

Seasonal Effects of Urban form (H/W Ratio) on Outdoor Thermal Environment (MRT and AT) in a Hot-Arid Climate: The Case of Biskra, Algeria

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Abstract:

Urban morphology plays a major role in shaping outdoor thermal environments in hot-arid cities through its influence on solar exposure, airflow, and heat storage processes. This study investigates the seasonal relationship between urban form, expressed by the height-to-width ratio (H/W), and outdoor thermal conditions represented by Mean Radiant Temperature (MRT) and Air Temperature (AT) in Biskra, Algeria. Numerical simulations were performed using ENVI-met for three residential neighborhoods characterized by different urban configurations. Correlation and regression analyses were applied to quantify the relationship between H/W ratio and thermal variables during summer and winter periods. The results showed significant thermal differences between the investigated neighborhoods. In winter, neighborhood N1 recorded the highest MRT and AT values, estimated at 55.48°C and 22.22°C, respectively, while N3 exhibited the lowest values. Similarly, during summer, N1 showed the highest MRT and AT values, reaching 67.59°C and 41.04°C, whereas N3 recorded the lowest thermal conditions. Statistical analysis revealed a strong negative correlation between H/W ratio and MRT during summer $R=-0.895, R^2=0.801$, while AT also exhibited a very strong inverse relationship with H/W $R=-0.985, R^2=0.971$. In winter, MRT responses became weaker, whereas AT showed a positive relationship with H/W, indicating enhanced heat retention within compact urban canyons. The findings demonstrate that compact urban forms can effectively reduce summer thermal stress while improving winter thermal retention, highlighting the importance of climate-responsive urban design strategies in hot-arid environments.

1. Introduction

Urban thermal environments in hot-arid regions are strongly shaped by urban morphology and canyon geometry[1], which directly influence solar exposure, airflow patterns, heat storage, and pedestrian thermal comfort[2]. In desert cities such as Biskra, Algeria, rapid urbanization combined with increasing climatic stress has intensified the need to better understand the interaction between urban form and outdoor thermal conditions[3]-[4]. Consequently, numerous studies have investigated the relationship between urban morphology, microclimate, and thermal comfort within the study area. Several previous studies closely related to the present research have been conducted in Biskra[5]. Among the most significant contributions are the works of Khalissa Hamel, Mofidah Boukhabla[25],

and Mohamed Al-Hadi[6], which primarily focused on the effects of street geometry, urban compactness, vegetation, and environmental characteristics on outdoor thermal comfort and the urban heat island phenomenon[7]. Among the most relevant studies, investigated the compact city concept as a sustainable urban form for arid regions[8]. Later, examined the influence of palm groves and building density on urban microclimatic behavior in oasis environments[9]. Similarly, analyzed the role of vegetation in improving outdoor thermal conditions through urban microclimate thermal modeling[10], using Republic Street in Biskra as a case study. In another study, [11] investigated the energy balance behavior of open urban street canyons in Biskra, Algeria. More recently, [12] explored the potential impacts of climate change on outdoor thermal comfort in arid regions[13]- [15]. Although these studies have

provided valuable insights into urban climate behavior in Biskra, several research gaps remain insufficiently addressed. Previous investigations mainly focused on street geometry, urban openness and enclosure, vegetation effects, and their relationship with thermal comfort indicators and the urban heat island phenomenon. However, limited attention has been paid to the direct statistical relationship between urban form parameters, particularly the height-to-width ratio (H/W), and outdoor thermal variables such as Mean Radiant Temperature (MRT) and Air Temperature (AT), especially under seasonal variability between summer and winter conditions. Furthermore, the combined influence of urban geometry on both radiative and atmospheric thermal responses has not yet been comprehensively quantified using regression-based statistical approaches. This limitation highlights the need for further investigation into the seasonal thermal performance of different urban forms in hot-arid environments. The main objective of this research is to develop a deeper understanding of how neighborhood urban form influences outdoor thermal conditions, particularly Mean Radiant Temperature (MRT) and Air Temperature (AT), across different seasons in a hot-arid climate. More specifically, the study aims to: Investigate the influence of the urban form aspect ratio (H/W) on outdoor thermal conditions at the neighborhood scale; Analyze the seasonal variation of thermal responses during summer and winter periods; Establish statistical and regression relationships between urban geometry parameters and thermal indicators (MRT and AT) [16]- [24].

