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Experimental Study of the Evolution of Temperatures in Pavement Structures and Influence of Traffic on the RN1 in Burkina Faso in a Hot and Dry Climate

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Abstract

Asphalt concrete pavements in hot and dry climates deteriorate prematurely some time after their construction. This degradation is accelerated under the effect of heavy vehicle traffic pressure and high temperatures after the bitumen has softened. A study was conducted on the RN1 in Burkina Faso in order to analyze the evolution of temperature and traffic in the process of degradation of asphalt concrete pavements. It consisted on the one hand in recording the temperatures at different points inside the layers of asphalt concrete pavements and the layer of laterite. These results were compared with the values of the softening temperatures of the bitumen obtained in the laboratory. On the other hand, this study is supplemented by the daily counting of heavy goods vehicles passing through the RN1 during the month of April in order to study the influence of the evolution of heavy goods vehicle traffic on the degradation of pavements in hot and dry climatic conditions. The results obtained for temperatures and the frequency of heavy goods vehicle traffic favor pavement deterioration under certain conditions.

Keywords

Temperature, Pavement, Traffic, Climate, Bituminous Concrete

1. Introduction

The road is a national heritage for the development of a country. Burkina Faso, a transit country, more than 75% of goods transport is carried out by road traffic. However, the pavements deteriorate just as quickly some time after their construction in a Sahelian climatic context. The average annual temperature is around 33.7˚C, while the annual minimum is 27.4˚C and the annual maximum is 39.9˚C [1]. The solar energy potential is estimated at 1500 GWh/year·per·km^2, *i.e.* 4 to 6 kWh/d·per·m^2 [2]. This energy impacts the soils which accumulate heat over time in the different layers of asphalt concrete pavements.

In Burkina Faso, the bitumen generally used for the construction of our roads is class 35/50 and 20/30. These are the hardest bitumens. Laboratory results show that their softening temperatures are between 50˚C and 58˚C for class 35/50 bitumen, 55˚C and 63˚C for class 20/30 bitumen [3]. For the RN1, the bitumen used for its implementation was class 35/50. It is a particularly important road for the interregional relations of Burkina Faso. There is a significant increase in traffic, especially heavy goods vehicles. Observations made on the pavement in 2022 show premature degradation of cracks, deformations, potholes after its reconstruction in 2012. It is with this in mind that we have looked into the problem of degradation of the pavements by carrying out an experimental study of the evolution of temperatures in pavement structures and influence of traffic on the RN1.

We first present the experimental results of recording temperatures that we compared to laboratory temperature values. Then we compare the number of heavy vehicles during the experiment to the values of the commissioning traffic defined by the design. Finally, we show the effect of temperature in the accelerated degradation process of pavements in the Sahelian zone.

2. Presentation of Experimental Materials and Equipment

2.1. Pavement Materials

In the continuation of our work we consider that the surface of the pavement is flat and the loading applied on all the surface is uniform. The roadway of the RN1 consists of 5 cm of thin bituminous concrete (BBM) and 16 cm of layer of gravel bitumen 3 over the total width of the roadway. These two layers are placed on the existing pavement before reinforcement (**Figure 1**). The part of the pavement subjected to our experiment after reinforcement is a longitudinal section of a section of the pavement 50 cm long and 16 cm deep. It consists of 6 cm of bituminous concrete layer and 10 cm of late rite layer (**Figure 2**).

The physical characteristics of the studied materials of the RN1 pavement are given in **Table 1**.

2.2. Softening Temperatures of Bitumen and Their Class

In France, the most used classes are: 20/30 – 35/50 – 50/70 – 70/100 – 160/220, for conventional bitumen. The hardest bitumen are class 20/30 and 35/50 bitumen. 35/50 bitumen has a softening point of between 50˚C and 58˚C for a penetrability of around 40 × 0.1 mm. The softening temperatures of 20/30 bitumen

