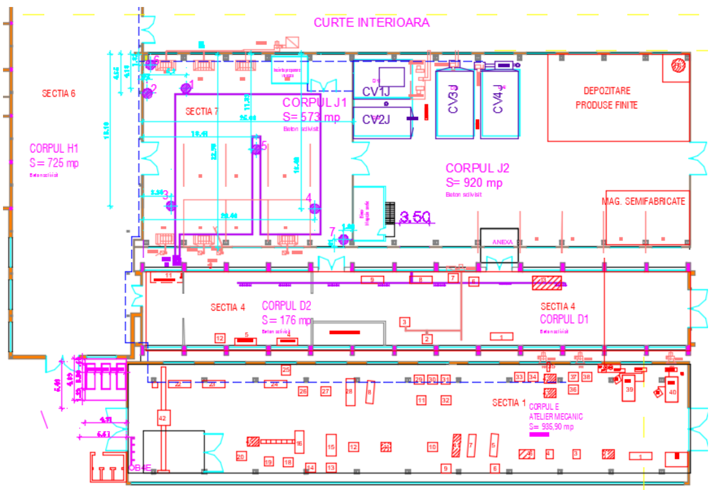


Fig. 1. Site plan

The space is heated with an OHA 20-100 radiant system, with a thermal power of 100kW, powered by natural gas from the public network. The heating system must ensure a temperature of at least 18ºC, at the height of the work surface 1.15-1.25m.

3. Description of the temperature measurement procedure

The temperature monitoring station was executed within the "Automation Laboratory" at the Faculty of Construction in Timișoara, it uses 5 high-performance temperature sensors DS18B20, with a resolution from 9 to 12 bits, with a conversion time of 750 ms to 12-bit, connected to an ARDUINO UNO development board. The measurement of the on vertically temperature in the production space, and of the outside temperature was carried out with the help of the measuring station (at an interval of 5 minutes). 4 temperature sensors (S1, S2, S4, S5) are installed inside the production hall, and one temperature sensor (S3) was used to measure the outside temperature. The sensors inside are placed on a metal pole at the elevations shown in (Fig. 2), the sensor S3 is taken outside the building through a hole made in the outer wall.

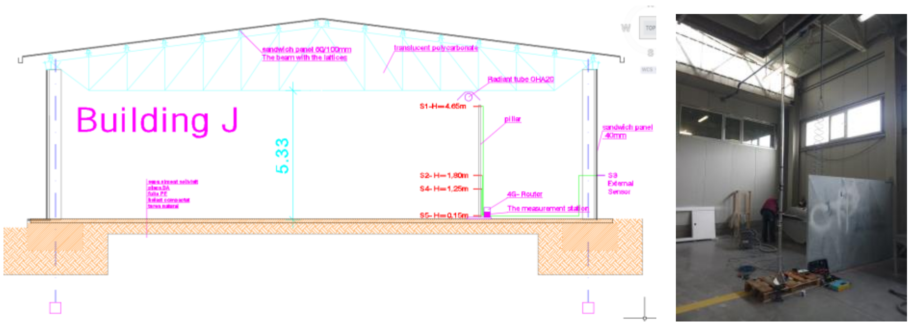


Fig. 2 The measurement station

The vertical temperature measurement was carried out in 5 distinct points inside the production space (P1, P2, P3, P4, P5) which are indicated in Fig 3.

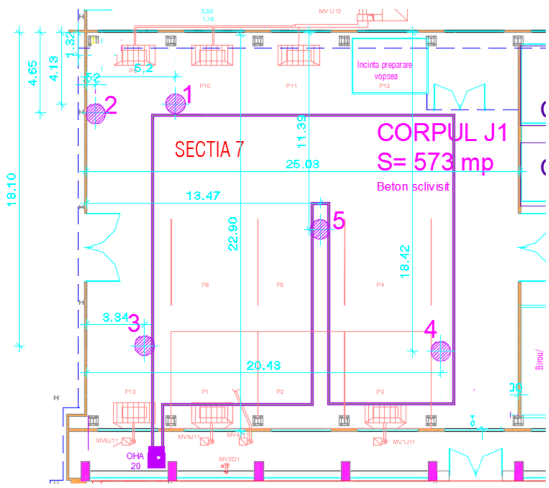


Fig. 3. Location plan of the measuring station

The temperature measurement at the floor level was carried out with a FLIR thermovision camera, which is in the equipment of the Installation Measurements Laboratory at the Timișoara Faculty of Construction. The transmission of the measured values is done in real time with the help of a 4G 300Mbps Wireless TP-Link router. Internet access is provided with a SIM card, data (measured temperatures) are stored on a server through the Google Docs application.

