Binder performance and testing

Performance Bitumen Grades – Climatic Mapping Evaluation for Western Europe

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Abstract

There is a growing trend worldwide to introduce a performance approach to select bitumen for roads construction. This strategy has been adopted in North America for several decades. The assessment of bitumen performances goes through determining properties based on rheological measurements. They characterize the viscoelastic behaviour of studied bitumen under well-defined testing conditions. The result is to provide specific temperatures at which bitumen undergoes noticeable physical modifications which describe and differentiate product grades according to dedicated standards. Conducting such determinations is of great interest when obtained temperatures can be compared to climatic conditions encounter by roads throughout the year, and particularly during summer and winter periods where pavements may be affected by different types of physical damages. When binder rheological performances match climatic road conditions, selected binder can be used. For paving bitumen grades, Europe is currently following harmonized standards based on utilization of empirical test methods, but trends are also to develop new specifications more-directly performance related. The objective of this paper is to (1) Present a climatic mapping of selected countries to screen typical high and low pavement temperatures in Western Europe. (2) Compare if observed rheological performances of paving bitumen grades used to build those roads are aligned with determined high and low pavement temperatures requirements.

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I. Introduction

There is a growing interest worldwide to complement or replace empirical characteristics used to describe bitumen by new properties better adapted to address material performances[1,2,3]. In Europe, empirical tests (penetration at 25°C, ring and ball softening point …) used for decades, are rapid and easy methods to perform. They provide relevant information ensuring a good match with their applications in pavement mixes.

Recently, the European Commission expressed its request for higher material durability which should push the bitumen industry to consider having characteristics which describe the bitumen performance~~s~~.

This approach has been adopted in the United States (US) for several decades. This change has conducted to develop new norms to qualify bitumen based on a performance grade (PG) system framed by the AASHTO M320[4].

The assessment of product performances, which constitutes the first pillar of the US system, goes through determining properties based on rheological measurements which aim at characterizing the viscoelastic behavior of bitumen under well-defined conditions. The result of these tests is to provide relevant temperatures ranges for which bitumen undergoes noticeable physical modifications and which describe / differentiate product grades.

The conduct of such determinations is instructive in itself, but is of greater interest when the temperatures obtained is compared to the climatic conditions that roads encounter throughout the year, and particularly during the summer and winter periods where the pavement may undergo different types of physical constraints.

This step constitutes the second pillar of the system implemented in the US. When the performance grade determined on a given bitumen matches the climatic road conditions where the material has to be used, this one can be applied. It has to be noticed that an extra dimension was introduced to address traffic loading which has an effect on selected bitumen also. In Europe, the selection of bitumen for a given application is still based on conventional properties like the penetration at 25°C. The determination of the rheological properties as proposed in the recent EN 12591 draft is informative for the time being but may be seen as a first step towards a future system such as the one implemented in the US.

The objective of current paper is to provide the readers with an explanation on how the AASHTO system works and can be applied to Western Europe. A first part will address the climatic mapping required to establish thermal conditions that roads undergo. A second part will allow positioning typical bitumen used in Western Europe versus this climatic mapping.

II. Climatic Mapping Concept

In 1987 started the Strategic Highway Research Program (SHRP) which aimed to improve the performance and durability of roads in the US. The objective was to develop performance based bitumen material specifications to relate laboratory analysis with field performances.

The outcome of this program was the creation of the Superpave system which is a comprehensive bitumen mix design and analysis system. The Superpave binder selection procedure is based on the lowest and highest temperatures expected at a given road location.

The determination of the two temperatures mentioned above is the outcomes of the Long Term Pavement Performance (LTPP) program which begun in 1987 and which aimed to evaluate pavement performances and the factors that affect them. From this program, models were developed to evaluate the pavement low and high temperatures defined by the two equations reported in Tables 1 and 2 respectively[5]. Each of them is built according to a same structure based on a constant modulated by four functions which take into account the air temperature of the selected location based on several years of records, the latitude of this location, the depth in the pavement and a statistical adjustment based on the air temperature records.