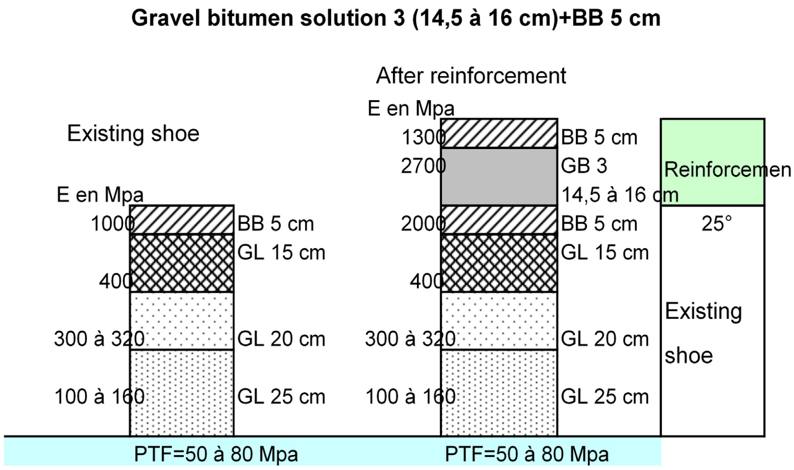

Figure 1. Pavement before experiment.

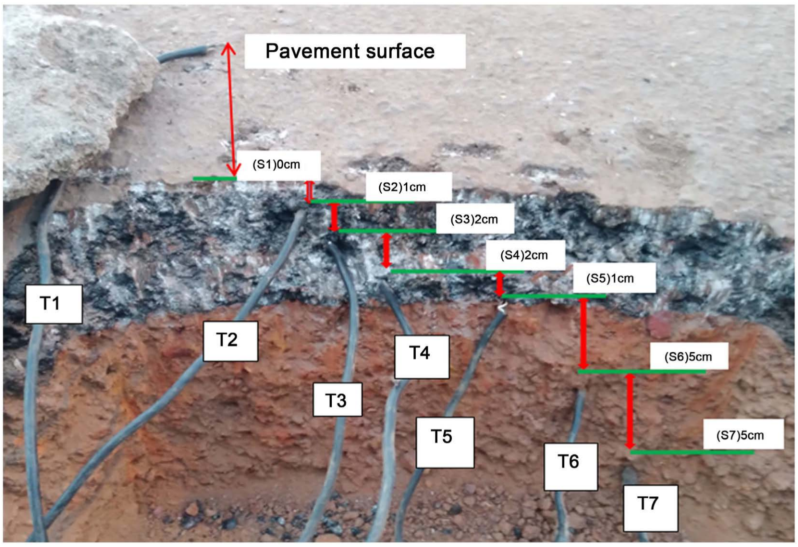

Figure 2. Section of the roadway of the RN1.

Table 1. Physical characteristics of RN1 pavement materials.

N°	Materials	Thermal Conductivity: λ (W/m K)	Mass heat capacity: c (J/kg K)	Density (kg/m^3)	Porosity
1	Asphalt concrete	2.20	869	963	0.07
2	Laterite	1.80	2350	2600	0.23

(T_{AB}) can range from 55˚C to 63˚C according to French specifications with a penetrability that can cover a range from 55 to 41 1/10 mm Guy RAIMOND *et al.*, [4] (**Table 2**).

2.3. Experimental Materials

The devices used for recording temperatures are:

Table 2. Softening temperature and class of road bitumen from standard NF EN 1291 (AZALT-ECO2-TOTAL) [4].

Features	METHODS	AZALT				
		20/30	35/50	50/70	70/100	160/220
Penetration at 25˚C	IN 1420	20 - 30	35 - 50	50 - 70	70 - 100	160 - 220
Ring and ball ˚C	IN 1427	55 - 63	20 - 58	46 - 54	43 - 51	35 - 43
Softening point (Cleveland) ˚C	IN ISO 2592	≥240	≥240	≥230	≥230	≥220
Solubility %	IN 12602	≥99.0	≥99.0	≥99.0	≥99.0	≥99.0

- The Data logger: this is a real-time data recorder, such as voltage, current and temperature. In our study we used it to record the temperatures of the different points inside the pavement structures of the RN˚1 at the toll station of Yimdi at the western exit of Ouagadougou. The period defined for this study is the month of April 2022, a period during which the pavements receive strong daily irradiation for more than ten hours.
- The Pyranometer is a device that records the power of the sun (global radiation).
- A source of current (battery) and type K thermocouples.

Figure 3 illustrates the diagram of the experimental device for recording temperatures on the RN1.

2.4. Description of the Experimental Protocol

The experiment consists of placing probes from the datalogger device on the different points of the 6 cm asphalt concrete layers and the 10 cm laterite base layer. Temperatures are recorded every five (05) minutes throughout the day. It was agreed to record the temperatures for 24 hours by the data logger using probes (S1, S2, S3, S4, S5, S6, S7) at the level of the pavement structures. The probes used are type K thermocouples. The AMS 2750 E standard defines a certain number of rules relating to the heat treatment of metals in the aeronautical sector. In the temperature range (0 - 100)˚C, it provides us with an absolute uncertainty of ± 0.4% of the value read.