4. Results

The results of the measurements were represented graphically by following the variation of temperature on vertically at the points Pi (i=1...5), where the measuring station was mounted Fig. 4. a), b), c), d), e).

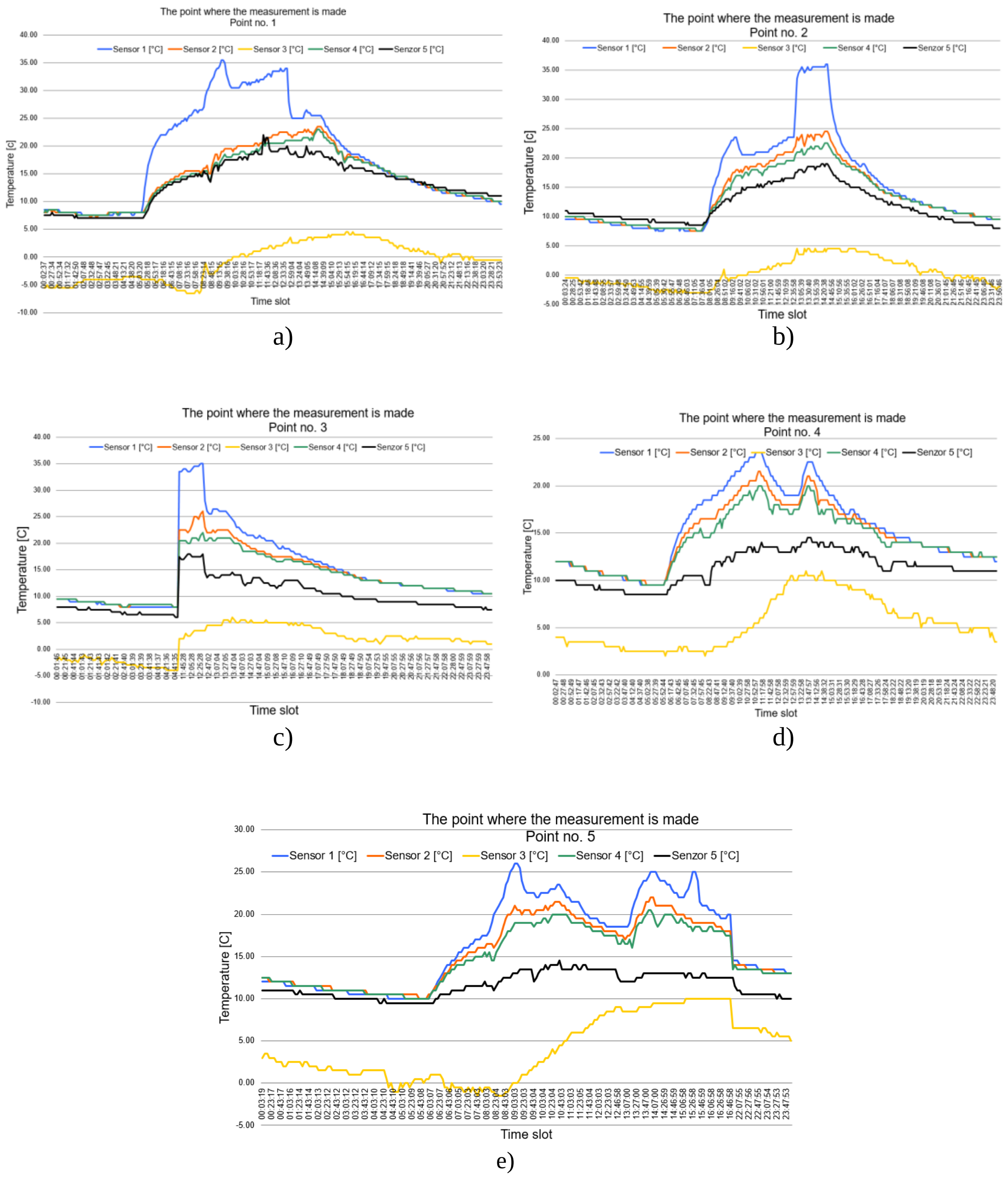
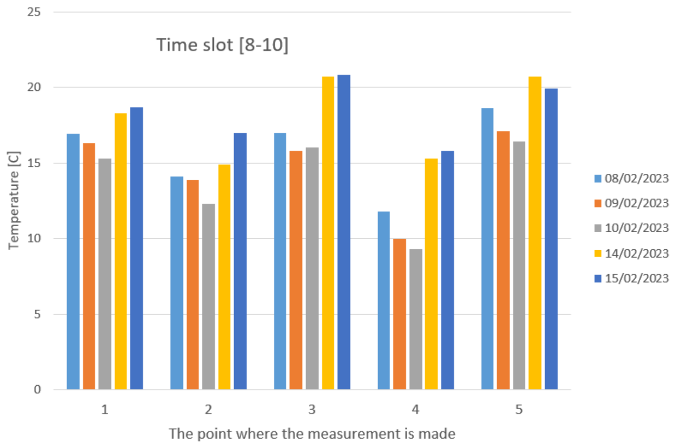
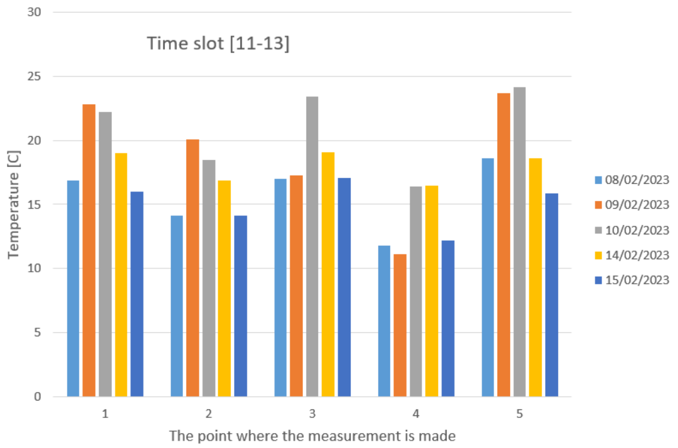


