Thermal Behavior of Exterior Coating Texture and Its Effect on Building Thermal Performance

Islam Boukhelkhal and Fatiha Bourbia

Introduction

Climate change constitutes one of the most debated subjects of the twenty-first century. The planet experienced various phenomena generated by this change, corresponding to rising temperatures, heat waves, rising sea levels, more intense storms, and wildfires. Since 1930, further than 100,000 new chemical compounds have been developed, specifically those used in construction field with a massive lack of information or studies of their effect on health. For example, Portland cement concrete, the most frequently used material in the world (more than 10,000 million tons/year, and whose production in the next 40 years will increase by around 100%), includes chemicals and adjuvants used to modify its properties, whose effects on health and the environment are still unknown [1].

The building envelope is an outer layer that can exclude disagreeable effects while allowing those that are estimable. It plays a crucial role in improving the building's energy efficiency and the interior comfort of its occupants. The choice of the exterior envelope is an initial issue which should be considered in the sustainable design of the building. Determining the appropriate exterior cladding material and texture to optimize energy efficiency is a very important step that can be provided by multiple elements such as slate, brick, cement, plaster, and marble. These elements are used to cover, consolidate, protect, or decorate exterior walls; they can also influence energy consumption and improve indoor thermal comfort because of their texture. This chapter approaches the question of the thermal design in the building envelope through the exterior texture. The configuration of this texture can ensure solutions related to the thermal of buildings such as the minimization of the energy demand and the minimization of the hours of thermal discomfort.

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How Exterior Cladding Texture Can Improve the Thermal Performance of Buildings in Hot and Arid Climate

The Algerian Great South is characterized by a rich architectural and urban heritage which merges with a way of life based on protection against climatic conditions; most of them are considered as protected architectural heritage. The strategy set in place by the ancestors was based on protecting the building against climatic conditions by covering the outer envelope of the building. This traditional decorative envelope used by these former builders in southern Algeria can play a fundamental role in improving the energy efficiency of the building. The use of these exterior coatings as a decorative element appears in various traditional architectural styles, particularly in the far south of the Algerian desert, similar to the texture shaped with bare hands in the M'Zab Valley, the texture of external coating in the form of balls projected on the wall in the region of Timimoun, the texture in the form of a cube of clay in the region of Taghit, and another type of stone crystal texture in the region of Hoggar (Fig. 1).

The question requested considers the strategy of the texture in the exterior coating, whether rough or smooth, as a solution affecting the thermal behavior and the thermal comfort of the building. In this way, it is logical to assume that covering the building with an exterior cladding, whether of a smooth or rough texture, makes it possible to avoid the exposure of the facades to intense sunlight and high temperatures and to reduce the irrational consumption of energy.

Theoretical Analysis

Several researches studied the effect of the exterior envelope on the thermal comfort of the building using many strategies as works related to the exterior coatings of the building [2–7], knowing that those researches particularly on this element are very rare. Therefore, studies made on the effect of self-shading which is considered a fundamental strategy at the level of the external envelope [8–12], other works based on the effect of the color and the albedo of the external coating in the building [13–18], or the effect of the intelligent envelope with particles of ecological materials on the thermal comfort and the energy needs in buildings [19–27]. Thus, studies were carried out on the effect of roughness and density of the exterior plant cover [28–34], in order to highlight the strategies that can be used at the level of exterior coatings.

Although all these works expose divergent results from one study to another, nevertheless, they share together reliable and useful results on the thermal behavior of the outer envelope, through the reduction of surface and air temperatures, and the reduction of the energy consumption of the building.

These theoretical syntheses can conclude that optimization in the configuration of the texture in the outer envelope can act as thermal insulation for buildings, by

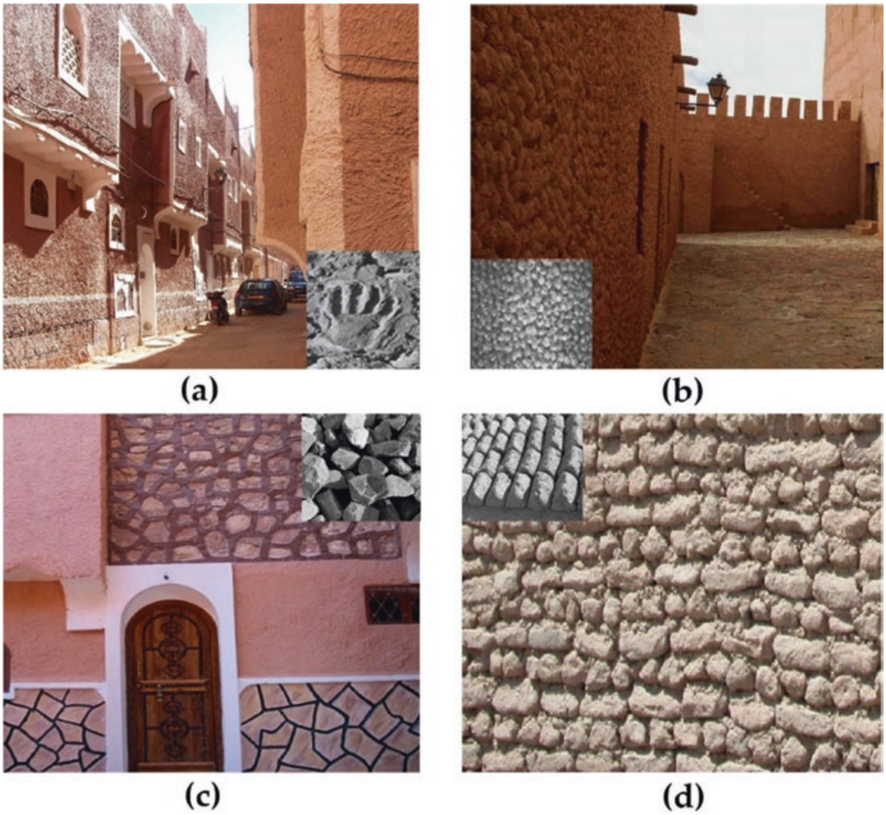


Fig. 1 Traditional wall texture design in the great south of Algeria. (**a**) Ghardaia region), (**b**) Timimoun region), (**c**) Hoggar region), (**d**) Taghit region). (Source: Boukhelkhal Islam, 2015)

protecting them from solar rays and reducing the need for thermal insulation materials. The improvement solutions through textured coatings are infrequently exploited; they are suggested as a new field which solicits eminently development in the future.

Modeling Approach

In Algeria, the use of plaster texture as a decorative element appears in several times in traditional architectural styles, particularly in the southern part of the country, characterized by its hot and arid climate, and whose traditional constructions are built to face difficult climatic conditions. The objective of this study is to evaluate the thermal behavior of the exterior envelope with different textures used in exterior claddings, inspired by traditional construction methods that used self-shading walls as a cooling strategy.