2- Materials and methods

2.1. Study area.

The city of Biskra is located in southeastern Algeria[26], approximately 430 km from the national capital, Algiers. Biskra is considered a strategic link between northern and southern Algeria and has historically been referred to as the “Gateway to the Desert” [27]-[28]. The city is situated in the northern part of Biskra Province at approximately 5°43’ east longitude and 34°51’ north latitude. According to the Köppen Climate Classification, Biskra has a hot desert climate characterized by extremely hot summers and mild winters. The study sample included three urban neighborhood fabrics located in the city center area, representing different building-density patterns. These neighborhoods are: 1) Al-Istiqlal (N1), 2) Al-Nasr (N2), and 3) Al-Zamala (N3). The selected neighborhoods exhibit different urban forms and, consequently, different height-to-width (H/W) ratios. The samples were arranged in

descending order according to urban density, from the highest to the lowest density.

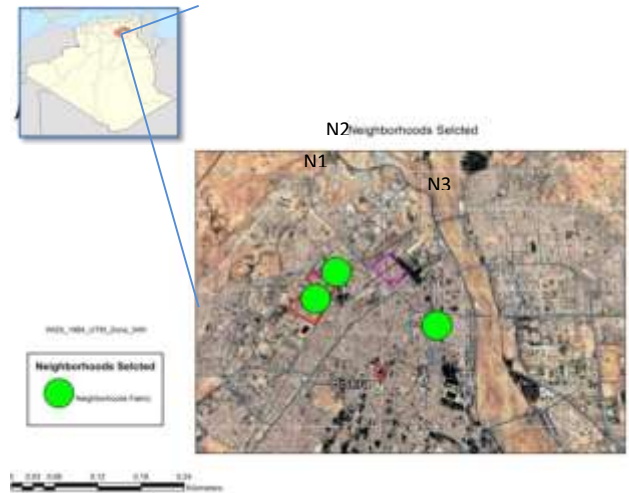


Figure 1. The location of Biskra city along with the selected

2.2.The measuring stations.

A total of 30 measurement stations were selected, as shown in the following figure, with 10 stations distributed within each neighborhood to measure the climatic factors. The measurement stations were arranged sequentially along the central area of each neighborhood and in different orientations to ensure accurate and representative average values of the climatic parameters for each urban fabric. Measurements were recorded every two consecutive hours over a 24-hour period. Data collection was conducted during two different seasons: 25–26 July 2021 for the summer season, and 27–28 February 2021 for the winter season. Table 1 presents the average technical parameters of each neighborhood[29].

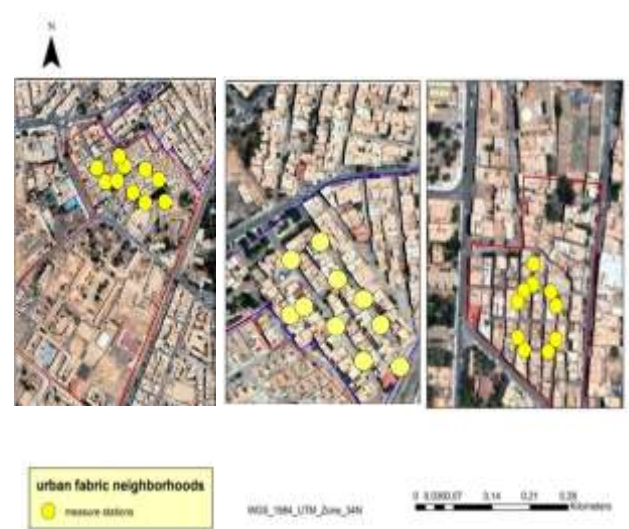





Figure 2. The measuring stations within urban fabric.

