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TIMBER STRUCTURES IN SUBTROPICAL CLIMATE ON DESIGN: BOIS DURAMHEN programs for Guadeloupe, Martinique and Guyane

Paul Quistin[1], Eric Fournely[2], Joseph Gril[3], Gael Godi[4], Luc Cador[5], Thierry Lamadon[6], Laurence Romana[7], Jacques Beauchêne[8], Rostand Moutou Pitti[9],

ABSTRACT: Mainly due to a lack of information on the local climate and its consequences on timber buildings, and regarding Eurocode standard, French West Indies islands and French Guiana remain considered as a service class 3 (SC3). Based on Meteo France (MF) data and moisture content measurements on more than 300 sites in the three departments, on local surrounding air humidity and temperature, the three programs Bois Duramhen 971 (European Synergîle), 972 and 973 (PACTE) are devoted to give answers on the impact of this climate on soft and tropical woods integrated in traditional or new timber structures. Data acquisition and analysis are described. Measurements are performed during more than one year, they are compared and completed by Meteo France data. The analysis is divided in two phases: equilibrium moisture content (EMC) calculated from HR(%) - T(°C) with NFEN1995-1.1/NA moisture diagram and direct measurement of instantaneous MC. Monitoring approaches are performed on, at least few members of two real buildings. In Guiana, drying element are also monitored in order to analyse this natural drying phase. Results obtained by the different approaches, comparison of measurements, calibration of measurement equipment, led to a wide data base and proposals of mapping have been deduced.

KEYWORDS: Service class, Moisture content, Equilibrium moisture content, durability

1 INTRODUCTION

Regarding Eurocode standard dedicated to timber structures, French West Indies islands and French Guiana are often considered as a service class 3 area (the most severe environmental conditions). This decision is partly based on the "severe" climate of these departments, but also mainly on a lack of information on the real local climate and its consequences on timber elements of buildings. A European project, *Synergîle-Bois Duramhen971:BD971*, is devoted to the study of environmental effects on timber structures in Guadeloupe island and two French national projects, *PACTE-Bois Duramhen972: BD972, and Bois Duramhen973: BD973,* propose the same approach for Martinique and French Guiana. The aim of these three programs is to produce a reliable data base and to build a map of service class zones (*SC2 & SC3)* whenever possible. The present work is the results of these studies related to Guadeloupe, Martinique and French Guiana. The chosen strategy is for each [1-3]:

- identification of available meteorological data;
- choice of different buildings or "sites" (≈ 100 for each department);
- 18-months measurement period: temperature (*T*) and relative humidity (*RH*) of surrounding air on the sites, and moisture content (*MC*) on timber elements;
- continuous analysis of the exploitation of data and measurements.

In order widen the data set, different axes of information were investigated (Figure 1). Data provided by Meteo France (MF), the National weather forecast agency, covered large period such as few decades but are limited to available MF stations. Project data covered narrow periods (12 months for the different sites) but a wide area with a large number of sites and buildings. They integrated environmental data but also *MC*.

To complete these measurements, two other main actions were conducted for each department:

- two sites were equipped with 3 monitoring sensors (*HR*%, *T*°C, *MC*%) for 10 months;
- specimens of wood were collected on site and studied for species identification and physical parameters determination on the one hand, tested in environmental chamber to obtain adsorption-desorption characteristics and validate (or not) the equilibrium moisture content (*EMC*) diagram, on the other hand.