In order to achieve this objective, measurements were taken to evaluate the thermal behavior of the texture in the exterior coating. The experimental system (Test Box) was set up in a private garden with open area in the city of Constantine, which is located in the northeast of Algeria (latitude: 36.9126 N, longitude: 7.0213 E) and with a semiarid climate. The figure below illustrates the methodological approach in this study (Fig. 2).

The experimental system (Test Box) is set up inside a private garden with area freed from all constructions or plantations. The measurement is taken using various instruments such as a thermal camera (FLIR), multimeter (TESTO 925), pyranometer (S-LIB-M003) with a data logger (HOBO H21 USB), weather station (Oregon Scientific) for in-situ measurements of air temperature, surface temperatures, solar radiation, wind speed and direction, relative humidity, atmospheric pressure, and precipitation rate.

The period chosen for the first phase of the study was the summer season ranging from June 23 to June 30, 2019 (08 days), which represent the longest days of the year, in where the hottest days are recorded on June 25, 26, and 27. The results are taken from 7:00 a.m. to 6:00 p.m. at an interval of 60 min. The second phase of measurements is carried out during the summer period of 2020, maintaining the same choice of period of the first phase. The results are recorded for 12 h, from 8:00 a.m. to 8:00 p.m. every 60 min.

Experimental Procedure

The first part represents an investigation in the field, comprising a series of measurements. The experiment consists in making four boxes of 1 m^3 which expose four types of external coating. The figures below give a detailed description of the textures developed under study (Figs. 3 and 4).

After an in-depth bibliographic research and investigation on the traditional texture in southern Algeria, the choice fell on four types of textures:

- Smooth texture (STB) considered as reference texture
- Rough texture (RTB)
- Crystalline texture (CTB)
- Texture of the blade texture (BTB)

Similar to the patterns shown in the figures below, the morphological configurations of the different coating textures are based on the percentage of shadow area projected over the total wall area (SO/ST). Below are the different configurations proposed in this study (Fig. 5).

The second part of this research consists in testing the effect by the incorporation of natural particles (ecological, organic, waste, and recycling components) in exterior coatings. This phase is based on a conclusion made from a state of the art on several researches in ecological materials and recycling. Finally, the choice is maintained on the rough texture in order to keep the same appearance and the

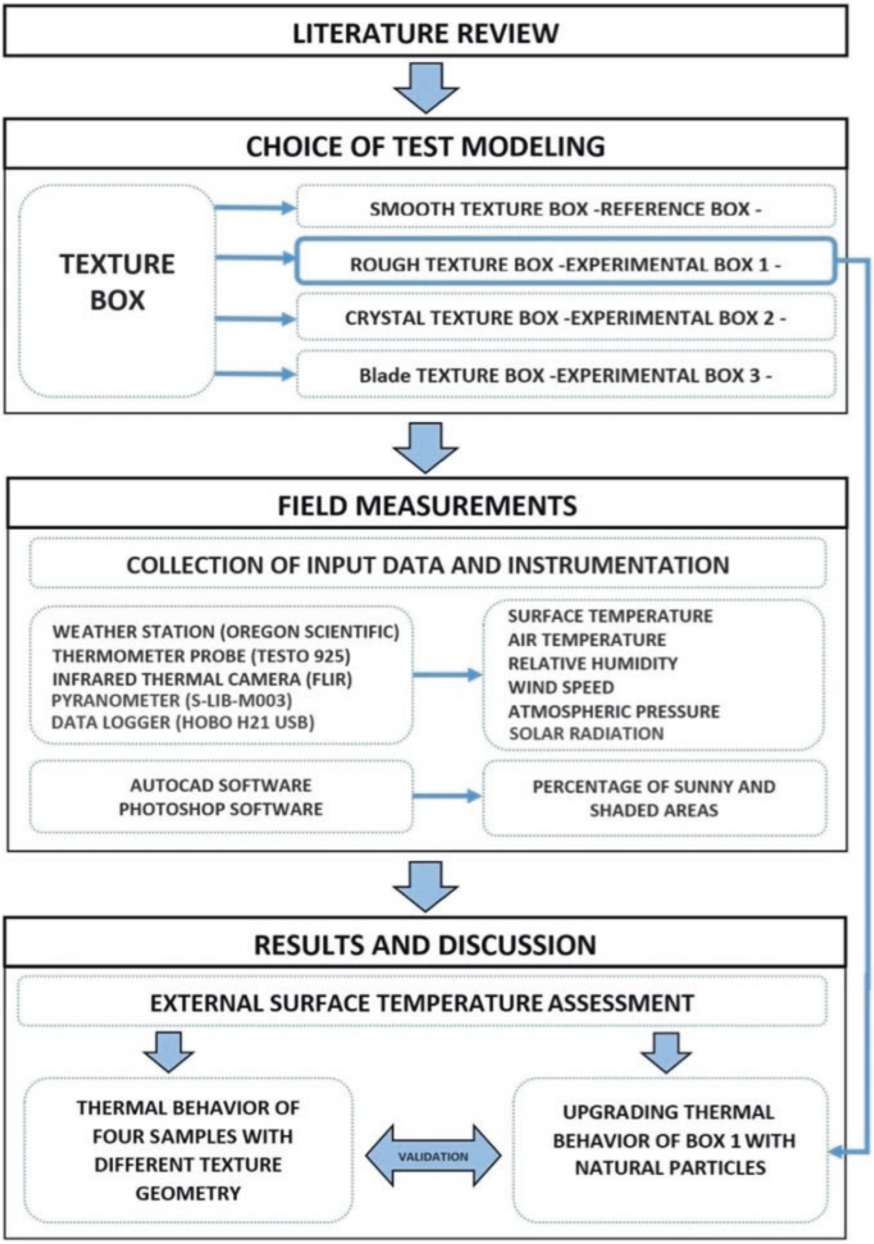


Fig. 2 Conceptual framework study. (Source: Adapted by Boukhelkhal Islam, 2021)

Fig. 3 Choice of materials for the measurement. (Source: Boukhelkhal Islam, 2019)

Fig. 4 Realization of measurement boxes. (Source: Boukhelkhal Islam, 2019)

projected shadow but with components of different mechanical and thermal characteristics.

In order to achieve this objective, a variety of particles are tested, and the selection is made according to three types with different thermal characteristics. The figure below shows a component from sand quarries, a second component produced from ecological recycling (tire waste), and another obtained from date palm waste (palm particles). These wastes are washed with distilled water to remove all impurities from their surfaces like salt and then dried in the oven. Then they were crushed and separated into different sizes, similar to sand aggregate (Fig. 6).