Table 1. The Technical Card of Neighbourhood

average	Al-istqala Neighbourhood N1	Al-Nasr - Neighbourhood N2	Al-Zamala Neighbourhood N3
BD	12/ha	35.51/ha	59.52/ha
floor	1	2	2+7R
H	3,6	8.33	8.33
W	9	8.16	3,8
H/W	0,40	1,02	2,1
Dir-tion	Nw/Ss	Nw/Ss	N/S
S,V,F	0,77	0,42	0,22
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3. Methods.

The research methodology adopted in this study is based on three main stages. The first stage involved field measurements of climatic factors, including air temperature, relative humidity, and wind speed, during two seasons of the year: winter and summer. Air temperature data were collected using a Testo 480 device. In the second stage, numerical modeling and simulation were carried out for the three selected neighborhoods using ENVI-met software in order to analyze the remaining outdoor thermal environment parameters[30].

Finally, statistical modeling and regression analysis were performed to determine the interaction between urban density, represented by the height-to-width ratio (H/W), and outdoor thermal conditions, particularly Mean Radiant Temperature (MRT) and Air Temperature (AT), across different seasons. In this analysis, the H/W ratio was considered the independent variable, while (MRT, AT) was treated as the dependent variableS, with the aim of statistically evaluating the effect of neighborhood urban form on outdoor air temperature.

3.1.Simulation settings and validation.

ENVI-met software was employed to perform numerical modeling and microclimatic simulations for the three selected neighborhoods in order to investigate outdoor thermal conditions, with particular emphasis on thermal parameters, namely Mean Radiant Temperature (MRT) and Air Temperature (AT) within each urban configuration. ENVI-met is a three-dimensional microclimate simulation tool widely used for analyzing interactions between urban morphology, surface characteristics, atmosphere, and vegetation at the neighborhood scale. The software enables the construction of detailed virtual urban environments, including buildings, streets, open spaces, and vegetation elements, in order to predict outdoor thermal environmental conditions and assess pedestrian-level microclimatic performance.

One of the major advantages of ENVI-met is its capability to generate high-resolution and reliable microclimatic simulations with considerable accuracy in representing urban thermal processes[31]. The model has been extensively applied in urban climate studies due to its effectiveness in simulating radiation exchange, airflow dynamics, heat storage, and surface-atmosphere interactions within complex urban environments.

Tables 2 and 3 summarizes the main simulation settings and input parameters adopted in the ENVI-met model, and detailed configuration parameters used for the numerical simulations and model validation procedures.

3.2. The Correlation and Regression Analysis.

Correlation analysis is a statistical method used to analyze the relationship between two continuous variables. It determines if there is a relationship between the variables and measures the strength and direction of that relationship. using the following equation:

$$r = \sum (x - \bar{x})(y - \bar{y}) / \sqrt{\sum (x - \bar{x})^2} \sqrt{\sum (y - \bar{y})^2}$$

Regression analysis is a statistical technique used to examine the relationship between a dependent variable and one or more independent variables [32]-[34]. It helps explain how changes in the independent variable affect the dependent variable and allows predictions to be made. In this study, linear regression analysis was performed using the average values of the independent variable, (H/W), measured at different points within the three neighborhoods. These values were compared with the average daytime values of the dependent variables, outdoor thermal conditions, particularly (MRT, AT). The regression coefficient (B_1) represents the amount of change in the dependent variables (MRT, AT) resulting from a change in the independent variable (H/W).As following equation:

$$y = \beta_0 + \beta_1 X + e$$

Where

y = the dependent variable	r =	correlation coefficient
x = the independent variable	x =	values of the x-variable in a sample
b ₀ = the intercept	\bar{x} =	mean of the values of the x-variable
b ₁ = the slope	y =	values of the y-variable in a sample
e = the error term	\bar{y} =	mean of the values of the y-variable