[1] Paul Quistin, ANCO Baie Mahault Guadeloupe, France, p.quistin@ancogroupe.fr
[2] Eric Fournely Université Clermont Auvergne, CNRS, Clermont Auvergne INP, Institut Pascal, Clermont-Ferrand, France, eric.fournely@uca.fr
[3] Joseph Gril Université Clermont Auvergne, CNRS, Institut Pascal and INRAE, PIAF, Clermont-Fd, France, joseph.gril@uca.fr
[4] Gael Godi Université Clermont Auvergne, CNRS, Clermont Auvergne INP, Institut Pascal, Clermont-Fd, France, gael.godi@uca.fr
[5] Luc Cador S3CB, Baie Mahault Guadeloupe France, direction.cadrybat@cadrybat.com
[6] Thierry Lamadon BUREAU VERITAS CONSTRUCTION Paris, France, thierry.lamadon@bureauveritas.com
[7] Laurence Romana Université Antilles UA Pointe à Pitre Guadeloupe, France, laurence.romana@univ-antilles.fr
8 Jacques Beauchêne CIRAD UMR EcoFoG, Cayenne, France, jacques.beauchene@cirad.fr
[9] Rostand Moutou Pitti, Université Clermont Auvergne, CNRS, Clermont Auvergne INP, Institut Pascal, Clermont-Fd, France, rostand.moutou_pitti@uca.fr

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Figure 1 illustrates the complementarity of these investigations.

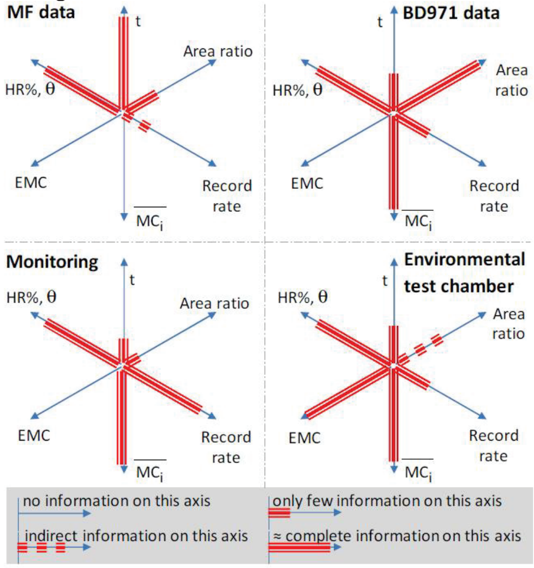
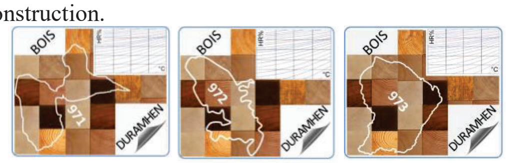


Figure 1: *Complementarity of investigations of projects BOISDURAMHEN [1-3]*

This paper will present successively the specificity of the tropical situation of French departments, the chosen strategy, experimentation on natural drying in Guiana and some results for BD971 (Guadeloupe), BD972 (Martinique) and BD 973 (French Guiana) regarding the sorption behaviour of local species typically used in construction.



2 SPECIFIC SITUATION OF FRENCH CARIBBEAN ISLANDS AND GUIANA

Guadeloupe (16-17°N, 61-62°W) is composed of a main island with two parts and few smallest islands; Martinique (14-15°N, 60-61°W) is one island [4], French Guiana is included in the South American continent.
The climate is a tropical marine one with a wet hot period and a slightly dryer one for the Caribbean islands [4]. French Guiana is located in the Eastern part of the Guiana Plateau, North of the Amazon basin. More than 90% of its territory is covered by humid equatorial forest [5]. The relief is a vast plateau of average altitude between 100 and 200 meters, with some massifs culminating at 800 meters. It is close to the equator (3-5° North latitude). For the study of the BOIS DURAMHEN projects, MF data (*T*, *RH*) were collected over 10 years for 10 to 16 MF stations per department [4-5]; they are positioned on the maps of Figures 2 and 3. The average *RH* history measured in French Guiana is shown in Figure 4.