After various in situ measurements, the choice fell on palm particles, which showed the ability to reduce the surface temperature more than tire waste aggregates. This choice was based on the ability to retain better thermal properties in

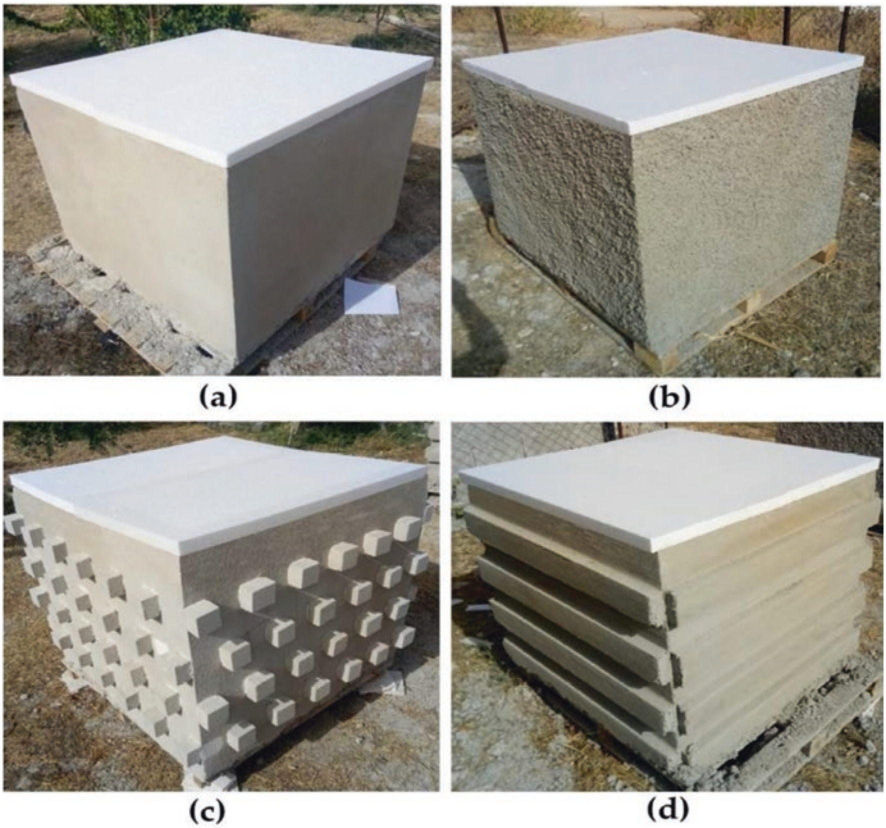


Fig. 5 The selected textures for surface temperature measurements. (**a**) smooth texture (STB), (**b**) rough texture (RTB), (**c**) crystal texture (CTB), (**d**) blade texture (BTB). (Source: Adapted by Boukhelkhal Islam, 2019)

order to be reused as mortar aggregates in the manufacture of exterior cladding textures. This material has been the subject of several researches. It has proven high heat capacity due to its ability to reduce thermal conductivity, compression, and coating weight [25]. Moreover, this material is widely available from date palms in the region of the great south of Algeria [26] (Fig. 7).

In order to evaluate the thermal behavior of the rough texture with and without palm particles, three boxes of 1 m^3 each are built separately: (RTB), (RTB_1), and (RTB_2). Each box is made with different concentrations of palm particle aggregates (0%, 30%, and 70%, respectively) (Fig. 8).

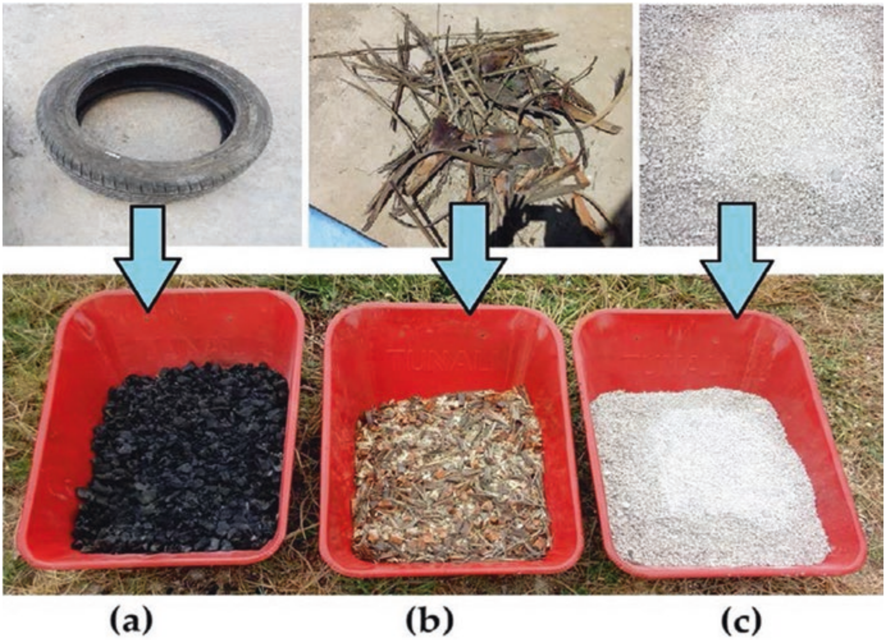


Fig. 6 Evaluation of the thermal behavior of the tested aggregate. (**a**) Sand aggregates, (**b**) palm particles, (**c**) tire waste. (Source: Adapted by Boukhelkhal Islam, 2020)

Texture Effects

Effect of Texture Geometry

The first investigation of this study focused on the effect of texture geometry on the exterior surface temperature. The idea of introducing texture on the outer surface can facilitate cooling by self-shading effect. Comparing the four measured samples, the results showed variable measurements relative to all orientations. The results of the outdoor surface temperature measured by the thermal camera (FLIR) and the multimeter (TESTO 925) are shown in the figures below. Taking as an example the south facade (Figs. 9, 10, 11, and 12).

The results of the external surface temperature of the four textures studied for all orientations (north, east, south, west) are presented in the figures below (Fig. 13).

The analysis and comparison of the four textures are presented in the table below. The comparison between each type of texture with the different orientations studied (north, east, south, and west) clarifies the previous results which confirm that the texture of the coating affects the external surface temperature (Table 1).