$LT_{pav} = - 1.56 + 0.72\ (T_{air}) - 0.004\ (L)^2 + 6.26 \log (H+25) - z\ (4.4 + 0.52\ (\sigma_{air})^2)^{1/2}$	
LT_{pav}	Low pavement temperature below the surface
T_{air}	Low air temperature (low 1-day) calculated as a mean of several consecutive years of records
L	Latitude of the section
H	Depth to surface
σ_{air}	Standard deviation of the low air temperature mean
z	From the standard normal distribution table with z = 2.055 for 98% reliability and 0 for 50% reliability

Table 1 – LTPP low pavement temperature model.

$HT_{pav} = 54.32 + 0.78\ (T_{air}) - 0.0025\ (L)^2 - 15.14 \log (H+25) - z\ (9 + 0.31\ (\sigma_{air})^2)^{1/2}$	
HT_{pav}	High pavement temperature below the surface
T_{air}	High air temperature (high 7-days) calculated as a mean of several consecutive years of records
L	Latitude of the section
H	Depth to surface
σ_{air}	Standard deviation of the high air temperature mean
z	From the standard normal distribution table with z = 2.055 for 98% reliability and 0 for 50% reliability

Table 2 – LTPP high pavement temperature model.

Currently, some states in North America use an updated version of the LTPP models which was developed to determine directly the PG high temperatures of required binders without establishing the pavement high temperatures like previously described. The new equation[6] developed for this purpose was built to integrate rutting damages (the process to determine the PG low temperature is unchanged). To address rutting damages in the PG high temperature determination, the equation considers axel loads which vary depending on the country (the US does not use the same values than Canada) and may not provide a good representation of what could be the European traffic type situation. Since current paper aims to provide a first approach to the concept of climate mapping applied to Western Europe for selecting binders based on road pavement temperature during summer and winter, these models were not considered in this paper.

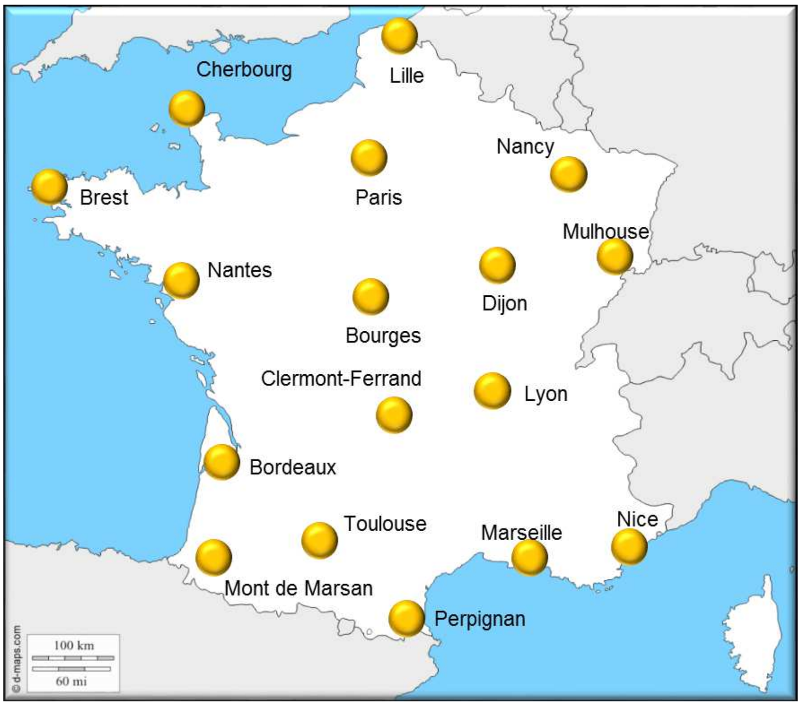
Along the same line, the last version of the PG specifications (the AASHTO M322[7] standard) which introduces the Multiple Stress Creep Recovery (MSCR) test was not considered in this paper. The major benefit of this new test is to eliminate needs of running tests to assess polymer modification of bitumen (elastic recovery, force ductility …). Because this screening addresses pure bitumen, the application of this standard was not considered in this paper.

III. Climatic mapping of Western Europe

Previous equations from the LTPP program, developed for the US and now used by all countries in North America (US, Canada and Mexico), can be applied to other regions of the world.

In order to assess pavement temperatures in Western Europe, France was selected because this country alone is a summary of the prevailing climatic conditions of this region that characterize countries such as the United Kingdom, Germany and Italy. Indeed, France is characterized by a temperate oceanic climate on its North West part, by a semi-continental climate on its North East part and by a Mediterranean climate in the South. The mountainous climate existing in France (and in Western Europe) was not considered in this study because specific binders are usually applied to satisfy road constraints in this specific environment.