Fig. 4. Temperature measurement in the Pi points
a) Point 1, b) Point 2, c) Point 3, d) Point 4, e) Point 5.

The results of the temperature measurements at the floor level (3 time intervals were targeted, between 8-10, 11-13, 15-17) are represented in Fig. 5.



a)



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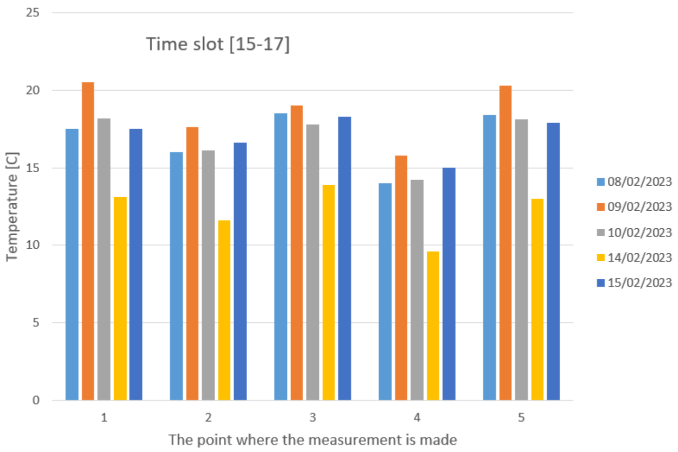
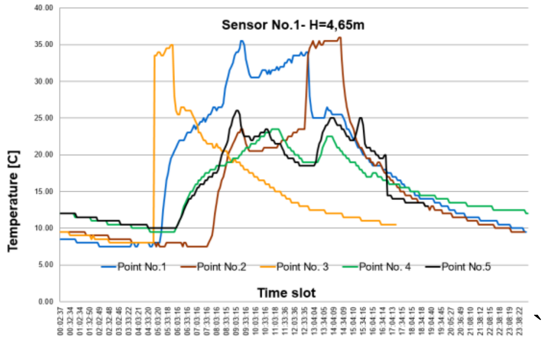