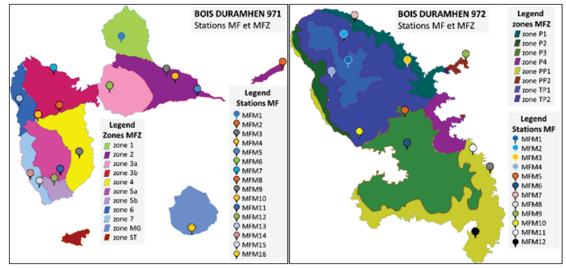


Figure 2: *Location of local meteorological measurement equipment in Guadeloupe and Martinique [4]*

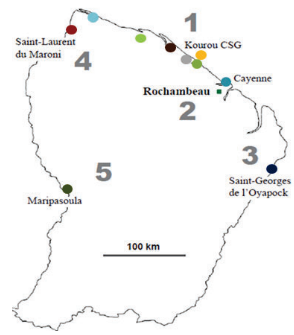
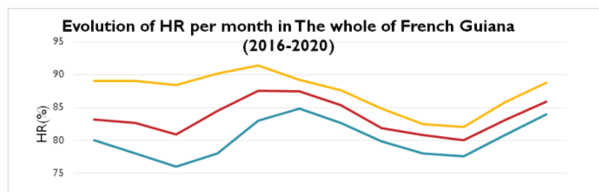


Figure 3: *Location of local meteorological measurement equipment in French Guiana [5]*



	1	2	3	4	5	6	7	8	9	10	11	12
min	80	78	76	78	83	84.8	82.6	79.8	78	77.6	80.8	84
max	89	89	88.4	90.2	91.4	89.2	87.6	84.8	82.5	82	85.8	88.8
moy	83.17	82.65	80.93	84.51	87.58	87.49	85.39	81.88	80.81	80.00	83.04	85.92

Figure 4: *Extreme values of monthly relative humidity of the air for several years, 10 French Guiana weather stations [5]*

3 DATA ACQUISTION

3.1 MONITORING OF CLIMATE AND MOISTURE CONTENT

For the 3 projects, the acquistion of data was based on two sources:

- data sets provided by Meteo France stations, principaly *HR* (%) and *T* (°C) of the surrounding air,
- on-site measurements of the same parameters and also *MC* (%), twice à month during 13 months with a manual measurement equipement (wood moisture meter with digital display, hand-held, non-destructive).

Some of the sites were chosen to be very close to MF station (less than 800 m) in order to compare *HR* and *T* coming from MF measurements records. In French Guiana, to complete the acquisition data and validate the measurements, 2 sites in different towns (Cayenne and Kourou) were equipped with monitoring sensors (3 per site) recording continuously *HR* and *T*, as well as *MC* of

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the wood element (outdoor location). This equipment and its set up are presented on Fig. 5.

Figure 5: *Monitoring 3 wood elements (softwood and hardwood) equipped with sensors in Cayenne.*

3.2 MONITORING OF NATURAL DRYING

To study the natural drying of hardwood under the humidity conditions of French Guiana, the moisture loss down to below fibre saturation point (*FSP*) was monitored for two Guyanese wood species, Angelique (*Dicorynia guianensis*) and Gonfolo (*Qualea rosea*) (Figure 6).

Figure 6: *Natural drying tests: left,* D. guianensis*; right, 8 wood elements (*D. guianensis *and* Q. rosea*) equipped with sensors.*

3.3 MEASUREMENT OF SORPTION ISOTHERMS

The expected *EMC* of wood in a given climate defined by *HR*% and *T*°C, used to define the service class of a zone, is commonly based on the abacus provided by the National Appendix to Eurocode 5- part 1.1 [12-13]. In order to check its applicability to the local context, specimens from 5 typical tropical species used for construction in French Guyana were prepared in Kourou and sent to Clermont-Ferrand, France. Table 1 shows the species designation and the measured specific gravity of the samples.

Table 1 *Species used for sorption isotherm tests*

Species	ID	Specific gravity
Handroanthus serratifolius	EBE	1.071 +/- 0.014
Goupia galbra	GOU	0.883 +/- 0.007
Dicorynia guianensis	ANG	0.816 +/- 0.036
Qualea rosea	GON	0.657 +/- 0.008
Sextonia rubra	GRI	0.590 +/- 0.016

Wood plates 20x20x5mm3 were tested at 28°C in a MKF 240 climatic chamber, with mass measurement at each change of set point. Two samples per species were measured, one oriented TL, one RT. The sequence of *RH* steps, desorption followed by adsorption, is given in Table 2. The *RH* value was previously checked by means of a mirror hygrometer and the set values adapted accordingly [14].