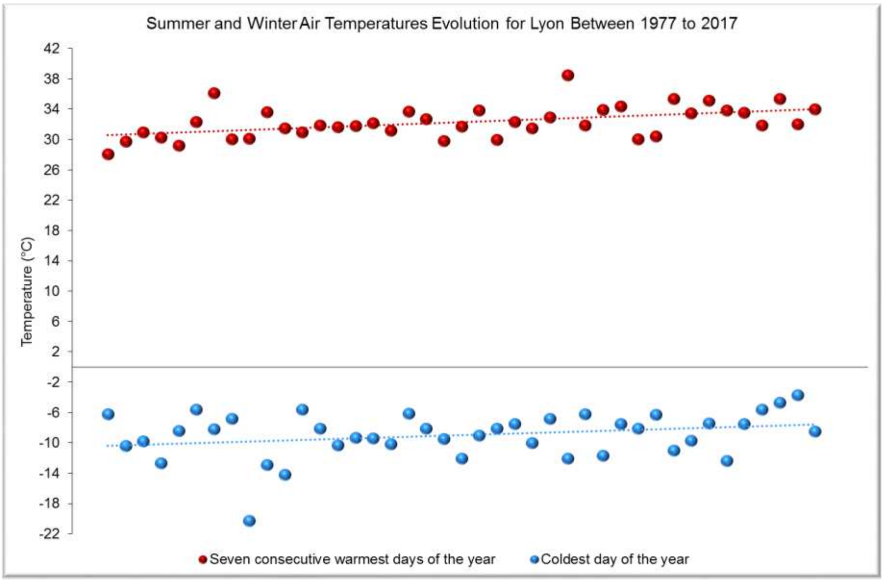
The climatic mapping of France was realized using the weather data provided by the National Center for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA)[8]. Graph 1 provides the weather land-based station locations used for this study. This selection has no intent to be an exhaustive coverage but it should be seen as a screening to assess general trends (no satellite data such as those provided by MERRA[9] where considered in this paper).



Graph 1 – Selected weather locations in France.

Such as mentioned in Tables 1 and 2, the determination of the LTPP high and low pavement temperatures is based on the mean of several consecutive years of air temperature records to get robust statistical trends. Consequently, for each location identified on Graph 1, weather data were collected arbitrary for the last 40 years between 1977 and 2017. For each year, the air temperature of the seven consecutive warmest days of the year and the temperature of the coldest day of the year were determined. For simplification purpose, those two air temperatures will be called respectively summer and winter air temperatures.

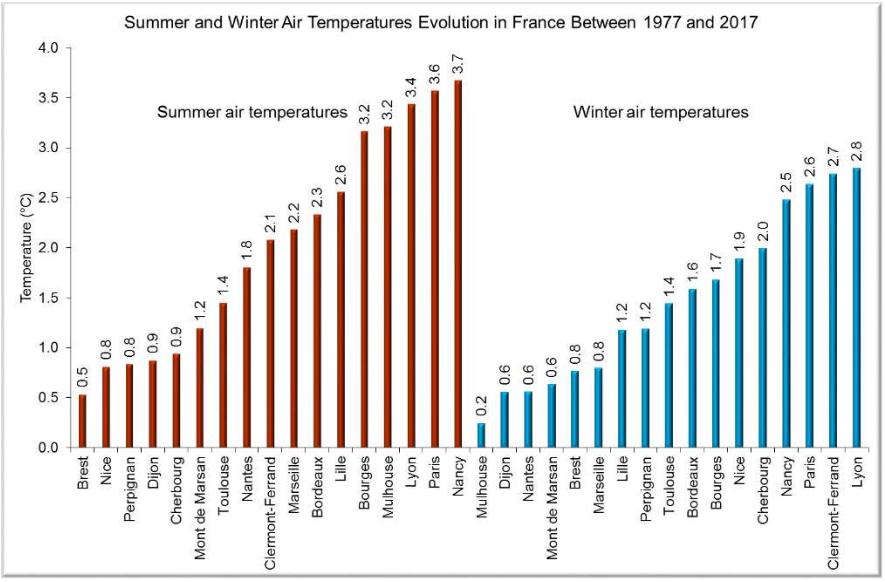
To illustrate this weather data collection, graph 2 provides an example for the Lyon area showing summer and winter air temperatures and how they have evolved during the last 40 years. It is interesting to note that both temperatures have increased respectively by around 3.4 and 2.8°C between 1977 and 2017 (averages based on a linear regression).