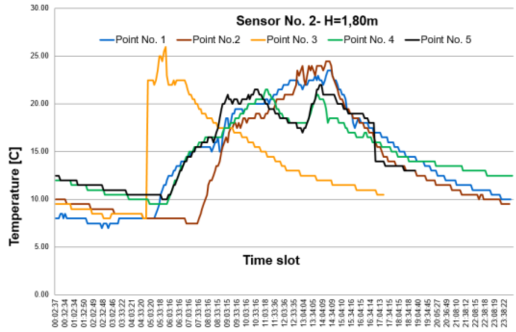
c)

Fig. 5. The temperature measured on the floor
a) time slot 8-10, b) time slot 11-13, c) time slot 15-17

The temperatures recorded by each sensor in the measurement points Pi (i=1...5) were also represented.



a)



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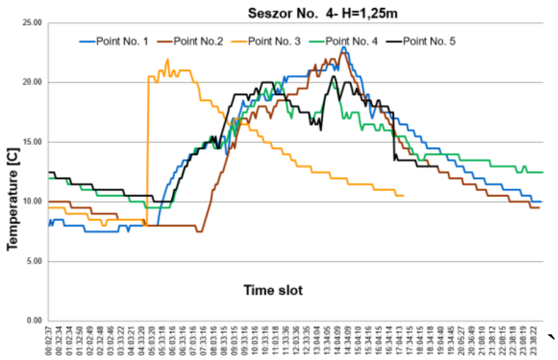

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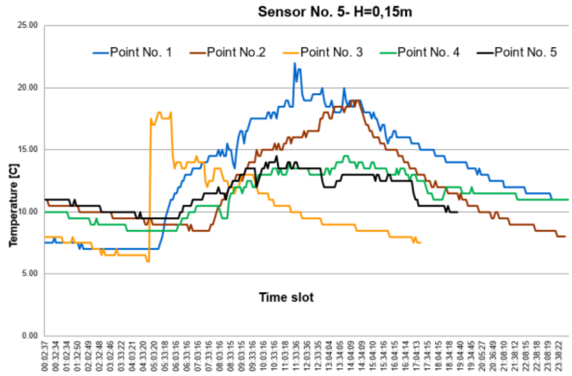

d)

Fig.6. Variation of temperatures in measuring points
a) Temperature measured by sensor S1, b) Temperature measured by sensor S2,
c) Temperature measured by sensor S4, d) Temperature measured by sensor S5

4. Conclusions

The paper analyzes the temperature of the indoor, outdoor air and the finished floor at various points in Section 7 wing building J1, according to Fig.2, equipped with a heating system with radiant tubes. The air temperature is measured during a period of one day, in each mentioned point on 4 levels of height related to the height of the finished floor, namely: h=0.15 m; h=1.25 m; h=1.80 m and h=4.65 m (near the radiant tubes).

The measurement points were selected considering the following working assumptions:

• point P1, near the point of intersection of the longitudinal radiant tube with the transverse one;

• point P2, near the inner wall that separates section 6 from 7 at a distance of 3.25 m from the intersection point corresponding to location 1;

• point P3, under the transverse radiant tube at a distance of 5.5 m from the burner of the radiant tube;

• point P4, on diagonal from location 1, for the configuration of the radiant tube;

• point P5, exposed to thermal radiation in 3 directions, 2 transverse and one longitudinal.

The temperature values at the established points and at the rates previously specified, during the productive period, are given in Table 1, Table 2, Table 3, Table 4 and Table 5.