These results show that the number of most critical hours (in red) is considerably high for the rough texture (RTB) (7 h from 10:00) in the south orientation, followed by the smooth texture (STB) with an average of 5 h, followed by the other two

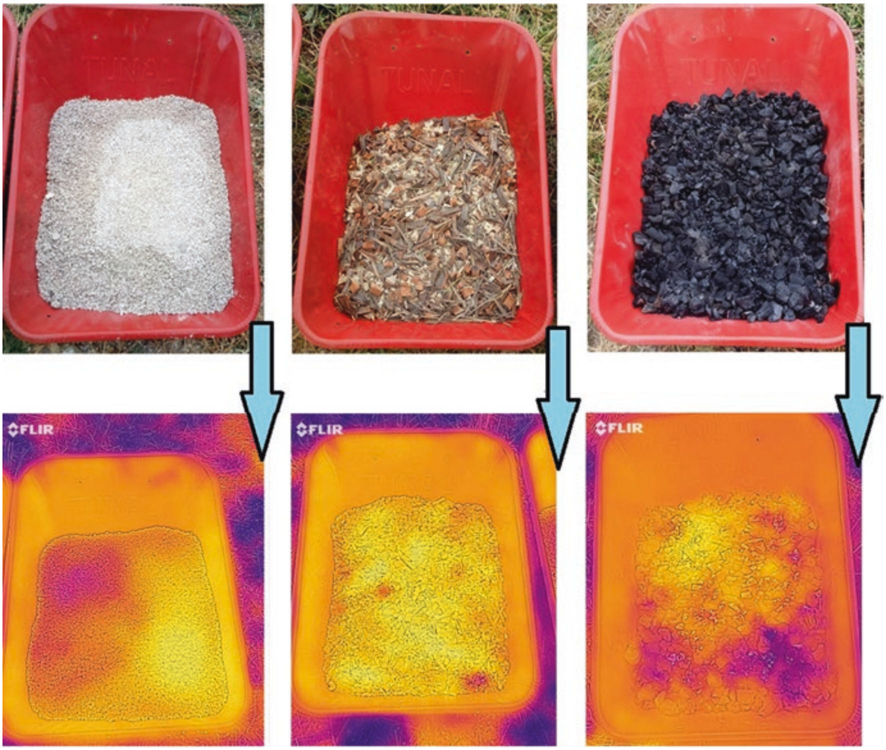


Fig. 7 Surface temperature values of the three samples. (Source: Adapted by Boukhelkhal Islam, 2020)

texture types (4 h). The hottest hours are recorded between 10 a.m. and 4 p.m. The rough texture (RTB) therefore frequently indicated and exhibited the greatest number of hot hours.

Based on the results obtained, it can be concluded that there is a correlation between the shadow fraction and the external surface temperature, as mentioned in the figure below, of which the rough texture (RTB) deploys the lowest correlation compared to the others (Fig. 14).

The figure below presents a grouped histogram of the evolution of shadow fraction compared to the exterior surface temperature of the south facade in the four types of texture from 8:00 a.m. to 6:00 p.m (Fig. 15).

The figure above demonstrates that at noon, the shadow fraction rate on the south wall is identical (about 40%) for the three textures RTB, CTB, and BTB. The comparison of the external surface temperature results recorded at midday shows that these values are of the order of 52.6 °C for the blade texture (BTB), 53.9 °C for the crystalline texture (CTB), and 58.5 °C for the rough texture (RTB) although all textures have the same shadow fraction rate. This can be explained by the fact that the rough texture (RTB) has small spots of shadows not exceeding 1 cm^2 and with

Fig. 8 Rough texture with different concentration of palm particles aggregate. (Source: Adapted by Boukhelkhal Islam, 2020)

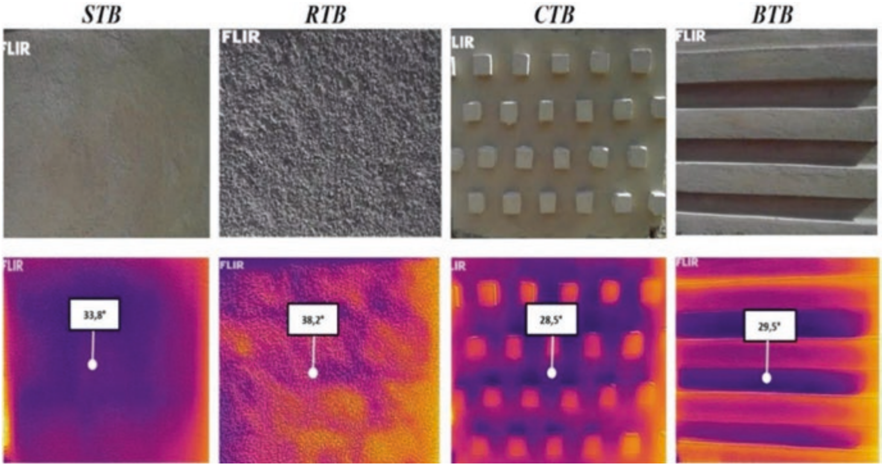


Fig. 9 External surface temperature of the south orientation at 9:00 a.m. (Source: FLIR, 2020)

random positions that favor small reflections and the absorption of solar radiation, unlike the textures in crystal (CTB) and blade (BTB), which feature an assemblage of larger, more authentic shaded surfaces that act as small canopies protecting the wall itself.

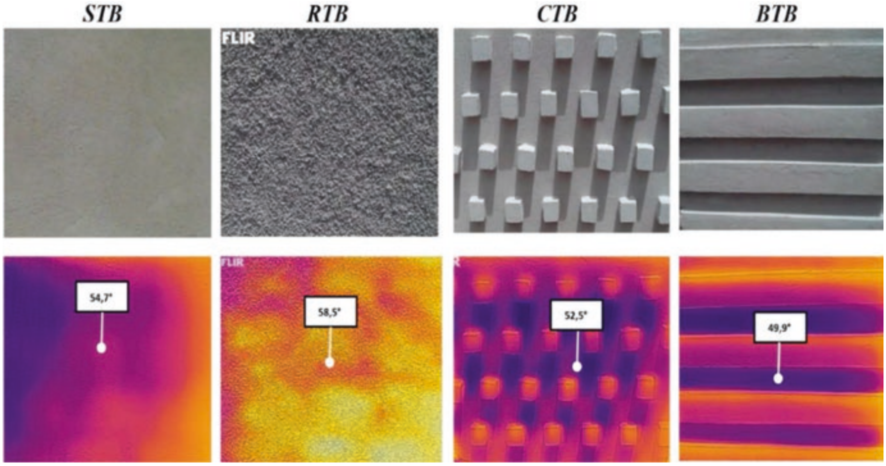


Fig. 10 External surface temperature of the south orientation at midday. (Source: FLIR, 2020)