To validate the output of the ENVI-met urban model, a comparison was conducted using field measurements collected on 28–February and 2021

25–26 July 2021. According to ASHRAE Guideline 14, a simulation model is considered valid when the hourly Mean Bias Error (MBE) values remain within ±10% and the hourly Root Mean Square Error (RMSE) values are below ±30% [35]–[36]. The results of the validation process are presented in Table 3.

Table 2 : The simulation settings and parameters inputs in the envi-met model

Parameters	Al-Istiqlal neighborhood (N1)	Al-Nasr neighborhood(N2)	Al-Zaima neighborhood (N3)
3D model			
Date of Simulation	25/07/2021 26/07/2021	25/07/2021 26/07/2021	25/07/2021 26/07/2021
Start time	05:00 AM	05:00 AM	05:00 AM
Total simulation time (hour)	24	24	24
Area grid boundary	1,34, x 20, z 25		
Size of grid cells in meter	dx=3,00 dy=3,00 dz=3,00 base length=6,00		
Wall material	Albino 0,2		
Roof material	Albino 0,2		
Soil profile	Albino values as follow: pavement 0,5, asphalt 0,2, sand 0,2		
Wind speed at 10 m height	1,1 acc following weather station records of Biskra's Airport		
Wind direction	135o from North		
Boundary length	0,07		
Single forcing air temperature (°C)	Min 33,00 at 06:00, Max 45,00 at 14:00		
Nothing grids	None were used since no buildings are placed near the edge of the model.		

Table 3 : accuracy of a simulation Envi-met model.

Simulation model validation						
Indices	(N1)		(N2)		(N3)	
RMSE	0,78	3,26%	0,61	2%	0,67	2,43%
NMBE	-	-	0,08	0,43%	0,19	1,02%
	0,15	0,78%				

4. Results

4.1. Average Outdoor Thermal Variables (MRT and AT) During Winter and Summer Daytime Periods.

Figure 3 presents the simulation results of the outdoor thermal variables, namely Mean Radiant Temperature (MRT) and Air Temperature (AT), for the three investigated neighborhoods during the winter daytime period.

The results indicate that Al-Istiqlal neighborhood (N1) recorded the highest average Mean Radiant Temperature (MRT), estimated at approximately 55.48°C during daytime hours, followed by neighborhood N2 with an average value of about 40.36°C, while neighborhood N3 exhibited the lowest MRT value, estimated at approximately 20.71°C.

Similarly, the graphical representation shown in Figure 3 demonstrates that neighborhood N1 also recorded the highest average Air Temperature (AT), estimated at 22.22°C, followed by N2 with an average value of approximately 17.83°C, whereas

N3 showed the lowest average AT, estimated at approximately 17.40°C.

The observed variations in MRT values indicate significant differences in radiative heat load between the investigated urban configurations. Mean Radiant Temperature (MRT) is considered one of the most important indicators of outdoor thermal conditions, as it reflects the combined effects of solar radiation and surrounding surface temperatures on the pedestrian thermal environment. Furthermore, MRT strongly influences surface heating intensity, outdoor thermal comfort, and the development of the Urban Heat Island (UHI) effect within urban areas.

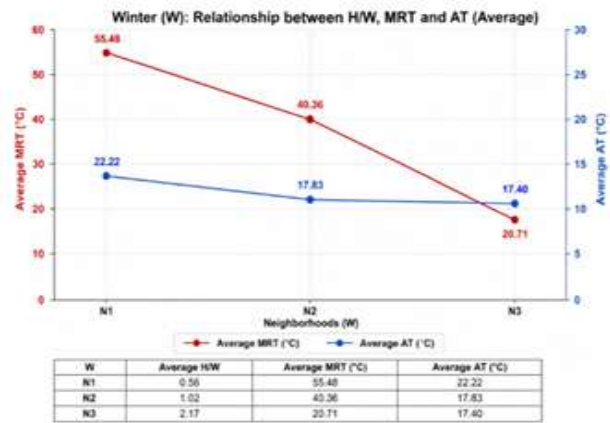


Figure 3. Average of (MRT and AT) During Winter.