Graph 2 – Summer and winter air temperatures evolution for the Lyon area.

The same analysis was made for the 17 locations selected and conduct to the same observations. Graph 3 illustrates for each location by how much summer and winter air temperatures have increased between 1977 and 2017 allowing to calculate an average increase for France of respectively 2.0 and 1.4°C during this period of 40 years.

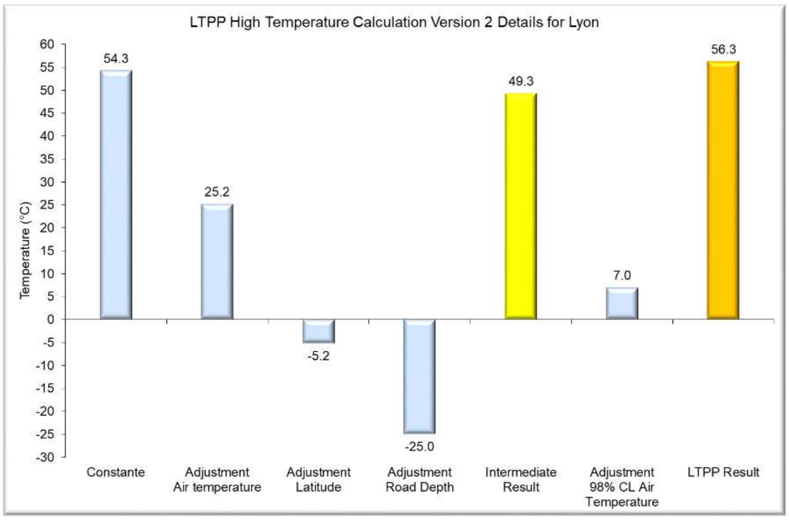
These values are consistent with information provided by the French Ministry for the Ecological and Solidary Transition which reports that the average temperature in France in 2014 was 1.9°C higher than the average temperature established on the 1961-1990 period (used as a reference)[10]. This information will have its importance to analyze current and future AASHTO road pavement PG requirements presented later in this paper.



Graph 3 – Increase of summer and winter air temperatures in France between 1977 and 2017.

IV. Understand the AASHTO system to define road pavement PG requirements

Prior to evaluate the road pavement PG requirements based on the climatic mapping of France and its meaning, it is important to understand how the AASHTO system is built to determine the type of binder to select and use on road works. Such as reported Table 1, the LTPP high temperature calculation is based on a constant adjusted using four functions. Graph 4 illustrates those details using the example of the Lyon location.



Graph 4 – Calculation details to establish the LTPP high temperature based on Lyon data.

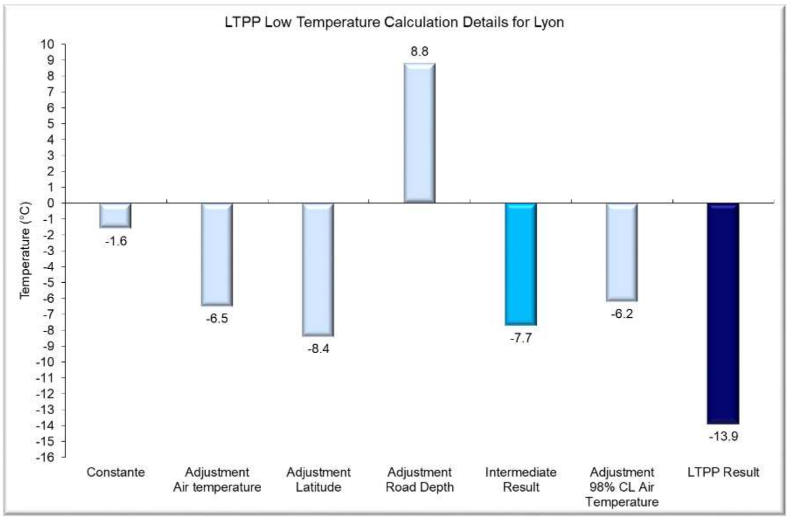
For this example, the constant +54.3°C is corrected by 3 adjustments linked to the summer air temperature +25.2°C, the latitude -5.2°C and the pavement depth at which temperature effects are evaluated -25.0°C. Obtained intermediate result +49.3°C should be considered as the average temperature at which a road in the Lyon area is subjected during the summer period.