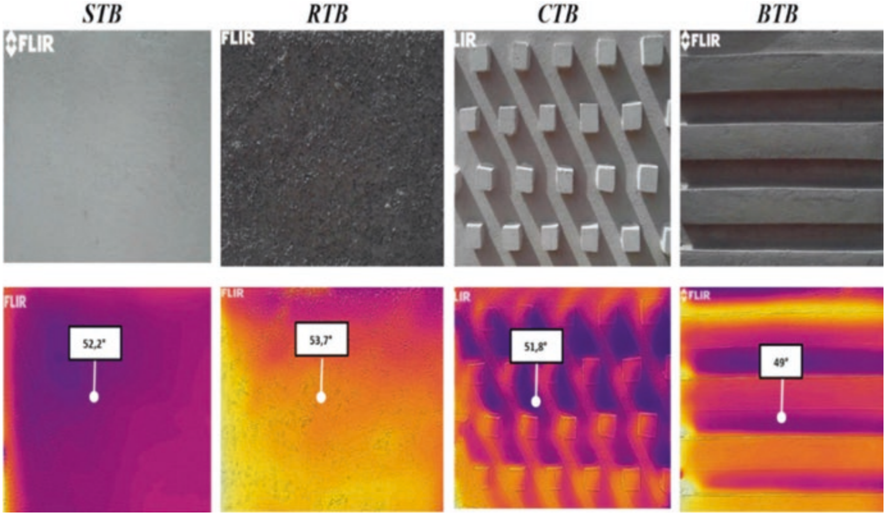


Fig. 11 External surface temperature of the south orientation at 3:00 p.m. (Source: FLIR, 2020)

Effect of Texture Particles

The results of the first phase of this study show that the rough texture registers considerably critical results for the external surface temperature. However, this texture is used for most of the exterior coatings of buildings, more particularly in Algeria. Improving the thermal behavior of this texture is essential by adding new components favorable to the harsh climate of the region. This method is carried out using natural aggregates, such as palm particles, in order to optimize thermal efficiency.

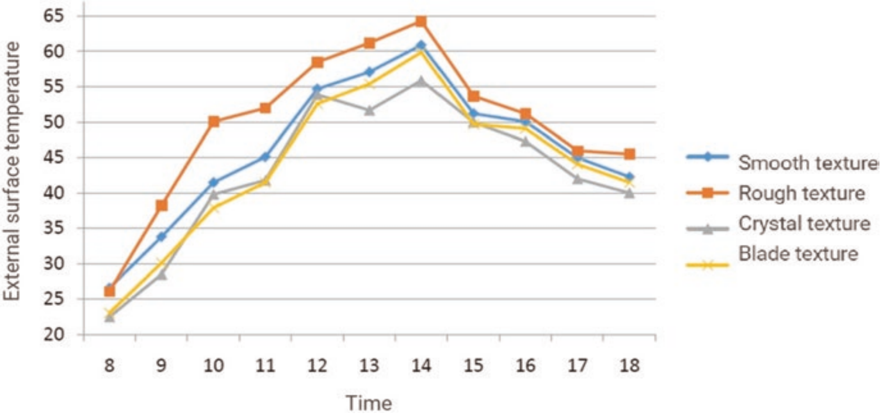


Fig. 12 External surface temperature of the south orientation. (Source: Boukhelkhal Islam, 2020)

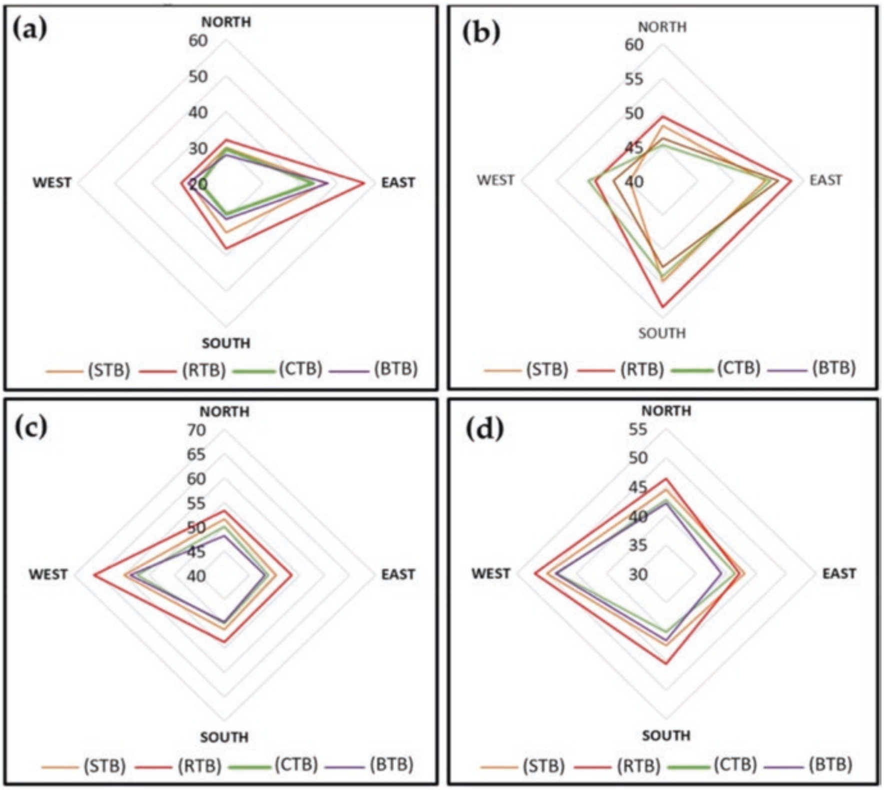
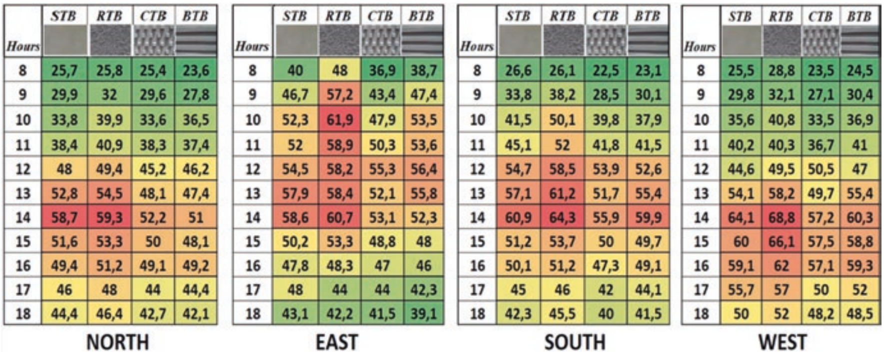


Fig. 13 External surface temperature for all textures and orientations. (**a**) 9:00 a.m., (**b**) midday, (**c**) 3:00 p.m., (**d**) 6:00 p.m. (Source: Boukhelkhal Islam, 2020)

Table 1 External surface temperature for the listed orientations (north, east, south, west)