- The S8 and S9 probes respectively record the temperatures of the ground outside the roadway and that of the air in the shade. The S10 records the power of the sun through the pyrometer throughout the day. We chose to randomly place the different probes suitably described as follows.

Probes placed at the level of the bituminous concrete layer

- S1 records the evolution of the temperature on the surface of the roadway.
- S2 records the temperature of the bituminous concrete at 1 cm from the road surface.
- S3 records the temperature of the asphalt concrete at 3 cm from the road surface.

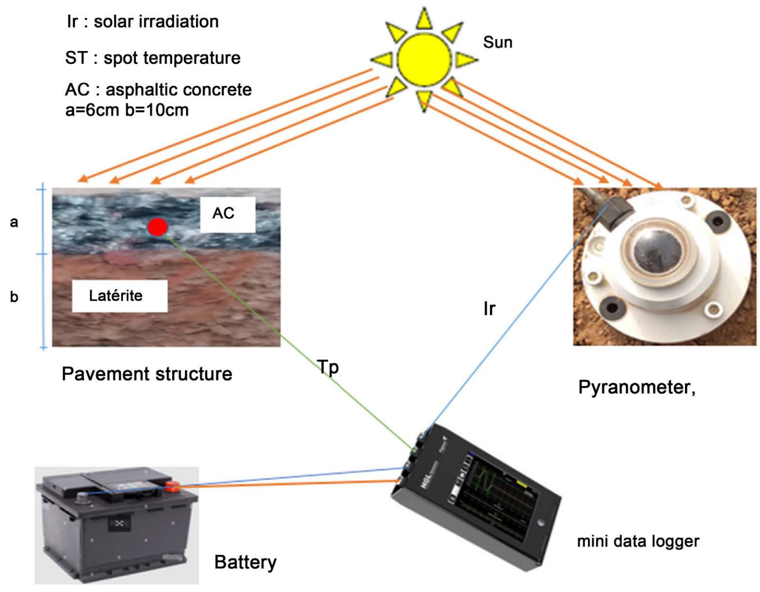

Figure 3. Diagram of the experimental device.

- S4 records the temperature of the asphalt concrete at 5 cm from the road surface.
- S5 records the temperature of the laterite at 6 cm from the road surface. This probe is placed between the layer of bituminous concrete and that of laterite.

Probes placed at the level of the laterite layer

- S6 records the laterite temperature at 11 cm from the road surface. It is placed 5 cm from the road surface of the bituminous concrete layer.
- S7 records laterite temperature. It is placed 10 cm from the bituminous concrete layer.

Probes placed off road

- S8 records soil temperature at 5 cm depth off road.
- S9 records the ambient air temperature under the shade.

Probes placed at the level of the Pyranometer

- S10 measures the power of the sun recorded by the datalogger every 5 min during the experiment.

For sunny days the results of the experiment show that maximum temperatures recorded at the level of the bituminous concrete is in the order of (64.3 ± 0.3)˚C. The average temperature is (56.0 ± 0.3)˚C. These temperatures are higher than those of bitumen softening which are between (50.0 ± 0.2)˚C and (58.0 ± 0.3)˚C for class 35/50 bitumen commonly used in Burkina Faso.

3. Heavy Vehicle Counting Operation

The operation consisted in counting during 24 hours the number of heavy vehicles including light vehicles and two-wheeled motorcycles passing on the RN1. There, we counted 1671 heavy goods vehicles, 1299 light goods vehicles, 2952 two-wheeled motorcycles on average per day from April 1 to 30, 2022. In this part we are interested in the numbers of heavy goods vehicles which apply a great pressure to the roadway. Table 3 below gives the percentage of heavy goods vehicles in hours of traffic per day recorded during the experiment.

These results of counting (1671 Pl/d) are three times higher than that defined for the study before the work, which is around 600 Pl/d (DGR-BURKINA [5]). The frequency of heavy vehicle traffic is greater in the time interval from 10 a.m. to 6 p.m. with a number of 739 (Pl) or a percentage of 44.22%. The histogram shown in Figure 4 shows the different percentages of truck traffic and by hours of traffic.