Figure 4 presents the simulation results of the outdoor thermal variables, namely Mean Radiant Temperature (MRT) and Air Temperature (AT), for the three investigated neighborhoods during the summer daytime period. The results indicate that Al-Istiqlal neighborhood (N1) recorded the highest average Mean Radiant Temperature (MRT), estimated at approximately 67.59°C during daytime hours, followed by neighborhood N2 with an average value of about 50.96°C, while neighborhood N3 exhibited the lowest MRT value, estimated at approximately 43.41°C. Similarly, the graphical representation shown in Figure 4 demonstrates that neighborhood N1 also recorded the highest average Air Temperature (AT), estimated at 41.04°C, followed by N2 with an average value of approximately 39.75°C, whereas N3 showed the lowest average AT, estimated at approximately 38.28°C.

4.2. Results of Correlation and Regression Analyses.

A statistical regression approach was employed to analyze the relationship between H/W ratio and thermal variables (MRT and AT) based on field-based or simulated urban climate data at

neighborhood scale. The results reveal a significant inverse relationship between H/W ratio and MRT, indicating that increased urban enclosure leads to a

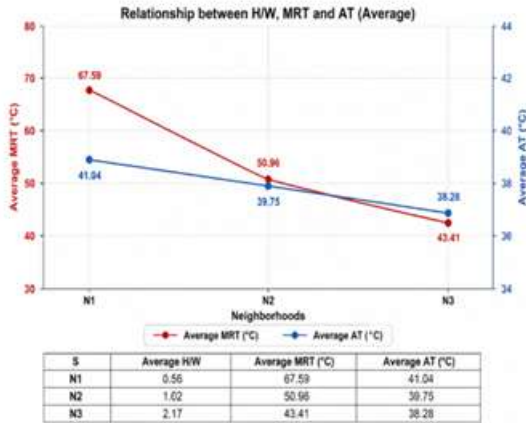


Figure 4. Average of (MRT and AT) During summer.

reduction in radiative heat exposure due to enhanced shading, and lower net radiation flux at pedestrian level. The regression model shows a negative slope (-1.62), confirming that compact urban forms effectively mitigate radiant heat stress under high solar load conditions.

Conversely, seasonal analysis highlights a contrasting wintertime behavior, where higher H/W ratios contribute to increased air temperature through reduced wind penetration, enhanced longwave radiation trapping, and improved heat retention within urban canyons. This seasonal duality demonstrates that compact urban morphology simultaneously reduces overheating in summer while improving thermal conditions in winter, although through different physical mechanisms. Tables 4 and 5.

Table 5 : correlation analysis results of MRT with H/W.

Independent Variables	Dependent Variables	R	R2	Constant	B
H/W	MRT _{summer}	-0.895	0.801	67.79	-11.79
	MRT _{winter}	-0.186	0.035	46.08	-1.62

The statistical correlation analysis revealed that the H/W ratio exhibits a strong and statistically significant negative relationship with Mean Radiant Temperature (MRT) during the summer season, with correlation results of $R=-0.895$, $R^2=0.801$, $p<0.05$. In contrast, during winter, the relationship becomes weak and statistically non-significant, as indicated by $R=-0.186$, $R^2=0.035$, $p=0.632$.