Hours	NORTH				EAST				SOUTH				WEST			
	STB	*RTB*	*CTB*	*BTB*	*STB*	*RTB*	*CTB*	*BTB*	*STB*	*RTB*	*CTB*	*BTB*	*STB*	*RTB*	*CTB*	*BTB*
8	25,7	25,8	25,4	23,6	40	48	36,9	38,7	26,6	26,1	22,5	23,1	25,5	28,8	23,5	24,5
9	29,9	32	29,6	27,8	46,7	57,2	43,4	47,4	33,8	38,2	28,5	30,1	29,8	32,1	27,1	30,4
10	33,8	39,9	33,6	36,5	52,3	61,9	47,9	53,5	41,5	50,1	39,8	37,9	35,6	40,8	33,5	36,9
11	38,4	40,9	38,3	37,4	52	58,9	50,3	53,6	45,1	52	41,8	41,5	40,2	40,3	36,7	41
12	48	49,4	45,2	46,2	54,5	58,2	55,3	56,4	54,7	58,5	53,9	52,6	44,6	49,5	50,5	47
13	52,8	54,5	48,1	47,4	57,9	58,4	52,1	55,8	57,1	61,2	51,7	55,4	54,1	58,2	49,7	55,4
14	58,7	59,3	52,2	51	58,6	60,7	53,1	52,3	60,9	64,3	55,9	59,9	64,1	68,8	57,2	60,3
15	51,6	53,3	50	48,1	50,2	53,3	48,8	48	51,2	53,7	50	49,7	60	66,1	57,5	58,8
16	49,4	51,2	49,1	49,2	47,8	48,3	47	46	50,1	51,2	47,3	49,1	59,1	62	57,1	59,3
17	46	48	44	44,4	48	44	44	42,3	45	46	42	44,1	55,7	57	50	52
18	44,4	46,4	42,7	42,1	43,1	42,2	41,5	39,1	42,3	45,5	40	41,5	50	52	48,2	48,5

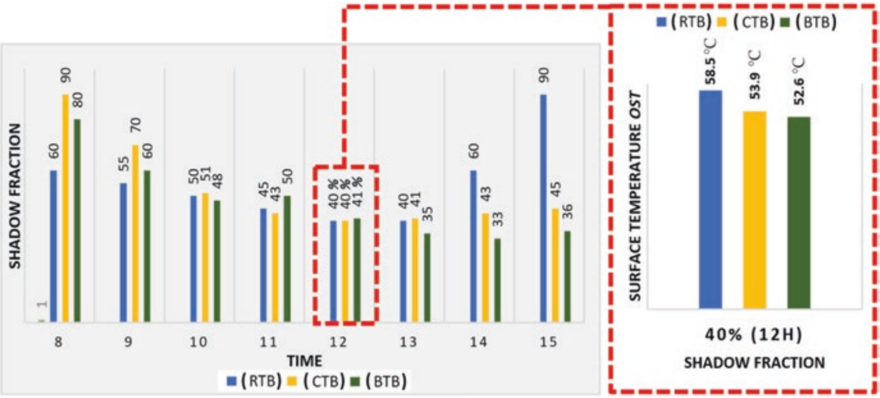
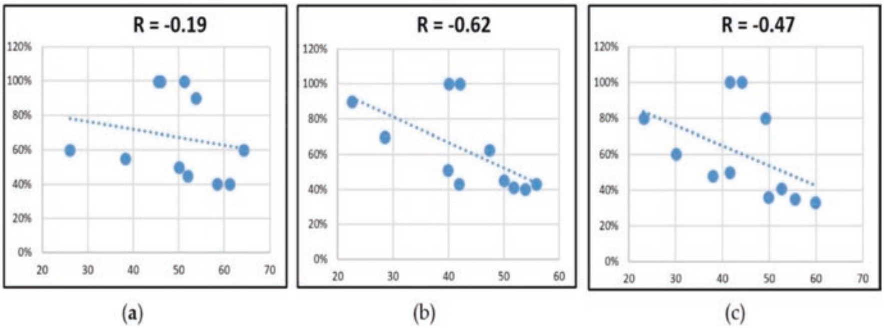


Fig. 15 External surface temperature at midday compared to SF percentage (south orientation). (Source: Adapted by Boukhelkhal Islam, 2020)



(a) (b) (c)

Fig. 14 Correlation results of external surface temperature (EST) and shadow fraction (SF) for (**a**) RTB, (**b**) CTB, and (**c**) BTB. (Source: Boukhelkhal Islam, 2020)

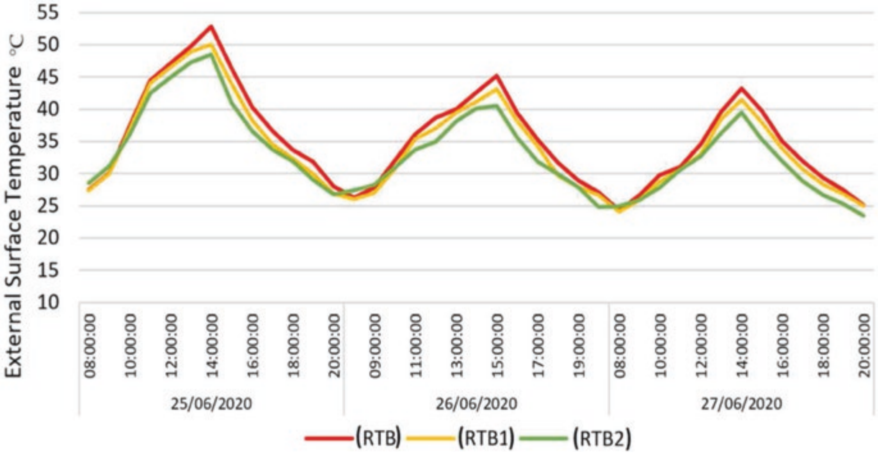


Fig. 16 External surface temperature of rough textures made up of palm particles with different concentrations of aggregates. (Source: Boukhelkhal Islam, 2020)

The figure below shows the results of the outdoor surface temperature obtained after adding to the rough texture the palm particles with different concentrations (RTB: 0%, RTB_1: 30%, and RTB_2: 70%), respectively (Fig. 16).

Palm particulate aggregate is added in different concentrations, starting with RTB of 100% sand aggregate, RTB_1 of 30% palm particulate and 70% sand aggregate, and finally RTB_2 of 70% palm particles and 30% sand aggregates, respectively. This diagram shows that the highest external surface temperatures are recorded at the reference coating RTB, the most critical value of which is recorded during the day of June 25, 2020, between 2:00 p.m. and 3:00 p.m., equal to 52.8 °C with a difference of 2.7 °C compared to RTB1 and 4.3 °C compared to RTB2.

These results prove that using palm particles in multiple densities can significantly reduce the external surface temperature at the rough texture, as the results show a difference of up to 4.3 °C.

Conclusions

Overall, the results of this work indicate significant credibility between exterior texture geometry, percent cast shadow, and exterior surface temperature. The results of this chapter show that the textured facade panels can improve the cooling, through its texture, and that there is a strong correlation between the created morphology of the texture, the shadow fraction rate, and the surface temperature. We can summarize the following:

Texture Depth

The results reveal that the textures with the least depth such as the smooth and rough texture recorded higher surface temperatures than the others. They confirm the hypothesis expressing that the deeper the surface texture, the more the surface protected by the self-shading effect increases and the greater the ratio (SF), and consequently the ability of the texture to lose heat is tall.