According to the normal evolution of traffic after ten (10) years of service, the number of HGV traffic in 2022 should be around 924 (pls/day) instead of 1671 (pls/day) with an increase of 4% by applying the relation TPL (last year) = (1 + τ) n + 1 TPL (year of commissioning). The road receives 747 (pl/day), *i.e.* a heavy load of more than 80.84% compared to the normal evolution of traffic.

With τ = traffic growth rate, n = number of years of service, TPL = heavy goods vehicle traffic.

4. Mechanism of Degradation of the Pavement Structures of the RN1

The design results of French pavements using the Burmister elastic model of Denis Duhamel *et al.*, show that the stresses and deformations of the pavements are subjected to heavy heavy traffic and strong temperature guardians. Based on these results, we propose a degradation equation for pavement structures defined by Equation (1):

Climate + Traffic = Degradation

$$\underbrace{\begin{pmatrix} \text{temperature} \\ \text{sunshine} \\ \text{precipitation} \\ \text{wind speed} \end{pmatrix}}_{\text{Climatic parameters}} + \underbrace{\begin{pmatrix} \text{traffic load} \\ \text{vehicle vibration} \\ \text{vehicle speed} \\ 0 \end{pmatrix}}_{\text{Traffic Parameters}} = \underbrace{\begin{pmatrix} \text{cracks} \\ \text{surface deformation} \\ \text{potholes} \\ \text{flaws in the urban area} \end{pmatrix}}_{\text{Types of degradation}}$$

In the case of our study of the RN1, we have retained three types of major degradation, namely the deformation of the pavement (Figure 5), the pavement cracks (Figure 6) and the potholes (Figure 7) resulting from the action of temperature and traffic pressure at the YIMDI toll booth at the western exit of Ouagadougou.

Table 3. Percentage of heavy goods vehicles in hours of traffic per day.

N°	Traffic period	Number of heavy goods vehicles	Percentage of heavy goods vehicles
1	0 am to 10 am	527	31.54%
2	10 am to 6 pm	739	44.22%
3	6 pm to midnight	405	24.24%
	Total	1671	100%

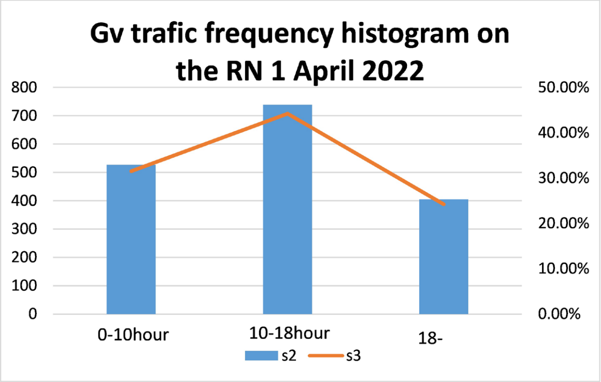

Figure 4. Percentage of hourly heavy goods vehicle traffic on RN 1.

Figure 5. Pavement deformation due to temperature and traffic pressure.

Figure 6. Pavement cracks due to temperature and traffic pressure.

Figure 7. Potholes due to traffic pressure.

5. Results

In this part of our work we will present the experimental results through the representations of the graphs of the evolution of the temperatures recorded by the thermocouples according to the solar irradiation. We have three types of values;

- The values recorded during the hot and dry period on dates 1 to 11, 13, 14, 15 and from 17 to 27 and from 29 to 30 April 2022, the maximum temperatures of which at 1:40 p.m. recorded at the level of the bituminous concrete are of the order 65.5˚C.
- The values recorded during the humid and less hot period on April 12 and 16, 2022, of which the maximum values recorded in the asphalt concrete at 1:40 p.m. is 42.5˚C on 12-04-22 and 23.5˚C on 16-04-22. These temperature drops are due to the rains of April 12 and 16, 2022.
- The values recorded during the dry and less hot period on April 28 and 29, 2022, of which the maximum values recorded in the asphalt concrete at 2:40 p.m. is 40.6˚C on 28-04-22 and 39˚C on 29-04 -22. This drop in temperature is due to cloud cover during the two (02) days.

The results of the experiments gave minimum temperature values of between 25˚C and 40˚C from midnight to 9 a.m. and from 6 p.m. to 11 p.m. The maximum temperatures are between (50.0 ± 0.2)˚C and (65.5 ± 0.3) in the time interval between 10 a.m. and 6 p.m. for sunny and dry days.