Similarly, the analysis showed that the H/W ratio has a strong statistically significant negative relationship with Air Temperature (AT) during summer, whereas a positive relationship was observed during winter. The correlation results were $R=-0.985$, $R^2=0.971$, $p<0.001$ for the summer season and $R=0.754$, $R^2=0.569$, $p<0.019$ for the winter season. The regression analysis further confirmed the inverse relationship between the H/W ratio and MRT in both summer and winter seasons. The obtained regression equations were:

Summer:

$$Y=67.79-11.79X$$

Winter:

$$Y=46.08-1.62X$$

Table 4 : correlation analysis results of AT with H/W.

Independent Variables	Dependent Variables	R	R2	Constant	B
H/W	AT _{summer}	-0.985	0.971	41.49	-1.49
	AT _{winter}	0.754	0.569	17.72	1.46

These equations indicate that increasing the H/W ratio contributes to reducing MRT values, although the cooling effect is considerably stronger during summer than in winter. Regarding Air Temperature (AT), the regression analysis demonstrated a negative relationship with the H/W ratio during summer and a positive relationship during winter. The corresponding regression equations were:

Summer:

$$Y=41.49-1.49X$$

Winter:

$$Y=17.72+1.46X$$

These findings suggest that compact urban forms characterized by higher H/W ratios contribute to lowering outdoor thermal conditions during summer through increased shading and reduced solar exposure, while in winter they may enhance heat

retention and slightly increase air temperature within urban form.

5. Discussion

These findings highlight the importance of seasonally adaptive urban design strategies in hot arid climates. Urban Climate Studies may be considered beneficial in terms of outdoor thermal comfort during winter. Understanding that urban density is not inherently "good or bad". It depends on: radiation, wind, and season. The same urban form (compact urban form) has a dual effect depending on the season (season-dependent effect).

1. Urban form and Mean Radiant Temperature (MRT)

The obtained regression results demonstrate a clear relationship between urban canyon geometry, expressed by the H/W ratio, and the Mean Radiant Temperature (MRT). The negative regression coefficient (-1.62) indicates a consistent inverse relationship, where increasing urban enclosure is associated with a reduction in MRT values. The intercept value (46.08) represents the theoretical MRT under fully open conditions ($H/W = 0$), corresponding to a non-urbanized or highly exposed environment. This relationship highlights the strong role of urban morphology in regulating the radiative environment at the pedestrian level, particularly through modifications in solar access, sky view factor, and surface radiation exchange.

2. Mechanisms of MRT Reduction in Hot Periods (Summer Regime)

Under hot and arid climatic conditions, such as those characterizing Biskra, increased urban enclosure (higher H/W ratios) contributes to a reduction in MRT through several physical mechanisms: Enhanced shading of street canyons, leading to reduced direct solar radiation load. Reduced effective surface temperature of exposed urban materials due to shading effects. Lower net radiative flux reaching the pedestrian level. These combined effects explain the observed decrease in MRT with increasing urban compactness, confirming the effectiveness of high-aspect-ratio urban canyons in mitigating radiative heat stress in hot climates.

3. Wintertime Urban Microclimatic Response

In contrast, during the winter season, the same compact urban morphology exhibits a different microclimatic behavior. Higher H/W ratios contribute to: Reduction of convective heat losses

due to wind shielding effects within street canyons. Enhanced

Table 6 : Regression analysis results

Independantes			
Variables (X)	(Y)	SUMMER	WINTER
H/W	MRT	Y = 67.79 - 11.79 ??	Y = 46.08 - 1.62 ?? 1
	AT	Y = 41.49 - 1.49 ??	Y = 17.72 + 1.46 ??

longwave radiation trapping, resulting from reduced sky exposure. Increased heat storage within urban fabric elements and delayed nocturnal cooling. Overall moderation of cold stress in outdoor environments. Consequently, compact urban forms generate relatively warmer microclimatic conditions compared to open urban layouts, primarily through the phenomenon of urban heat retention.