Organizing and Assembling the Texture

The results clearly illustrate that textures with a suitably organized layout and assembly contributed to better cooling than rough textures. The organization of texture devices seems to be more efficient and effective, creating organized breaks in a well-defined layout. This organization can provide more protection by increasing the shaded area. Moreover, this assumption explains that the arrangement and the assembly of the texture are a very effective solution in order to increase the shadow fraction rate and consequently decrease the effect of the external surface temperature.

Texture Thickness

By examining the impact of the different thicknesses of the texture on their thermal performance, this study deduced that the thicker textures such as the blade and crystal texture have a greater ratio (SF) than the thin textures such as the smooth and rough texture. These results are consistent with the study by Bergman Watt et al. (2010) [35], which reveals that as thinner the facade panel was, the faster the panel heats up, and therefore its temperature is higher.

Texture Components

The results of the second phase of this investigation clearly illustrate that the integration of natural components in the texture, such as aggregates based on palm particles, can significantly reduce the external surface temperature. The study concluded that by increasing the concentration of palm particle-based aggregates, the surface temperature decreases, and the coating cools rapidly. Therefore, the use of a concentration with more than 70% palm particles allows better surface temperature results when mixed with adjuvants to avoid deterioration caused by weather conditions.

Things to Think About

This work assists to identify the real thermal behavior in any type of texture. It creates and develops a framework for future research and designer's works to provide applicable architectural solutions for existing and new buildings and to open up new opportunities for solving overheating problems through passive design strategies. The development of this research will be to establish other similar works on the types of textures which could include numerical simulations or on other climatic regions, otherwise through other elements of buildings such as roofs, in order to assess the effect of the latter on the thermal performance of the building.

This work can also be part of the preservation and enhancement of the built heritage of southern Algeria in order to contribute to the sustainable development of these regions characterized by a hot and arid climate.

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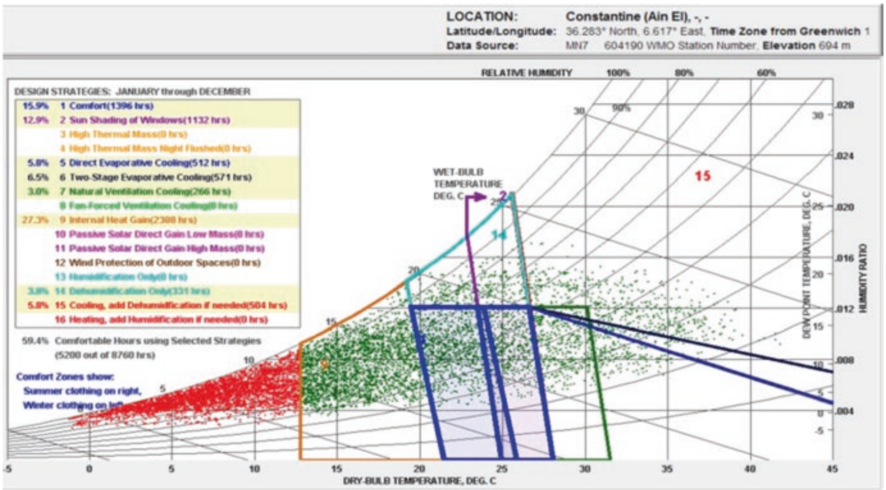
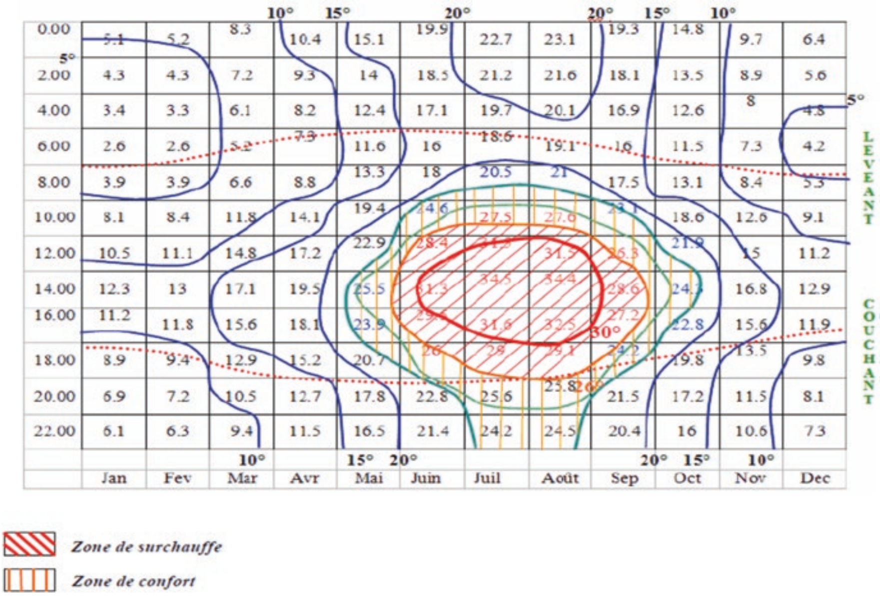
Appendix

- Climate data of Constantine

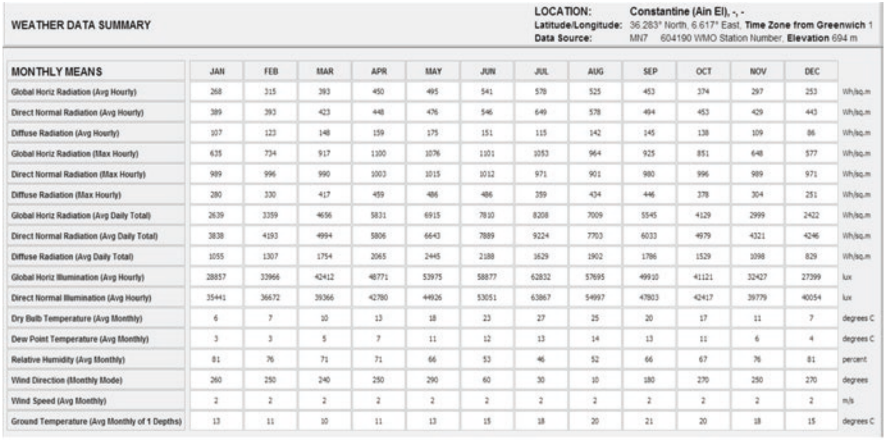


Psychrometric diagram of Constantine
(Source: Climate Consultant)