5.1. Evolution of the Temperature in Pavement Structures on the Hottest and Driest Days from 1 to 11, 13, 14, 15 and from 17 to 27 and from 29 to 30 April 2022

Figure 8 and **Figure 10** show the profiles of the maximum temperatures recorded by the thermocouple (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10) on the day of 04-01-22 and 04-27-22 depending on the solar irradiation indicated by **Figure 9** and **Figure 11**. The shape of the curves is the same for the days from 1 to 11, 13, 14, 15 and from 17 to 27 and from 29 to 30 April 2022. The maximum temperatures recorded during this period, from 10 a.m. to 6 p.m., are between 50.5 and 64.3˚C at the level of the asphalt concrete layer. Those recorded at the level of the laterite layer are between 50˚C and 54.3˚C. Maximum ground temperatures in the shade vary between 39.4˚C and 41.6˚C. Those in the sun vary between 63.7˚C and 66.2˚C on the ground. The maximum irradiation is more than 980.2 (w/m^2). The temperatures recorded at the level of the bituminous layer show a difference of more than 7˚C compared to those of the softening of the bitumen which is between 50˚C and 58˚C for the bitumen of class 35/50. During the night from 6 p.m. to 10 p.m., the minimum temperatures inside the asphalt concrete are between 33˚C and 35˚C and those minimum inside the laterite are between 37˚C and 39˚C. We can say that the laterite has stored the heat coming from the layer of asphalt concrete during the day. In the absence of sunshine, the heat rises from the laterite to the bituminous concrete. It spreads from warmer areas to colder areas. The maximum temperature difference of 64.3˚C at the level of bituminous

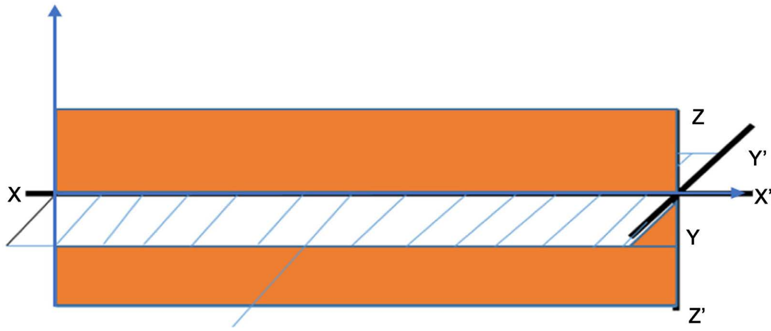

Figure 8. Pavement diagram.

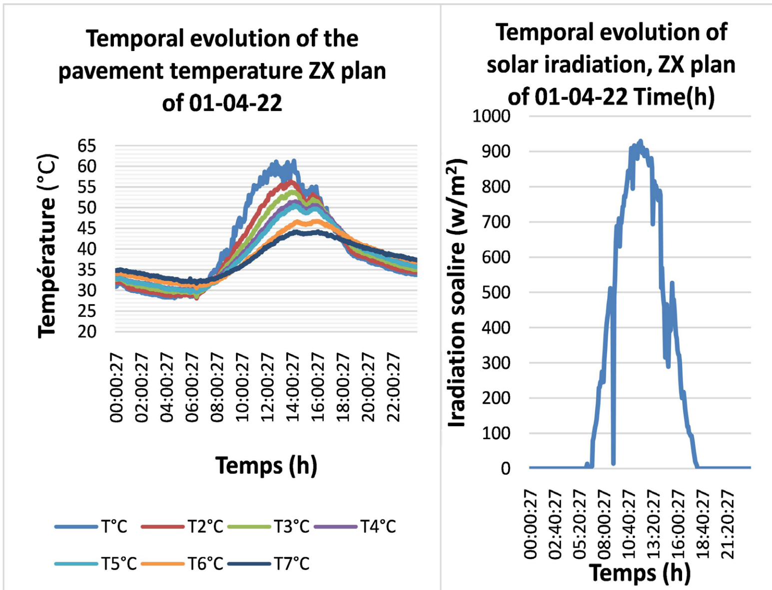

Figure 9. Profile of pavement temperatures and solar irradiation on 01-04-22.

concrete and that of laterite 54.7˚C could be justified by the fact that the thermal conductivity of laterite (1.85 W/mk) is low compared to to that of bituminous concrete (2.20 W/m·K). The greater the thermal conductivity of a body, the higher the thermal diffusivity recorded by this body. The increase in temperature in the bitumen is also linked to the black color of the bitumen, which by definition is a body that fully absorbs the solar radiation it receives. The value of the albedo of black bodies is substantially equal to 0 (significant absorption coefficient). The reflected flux is zero and at night, the outgoing flux is made up of the emitted flux (emission coefficient of the black body equal to its absorption coefficient, equal to 1).