6. Conclusions.

The findings emphasize that the impact of urban canyon geometry is strongly season-dependent and cannot be evaluated using a single climatic performance criterion. In hot-arid regions such as Biskra, compact urban forms appear to offer a favorable passive design strategy by enhancing outdoor thermal comfort across different seasonal conditions. However, the study also highlights the necessity of balanced urban design strategies that account for both cooling demands in summer and thermal retention needs in winter. Overall, this research contributes to a better understanding of urban climate–form interactions and provides quantitative evidence supporting the role of H/W ratio as a key parameter in shaping outdoor thermal environments in hot-arid cities. The results clearly indicate that the thermal impact of urban geometry is strongly season-dependent. While compact urban forms are beneficial in reducing excessive radiant heat stress during summer, they simultaneously enhance heat retention during winter. This dual behavior highlights the complexity of urban climate interactions and emphasizes that no single urban configuration is universally optimal across all climatic conditions. These findings contribute to the existing body of knowledge and provide valuable guidance for urban planners and designers in developing thermally comfortable cities in hot-arid climates. The results demonstrate that urban form control can be an effective passive strategy for

mitigating thermal stress and enhancing the environmental performance of urban areas, particularly under extreme hot and dry climatic conditions.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
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Appendix 1:

Air temperature	Al-Istqual neighborhood (N1)			Al-Nassr neighborhood (N2)			Al-Zamala neighborhood (N3)		
	P1	P2	P3	P4	P5	P6	P7	P8	P9
6,00	33,5	33,5	33,5	33,5	32,5	32,5	33,5	33,5	33,5
7,00	34,5	34,5	34,5	33,5	33,5	33,5	34,5	34,5	33,5
8,00	36,5	35,5	36,5	34,5	34,5	34,5	34,5	34,5	34,5
9,00	38,5	38,5	38,5	37,5	36,5	36,5	36,5	36,5	35,5
10,00	39,5	39,5	39,5	38,5	37,5	37,5	37,5	37,5	37,5
11,00	41,5	41,5	41,5	40,5	39,5	40,5	38,5	38,5	38,5
12,00	41,5	41,5	41,5	41,5	42,5	41,5	38,5	38,5	38,5
13,00	43,5	43,5	43,5	42,5	43,5	43,5	40,5	40,5	40,5
14,00	44,5	44,5	44,5	43,5	44,5	44,5	40,5	40,5	41,5
15,00	45,5	45,5	45,5	43,5	44,5	44,5	41,5	41,5	41,5
16,00	45,5	45,5	45,5	43,5	44,5	44,5	41,5	41,5	41,5
17,00	44,5	44,5	45,5	43,5	43,5	43,5	41,5	41,5	41,5
18,00	43,5	43,5	44,5	42,5	42,5	42,5	40,5	40,5	40,5
19,00	42,5	42,5	42,5	40,4	40,5	40,5	38,5	38,5	38,5
20,00	40,5	40,5	40,5	37,5	37,5	37,5	37,5	37,5	37,5

Table 1. MRT during winter

mrt		(N1)	(N2)	(N3)
AVERAGE	8	26,53	9,3	9,7
HOUR	9	53,9	36,8	14,1
	10	62,3	44,6	18,3
	11	64,1	50	22,6
	12	66	59,6	24,2
	13	67,6	60,2	24,6
	14	67,8	60,4	29,8
	15	67,4	42,9	29,2
	16	64	39,6	23,1
	17	53,7	25,5	19,1
	18	17	15,1	13,1

Table 2. Air temperature during winter

AT		(N1)	(N2)	(N3)
AVERAGE	8	20,00	12,90	14,30
HOUR	9	20,8	13,8	14,8
	10	21,8	15,8	15,7
	11	22,3	17,4	16,6
	12	22,8	18,3	17,5
	13	23,3	19,1	18,5
	14	23,5	19,4	19,2
	15	23,4	20	19,4
	16	23	20,3	18,9
	17	22,2	19,9	18,5
	18	21,3	19,2	18