This value corresponds also to the LTPP high temperature result when the standard deviation on summer air temperature is applied with a 50% confidence level. When a 98% confidence level is used, an extra adjustment +7.0°C is added to previous result. The addition of this 'safety margin' conducts to the formal result +56.3°C of the LTPP equation for determining the pavement high temperature in the Lyon area.

The same methodology is applied to determine the LTPP low temperature as described in Table 2 and illustrated for Lyon on Graph 5. For this example, the constant -1.6°C is corrected by 3 adjustments linked to the winter air temperature -

6.5°C, the latitude -8.4°C and the pavement depth at which temperature effects are evaluated +8.8°C. Obtained intermediate result -7.7°C should be considered as the average temperature at which a road in the Lyon area is subjected during the winter period.

This value corresponds also to the LTPP low temperature result when the standard deviation on winter air temperature is applied with a 50% confidence level. When a 98% confidence level is used, an extra adjustment -6.2°C is added to previous result. The addition of this 'safety margin' conducts to the formal result -13.9°C of the LTPP equation for determining the pavement low temperature in the Lyon area.



Graph 5 – Calculation details to establish the LTPP low temperature based on Lyon data.

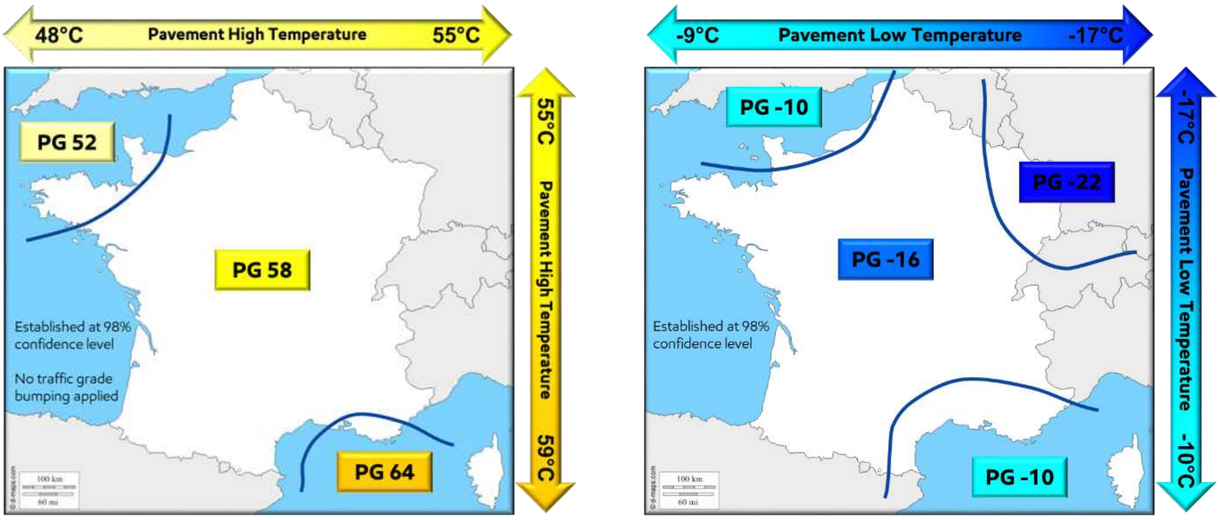
From those results, the next step consists in determining the type of PG binder high and low temperatures that should be selected for complying with summer and winter pavement temperatures. According to previous example, the binder to be selected for Lyon should include a range of temperature from -13.9 to +56.3°C.

Based on the AASHTO M 320 standard, selected grade should be a PG 58-16 (which covers temperatures from -16 to + 58°C) to satisfy road temperature in the Lyon area. It has to be noticed that temperature ranges covered by both grades exceed the temperature ranges established by the LTTP equations which constitutes an extra 'safety margin' which guaranties that no damage should occur on the roads when such binders is applied.