The road subject to the experiment is materialized in a plane along the axis (ZX) in Figure 8. The axis (X) follows the direction of circulation of the road and that of (Z) follows the different thicknesses of the layers of pavements.

The temperature evolution curves in the pavement structures and that of the evolution of the solar irradiation of the hot days of 01 and 27-04-22, are indicated in Figure 9, Figure 10 by way of example.

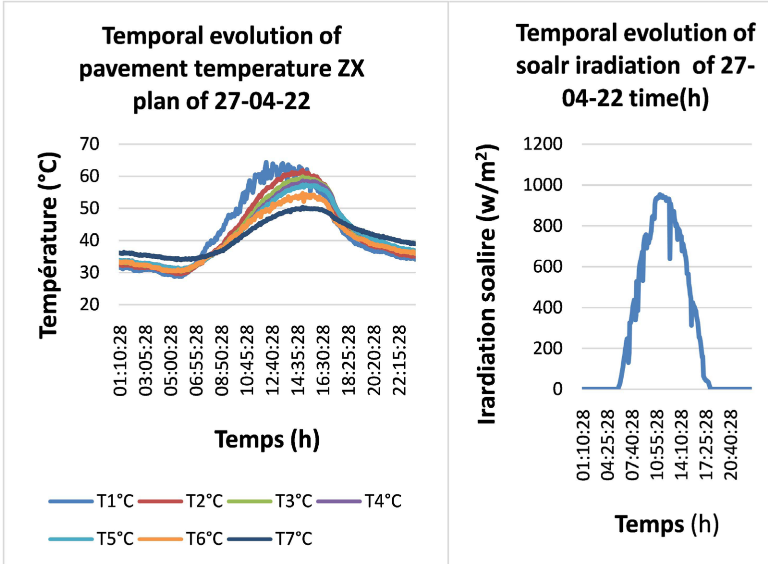

Figure 10. Profiles of pavement temperature and solar irradiance on 27-04-22.

In this part of the study of the hottest days of the month, the recording temperatures of 64.3˚C are higher than that of the softening of the 35/50 class bitumen which is between 50˚C and 58˚C. Class 35/50 bitumen may soften faster than expected. The roadway of the RN1 registers a significant load of more than 80.84% of the traffic of the heavy goods vehicles compared to the normal evolution of the traffic. The pavement could undergo deformation due to the increase in temperature and that of traffic. This could lead to the breaking of the bonds of the particles that constitute the materials in the time interval from 10 a.m. to 6 p.m. and consequently the pavement could deteriorate more quickly than expected.

5.2. Evolution of the Temperature in the Pavement Structures of the Less Hot and Humid Days of April 12 and 16, 2022 (Rainy Days)

Figure 11 and **Figure 12** show the temperature profiles inside the pavement structures for the less hot and humid days of April 12 and 16, 2022. The maximum temperatures recorded on 12-04-22 at 1:40 p.m. are 42.5˚C in the bituminous concrete layer is 39˚C in the laterite layer. Maximum temperatures recorded from 16 -04-22 to 1:40 p.m. are 23.5˚C in the bituminous concrete layer and 27˚C in the laterite layer. These temperature drops are due to the rains of April 12 and 16, 2022. The maximum temperature in the bituminous concrete layer of the two days shows a deviation of less than 16.5˚C and 31˚C respectively from that of the softening of the 35/50 class bitumen. Solar irradiation also changes according to the rainfall conditions (**Figure 10** and **Figure 11**). The more rain there is, the lower the solar irradiation. The pavement registers less heat and the bitumen softens less quickly. There will therefore be no deformation of the pavement structure when it is subjected to heavy vehicle traffic.