Table 2 *Conditions of sorption isotherms*

Date	*HR* %	*T*°C	Date	*HR* %	*T*°C
01/4/21	93,8	Desorption, 28°C	19/4/21	10,0	Adsorption, 28°C
02/4/21	90,0		20/4/21	20,0	
06/4/21	80,0		21/4/21	30,0	
07/4/21	70,0		22/4/21	40,0	
08/4/21	60,0		23/4/21	50,0	
09/4/21	50,0		26/4/21	60,0	
12/4/21	40,0		27/4/21	70,0	
13/4/21	30,0		28/4/21	80,0	
14/4/21	20,0		29/4/21	90,0	
15/4/21	10,0		30/4/21	93,8	
16/4/21	7,7		03/5/21	0	103°

As the starting state of the wood was unknown, the first point could not be located between the adsorption and desorption isotherms. To clarify this point, a complementary campaign was carried out for the maximum RH level, imposing beforehand a saturation of the same samples by immersion in water for 72h. On this occasion, the hygrometer was recalibrated.

4 RESULTS AND DISCUSSION

4.1 SORPTION ISOTHERMS

The measured sorption isotherms at 28°C are shown in Fig. 7. For each species, the initial desorption is shown in blue and the subsequent adsorption in red. The prediction of the National Appendix [13] for this temperature is shown is dashed line, and the point measured a second time at high humidity, after resaturation, is indicated by the + sign.

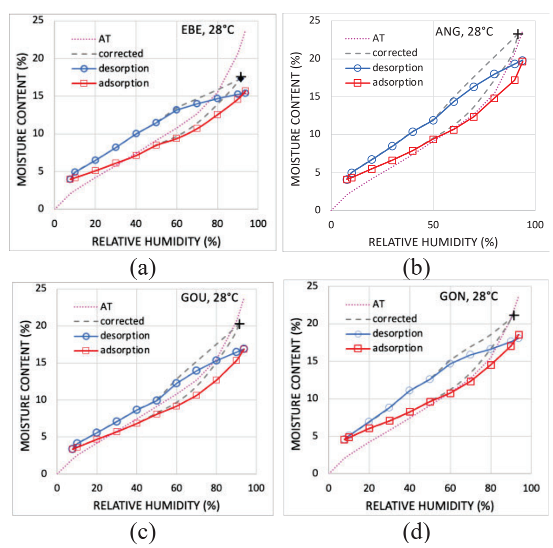

Figure 7: *Sorption isotherms at 28°C: (a)* H. serratifolius*; (b)* G. Galbra*; (c)* D guianensis*; (d)* Q. rosea*; (e)* S. rubra*. Dotted line: abacus from the National Appendix (AT). Dashed line: correction from new measurements after re-saturation.*

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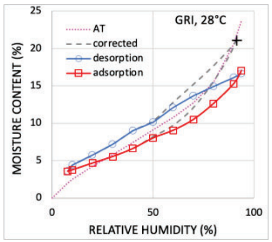

(e)

In the curves of the first campaign, a strong hysteresis between adsorption and desorption can be observed, which can be explained in part by the fact that the duration of the humidity steps is too short to reach a true equilibrium. In view of these results [14], a good agreement with the predictions of the Appendix appears for 40<*HR*<75%, these being placed in an intermediate position between the adsorption and desorption curves. At low humidities, the values are systematically slightly higher. This can also be explained by the slow diffusion process at low humidities. On the other hand, at high humidities the measured values were much lower, suggesting that these tropical woods are less hygroscopic than the temperate woods on which the Appendix charts are based. The measurements of the second campaign led us to question this analysis, as the points obtained, indicated by a cross on the graphs, were, on the contrary, very close. In addition to the correction on the mass allowed by the prior saturation, the more precise measurement of the hygrometry suggests that it had been slightly overestimated during the first campaign. The lower value observed for *H. serratifolius* could be explained by the high density (higher than 1) of this wood, which might have resulted in incomplete saturation. Independent observations [15] (J. Beauchêne, personal communication) suggest, however, that this species is really less hygroscopic than normal; it could be, especially for this species, that the bias on the slow diffusion applies to the whole isotherm, which would be globally overestimated. This reservation could also apply, to a lesser extent, to *G. galbra* which comes behind *H. serratifolius* in density and reputation for lower hygroscopicity [8, 10, 11, 14].