V. Road pavement PG requirements in France in 2017

The LTPP high and low temperatures were determined for the 17 locations selected to represent France. Across the country, the LTPP high temperatures (summer) range from +46.5°C (Cherbourg) to +57.1°C (Marseille). For the LTPP low temperatures (winter), the range is established between -5.3°C (Nice) to -17.4°C (Nancy). Those results can allow determining the PG binders needed to meet the road requirements across the country as represented on Graph 6. On this graph, it can be observed that France is represented by 3 main PG high temperatures corresponding to PG 52, 58 and 64°C. On the PG low temperatures side, France is also characterized by 3 main temperatures corresponding to PG -10, -16 and -22°C.

For the North West part of France, a PG 52-10 should satisfy both summer and winter road temperatures. This type of material should represent the binder suitable for European countries characterized by a temperate oceanic climate (UK for example). For the North East part of France, a PG 58-22 should be selected. This is also the type of grade that should be used by European countries under a semi-continental climate (Germany for example). A PG 58-16 should satisfy the needs for the Center of France and finally the South of France which described European countries characterized by a Mediterranean climate (Italy or Spain for example) should use a PG 64-10. In general, a PG 58-16 should satisfy most of current needs in France.



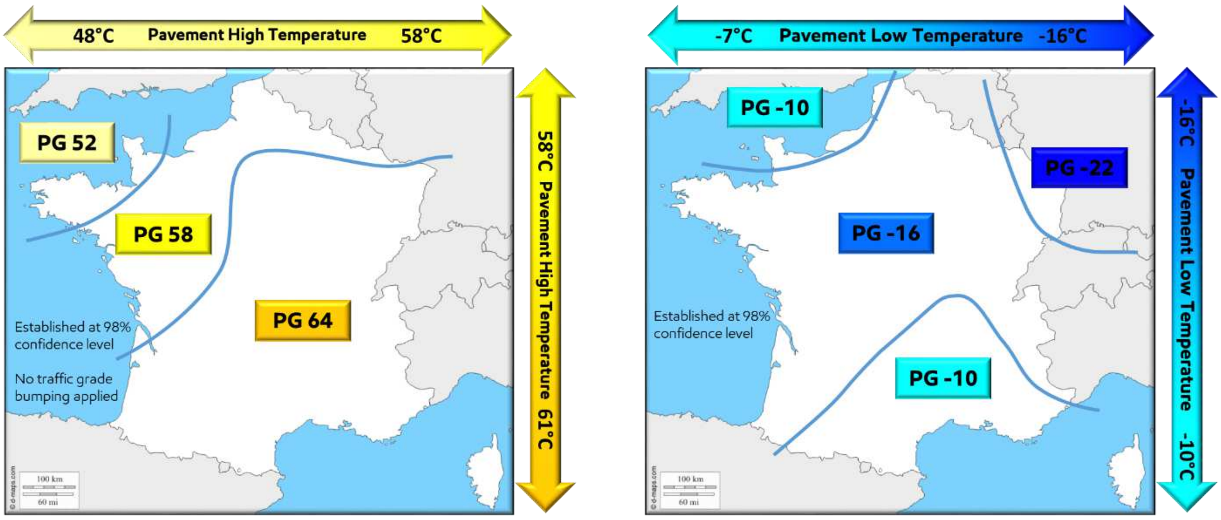
Graph 6 – PG high and low temperatures trends in France in 2017.

VI. Estimation of road pavement PG requirements for France in 2057

Graph 3 has shown the summer and winter temperature increases for France between 1977 and 2017. Assuming this trend will continue in coming years, summer and winter temperature in 2057 (next 40 years) can be estimated by extrapolation for the 17 locations selected for this study (this assumption is consistent with the projections made by the French administration[11]). Under such future weather conditions, the LTPP high and low temperatures were estimated for 2057.

The future LTPP high temperatures (summer) may range from +47.6°C (Cherbourg) to +60.3°C (Lyon) in 2057 and the LTPP low temperatures (winter) may range between -5.5°C (Nice) to -16.2°C (Nancy) in 2057.

As shown on Graph 7, the repartition of the PG high and low temperature may change between 2017 and 2057. Needs in PG -10°C should increase in the south of France up to Lyon and areas requesting a PG -22°C should be reduced. In many regions, needs in PG 58°C may decline replaced by PG 64°C. In general, a PG 64-16 should satisfy most of the needs in France in 40 years from now.