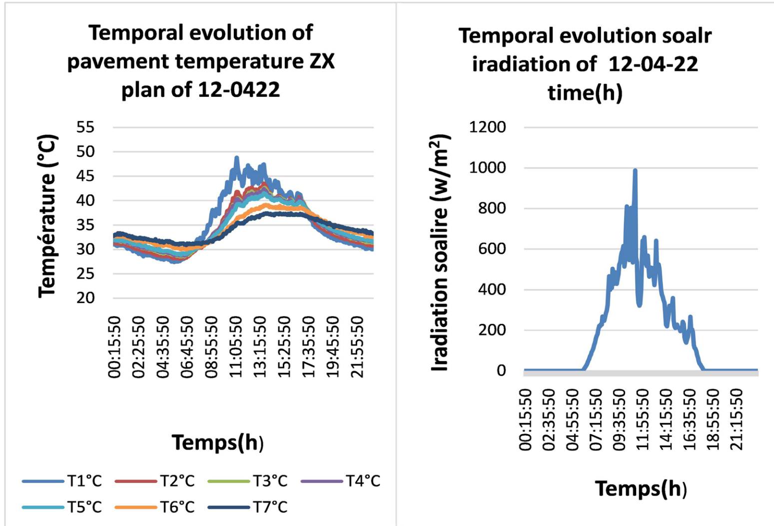

Figure 11. Temperature profiles of the pavement and the solar irariaditon of u 12-04-22.

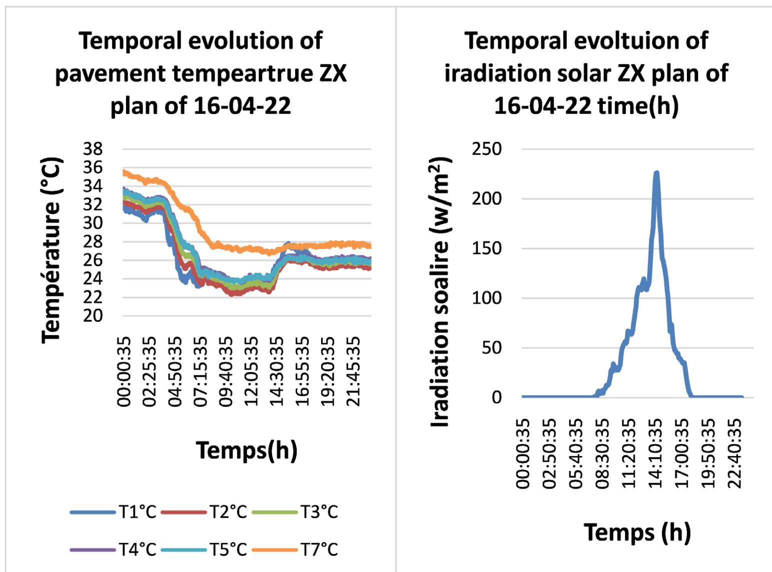

Figure 12. Temperature profiles of the pavement and solar irradiation on 16-04-2022.

Therefore, climatic conditions have an impact in the process of degradation of pavement structures.

5.3. Evolution of the Temperature in the Pavement Structures on the Less Hot and Dry Days of April 28 and 29, 2022 (Sky Covered with Cloud)

Figure 13 and **Figure 14** show the temperature profiles inside the pavement structures for the days of April 28, 2022. The maximum temperatures recorded on 28-04-22 at 2:40 p.m. are 40.6˚C in the concrete layer bituminous. Those recorded on 29-04-22 are 39˚C. This drop in temperature is due to cloud cover

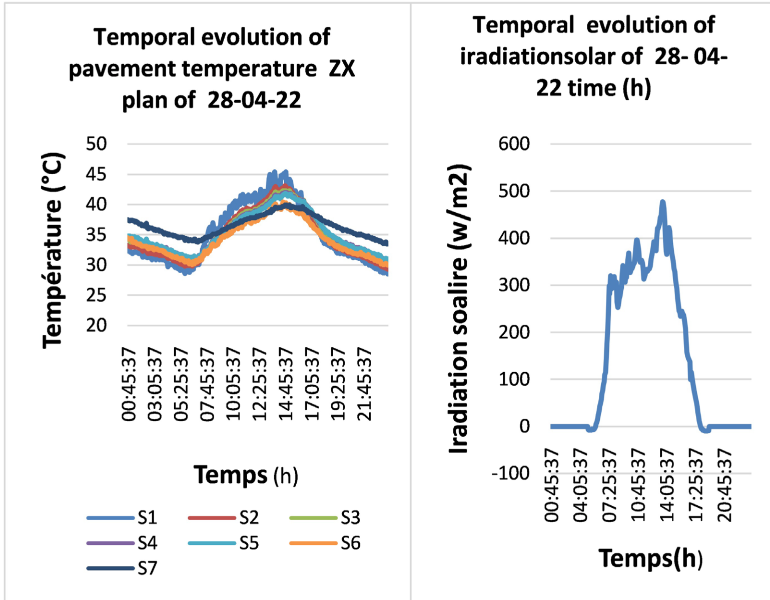

Figure 13. Profile of pavement temperatures and solar irradiation on 28-04-22.