	Jan	Fev	Mar	Avr	Mai	Juin	Juil	Août	Sep	Oct	Nov	Dec
0.00	5.1	5.2	8.3	10.4	15.1	19.9	22.7	23.1	19.3	14.8	9.7	6.4
2.00	4.3	4.3	7.2	9.3	14	18.5	21.2	21.6	18.1	13.5	8.9	5.6
4.00	3.4	3.3	6.1	8.2	12.4	17.1	19.7	20.1	16.9	12.6	8	4.8
6.00	2.6	2.6	5.2	7.3	11.6	16	18.6	19.1	16	11.5	7.3	4.2
8.00	3.9	3.9	6.6	8.8	13.3	18	20.5	21	17.5	13.1	8.4	5.3
10.00	8.1	8.4	11.8	14.1	19.4	24.6	27.5	27.6	23.1	18.6	12.6	9.1
12.00	10.5	11.1	14.8	17.2	22.9	28.4	31.3	31.5	26.3	21.9	15	11.2
14.00	12.3	13	17.1	19.5	25.5	31.3	34.5	34.4	28.6	24.3	16.8	12.9
16.00	11.2	11.8	15.6	18.1	23.9	29.5	31.6	32.5	27.2	22.8	15.6	11.9
18.00	8.9	9.4	12.9	15.2	20.7	26	28	29.1	24.2	19.8	13.5	9.8
20.00	6.9	7.2	10.5	12.7	17.8	22.8	25.6	23.8	21.5	17.2	11.5	8.1
22.00	6.1	6.3	9.4	11.5	16.5	21.4	24.2	24.5	20.4	16	10.6	7.3

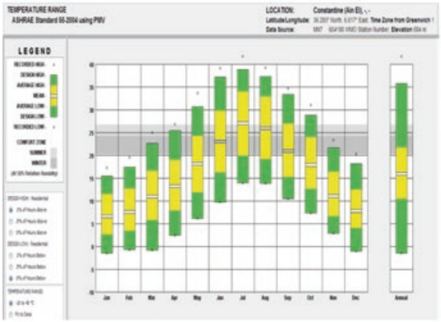
Isotherms of Constantine

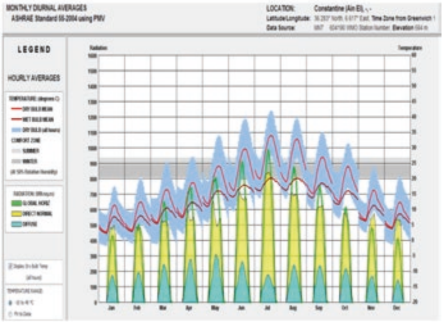


WEATHER DATA SUMMARY

LOCATION: Constantine (Ain El), -, -
Latitude/Longitude: 36.283° North, 6.617° East, **Time Zone from Greenwich** 1
Data Source: MN7 604190 WMO Station Number, **Elevation** 694 m

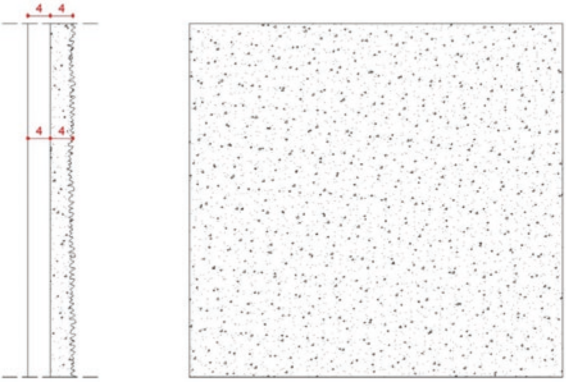
MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	268	315	393	450	495	541	578	525	453	374	297	253	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	389	393	423	448	476	546	649	578	494	453	429	443	Wh/sq.m
Diffuse Radiation (Avg Hourly)	107	123	148	159	175	151	115	142	145	138	109	86	Wh/sq.m
Global Horiz Radiation (Max Hourly)	635	734	917	1100	1076	1101	1053	964	925	851	648	577	Wh/sq.m
Direct Normal Radiation (Max Hourly)	989	996	990	1003	1015	1012	971	901	980	996	989	971	Wh/sq.m
Diffuse Radiation (Max Hourly)	280	330	417	459	486	486	359	434	446	378	304	251	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	2639	3359	4656	5831	6915	7810	8208	7009	5545	4129	2999	2422	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	3838	4193	4994	5806	6643	7889	9224	7703	6033	4979	4321	4246	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	1055	1307	1754	2065	2445	2188	1629	1902	1786	1529	1098	829	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	28857	33966	42412	48771	53975	58877	62832	57695	49910	41121	32427	27399	lux
Direct Normal Illumination (Avg Hourly)	35441	36672	39366	42780	44926	53051	63867	54997	47803	42417	39779	40054	lux
Dry Bulb Temperature (Avg Monthly)	6	7	10	13	18	23	27	25	20	17	11	7	degrees C
Dew Point Temperature (Avg Monthly)	3	3	5	7	11	12	13	14	13	11	6	4	degrees C
Relative Humidity (Avg Monthly)	81	76	71	71	66	53	46	52	66	67	76	81	percent
Wind Direction (Monthly Mode)	260	250	240	250	290	60	30	10	180	270	250	270	degrees
Wind Speed (Avg Monthly)	2	2	2	2	2	2	2	2	2	2	2	2	m/s
Ground Temperature (Avg Monthly of 1 Depths)	13	11	10	11	13	15	18	20	21	20	18	15	degrees C

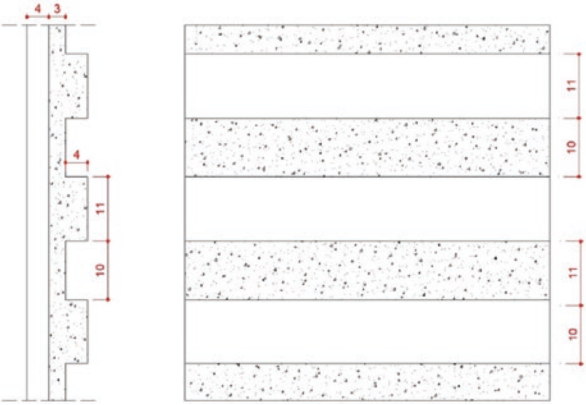


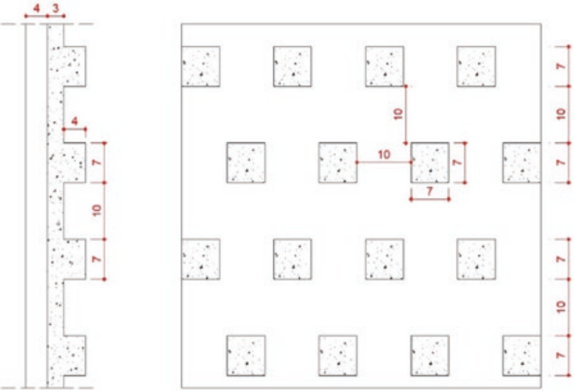


Variation in climate data for Constantine

- Description and detail of the studied textures







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