Table 1

Punctul P1 temperatura exterioară t_e=0 - 4°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	30 - 35
2	1.8	18 - 23
4	1.25	16,5 - 22
5	0.15	14 - 21

Table 2

Punctul P2 temperatura exterioară te=0 – 4,5°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	24 - 36
2	1.8	16,5 – 24,5
4	1.25	15 – 22,5
5	0.15	13 - 19

Table 3

Punctul P3 temperatura exterioară te=2 – 5°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	18 - 35
2	1.8	17 – 26
4	1.25	16 – 21
5	0.15	13 - 17

Table 4

Punctul P4 temperatura exterioară te=0 – 4,5°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4.65	20 - 23
2	1.8	16,5 – 24,5
4	1.25	15 – 22,5
5	0.15	13 - 19

Table 5

Punctul P4 temperatura exterioară te=1 – 9°C

Sensor	Elevation H [m]	Temperature t [°C]
1	4,65	20 - 26
2	1,8	18 – 22
4	1,25	16 – 20
5	0,15	12 - 16

It can be seen from the diagrams presented in Fig. 6, that the lower temperature values are found at the beginning and end of the productive period, when the heating systems starts and stops.

The heating installation works with indoor air temperature control, in which case certain temperature variations occur that generate the minimum and maximum values during the working program period.

The graphs of the temperature gradient corresponding to the average values of the air temperature in the time interval 8 – 16, considering the work schedule of the productive personnel in the mentioned locations, were built. Air temperatures at heights h=0.15 m are taken into account; h=1.25 m; h=1.8m and h=4.65m; as well as the average temperature of the finished floor.

From the temperature gradient graphs in Fig. 7 a), b), c), d), e), it is observed that the shape of the temperature variation curve on the height of the analyzed productive space is similar with the difference that there are changes in the indoor air temperature in the vicinity of the floor, respectively at a height above 4.5 m.

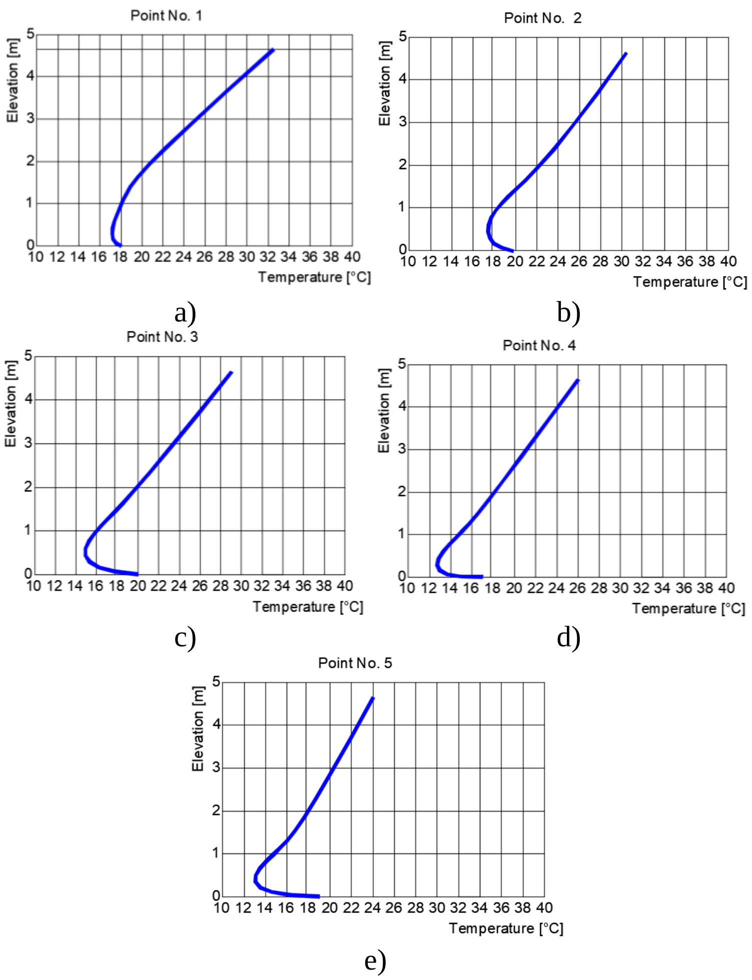

Fig.7. The temperature gradient corresponding to the average values of the air temperature in the 8 – 16 time interval

a) Measurements in P1, b) Measurements in P2 , c) Measurements in P3, d) Measurements in P4, e) Measurements in P5

The value of the floor temperature for the 5 specified points are in the range of 17 - 20ºC, a suitable temperature for the productive space. In all cases analyzed, it was observed that the temperature of the floor is higher than that of the air at a height of h=0.15 m, a phenomenon that is due to the radiant system that has the effect of heating the floor during the period of work, a fact that leads to a secondary radiation at the level of the finished floor.