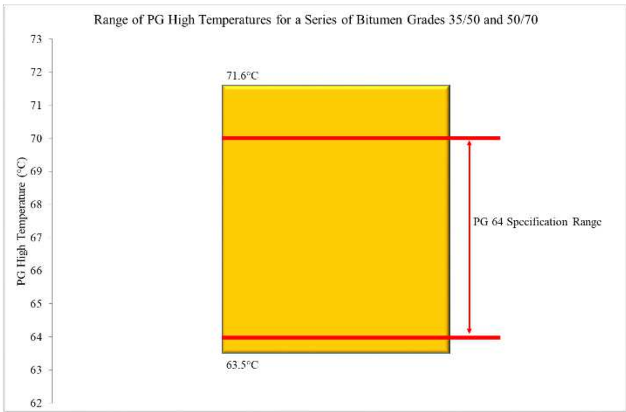
Graph 7 – PG high and low temperatures estimation in France for 2057.

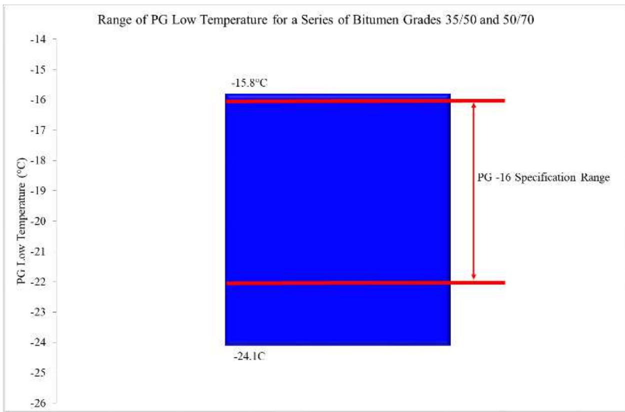
VII. Bitumen qualities versus climatic mapping and PG requirements for France

Today in Europe, bitumen classes are selected depending on the type of targeted layer and hot mix asphalt application. The selection depends as well on the climate and traffic intensity. For a large majority of road works in France, bitumen grades 35/50 and 50/70 are typically used. According to current study, most of the roads in France supporting regular traffic conditions, today (2017) and in the future (2057), should be built broadly with a PG 64-16 knowing that this last grade should progress in France due to the global warming.

At this stage, it was important to determine if there is appropriateness between typically bitumen grades 35/50 and 50/70 and the required PG 64-16 in application of the Superpave system.

Graph 8 presents PG high and low temperature ranges for a series of 40+ bitumen grades 35/50 and 50/70 determined according to the AASHTO M 320 standard and compare to the US specification ranges for a PG 64-16. Those bitumen are mainly produced from crude oils which represent the typical European situation by reference to the live cycle inventory conducted by Eurobitume in 2018 (not published yet).





Graph 8 – PG temperatures for a series of bitumen 35/50 and 50/70 compared to US PG 64-16 specifications.

Graph 8 indicates that for the 40+ bitumen grades tested, the PG high temperatures range from 63.5 to 71.6°C and the PG low temperatures range from -15.8 to -24.1°C. In conclusion, studied bitumen grades 35/50 and 50/70 satisfy the pavement high temperature of 64°C (range from 64 to 70°C) required to build most of the road in France in 2017 and in the future. This graph indicates also that for the same population of studied bitumen grades 35/50 and 50/70, the pavement low temperature of -16°C (range from -16 to -22°C) is also satisfied.

It can be concluded that bitumen grades 35/50 and 50/70 available in Europe (by reference to the live cycle inventory conducted by Eurobitume regarding the average crude oils composition) when translated under the AASHTO systems correspond to a binder PG 64-16. This result validates the potential application in Europe of the system developed for North America and illustrates which bitumen grades would be selected by applying European criteria for road construction.

VIII. Conclusion

The system of performance grading developed in the US is based on sound science which aims to make the link between binder and road properties. This study has shown that this system can work for France and more generally for Western Europe to accommodate a large diversity of climates and road traffics.

The LTPP models used to assess summer and winter pavement temperatures allowed determining temperature profiles for France in 2017 and to estimate future trends for 2057.

The application of these models determined that today and in the future most the hot mix asphalts would require a PG 64-16 binder which corresponds to current European bitumen grades 35/50 and 50/70, typically used for such type of application.

This study, which is a screening, should be thorough to better assess climatic details in Europe especially in a context where next generation of bitumen specifications could be performance related.

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Annex

Erratum for paper ID 0322

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