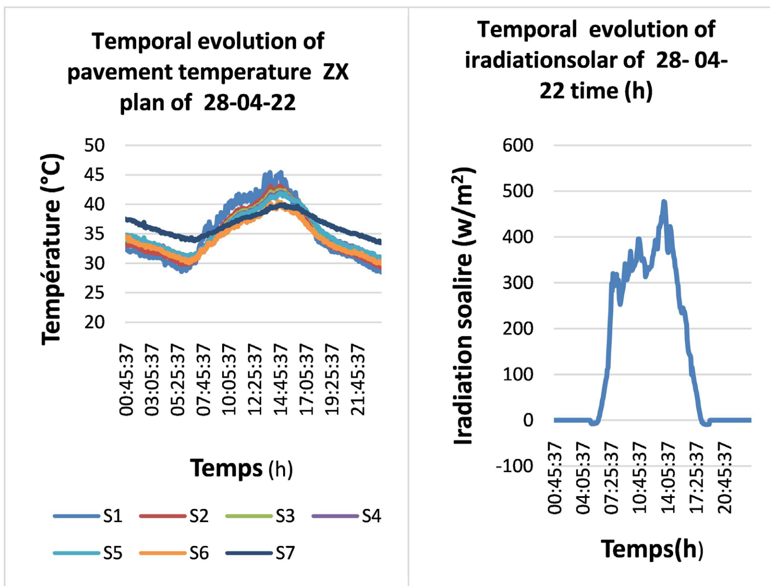

Figure 14. Temperature profile of the roadway and solar irradiation on 29-04-22.

during the two (02) days. These temperatures present in the bituminous concrete layer a difference of more than 11˚C than that of the softening of class 35/50 bitumen [50˚C and 58˚C].

- “square meter”, not “webers/m^2”. Spell out units when they appear in text: “...a few henries”, not “...a few H”.
- Use a zero before decimal points: “0.25”, not “0.25”. Use “cm^3”, not “cc”.

The maximum temperature in the asphalt concrete layer of the two days shows a deviation of minus 10.6˚C and 12˚C respectively from that of the softening of the 35/50 class bitumen [50˚C and 58˚C]. In this period of cloud cover, the roadway also recorded less heat. The asphalt concrete did not soften. There will therefore be no deformation of the pavement structure when it is subjected to heavy vehicle traffic. This confirms the fact that climatic conditions have an impact in the degradation process of pavement structures. The more cloud cover there is, the less solar radiation there is and therefore the roads will receive less heat.

6. Conclusions

In this article, an experimental study was conducted to assess the spatio-temporal evolution of temperatures inside the pavement structures of the RN1. The results obtained allowed us to compare the experimental values to the softening temperatures of class 35/50 bitumen carried out in the laboratories. These results show that the temperatures inside the pavement structures vary according to the solar irradiation. Naturally, the greater the solar irradiation, the higher the temperatures recorded. When the temperature recorded by the pavement is greater than that of the softening of the bitumen, the bituminous concrete softens prematurely, causing a displacement of the pavement materials.

For the month of April 2022, between 10 a.m. and 6 p.m. the maximum temperatures recorded are between 50˚C and 64˚C inside the bituminous pavements with a difference of more than 7˚C compared to those of the softening of the bitumen and a percentage of heavy goods vehicles of more than 80.84% compared to the normal evolution of traffic.

The results obtained will allow us to propose a short-term solution, a regulation defining the traffic period in the interval from 9 a.m. to 6 p.m. for the traffic of heavy goods vehicles with an automatic counting system for heavy goods vehicles in order to limit their daily number. This could be integrated into training courses on the Highway Code in particular in Burkina Faso and for the Sahelian countries in general.

In perspective, it will be a question of proposing an experimental study on the use of sugar cane residues for the construction of the surface layer of pavements in order to reduce the thermal conductivity of pavement materials.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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