Indoor air temperature at ankle level, at approx. 0.15 m from the finished floor, varies by location in the range of 15 – 19ºC.

At the level of the working plan, at approx. h=1.25 m, the temperature is in the range of 17.5 – 19.5ºC.

The temperature at the people head level, in the production space is also it has been verified, this being 16.5 - 26ºC, which falls within the normal limits regarding thermal radiation at the head level.

Practically, the air temperatures on the height of the analyzed productive space, in the specified locations, have values that fall within the parameters corresponding to the productive process, considering the high heat losses of the industrial building that is not properly thermally insulated.

A decrease in the internal temperature is observed in case of non-operation of the heating installation, due to the insufficient thermal insulation of the analyzed industrial hall, which leads to lower temperatures in the morning at the beginning of the work schedule, especially at the level of the ankles (h=0.15 m) as well as during the night.

References

[1] L. Yemao, X. Jianjun, F. Hao, S. Yingbo, J. Yi, "Case study on industrial surplus heat of steel plants for district heating in Northern China", in Energy and Buildings, vol. 102, pp. 397-405, 2016.

[2] Q. Wanga, Y.J. Hua, J. Hao, N. Lv, T.-Y. Li, B.J. Tang, "Exploring the influences of green industrial building on the energy consumption of industrial enterprises: A case study of Chinese cigarette manufactures", in Journal of Cleaner Production, vol. 231, pp. 370-385, 2019.

[3] M Bojic, D. Cvetković, M. Miletić, J. Malešević, H. Boyer, "Energy, cost, and CO 2 emission comparison between radiant wall panel systems and radiator systems", in Energy and Buildings, vol. 54, pp. 496-502, 2012.

[4] S. M. Tulevech, D. J. Hage, S. K. Jorgensen, C. L. Guensler, R. Himmler, S. H. Gheewal, "Life cycle assessment: a multi-scenario case study of a low-energy industrial building in Thailand", in Energy and Buildings, vol. 168, pp. 191-200, 2018.

[5] A. Filipovici , S. M. Țoropoc, M. Adam, D. Rusen, D. Tokar, A.Tokar, "Study on Thermal Comfort in Industrial Buildings, Heated by Radiation",WMCAUS - IOP Conf. Series: Materials Science and Engineering, vol. 1203, Article ID 022089, 2021.

[6] . R. d'Ambrosio Alfano, B. W. Olesen, B. I. Palella, G. Riccio, "Thermal comfort: Design and assessment for energy saving", in Energy and Buildings, vol. 81, pp. 326-336, 2014.

[7] C. Becchio, D. G. Ferrando, E. Fregonara, N. Milani, C. Quercia,V. Serra, " The cost optimal methodology for evaluating the energy retrofit of an ex-industrial building in Turin", in Energy Procedia, vol. 78 , pp. 1039 – 1044, 2015.

[8] I. Sarbu, A. Tokar, "Numerical modelling of high-temperature radiant panel heating system for an industrial hall", International Journal of Advanced and Applied Sciences, vol. 5, pp. 1-9, 2018.

[9] N. Kampelis, K. Gobakis, V. Vagias, D. Kolokotsa, L. Standardi, C. Cristalli, F. Montagnino, F. Paredes, P. Muratore, L. Venezia, M. Kyprianou-Dracou, A. Monteno, A. Pyrgou, Th. Karlessi, M. Santamouris, "Evaluation of the performance gap in industrial, residential & tertiary near-Zero energy buildings", in Energy and Buildings, vol. 148, pp. 58-73, 2017.

[10] I. Dincer, D. Erdemir, "Chapter 3 - Energy Management in Buildings", in book Heat Storage Systems for Buildings, pp. 91-113, 2021.

[11] D. Chinese, G. Nardin, O. Saro, "Multi-criteria analysis for the selection of space heating systems in an industrial building", in Energy, vol. 36, Issue 1, pp. 556-565, 2011.