4.2 EQUILIBRIUM MOISTURE CONTENT EMC%

For each country, *EMC* was derived from climatic data, and *MC* was measured. A monthly average value is firstly considered to define service classes; an example of results is shown in Figure 8 for French Guaina.

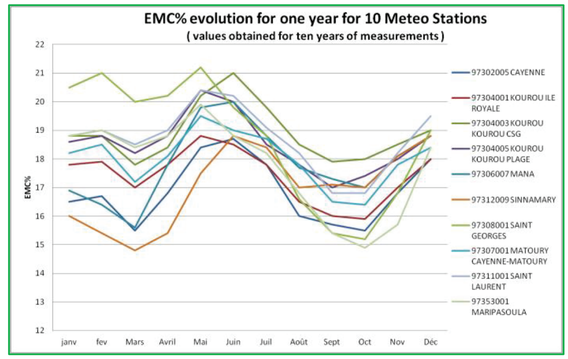

Figure 8: *French Guiana: calculated wood equilibrium moisture content (*EMC*, %) over 12 months [10]*

The average values of EMC and the difference between the minimum and the maximum during one year are taken into account. The results for 12 months can be illustrated in maps for each department (Figures 9-11).

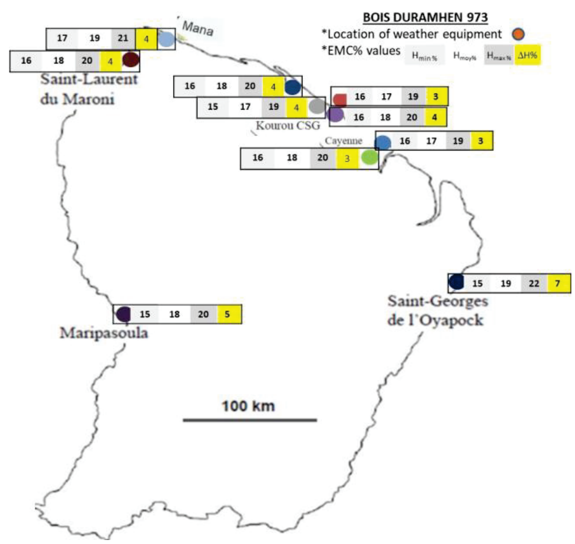

Figure 9: *12-months maps in French Guiana: extreme values of wood equilibrium moisture content (*EMC*, %) obtained for 10 weather stations [10]*

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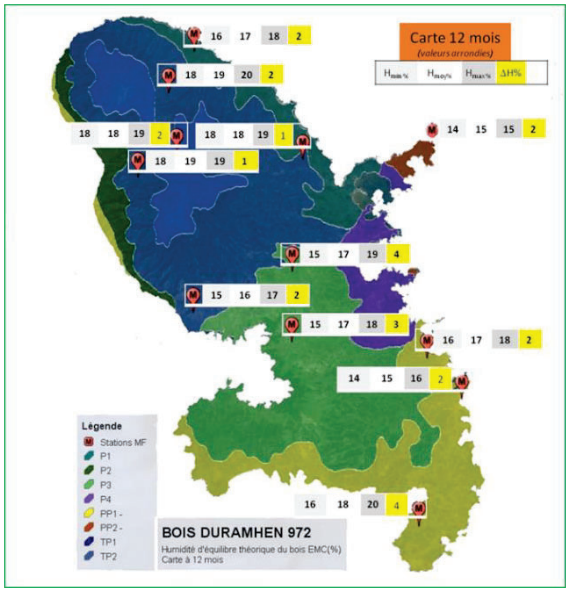

Figure 10: *12-months maps in Martinique: extreme values of wood equilibrium moisture content (*EMC*, %) obtained for 11 weather stations [9]*

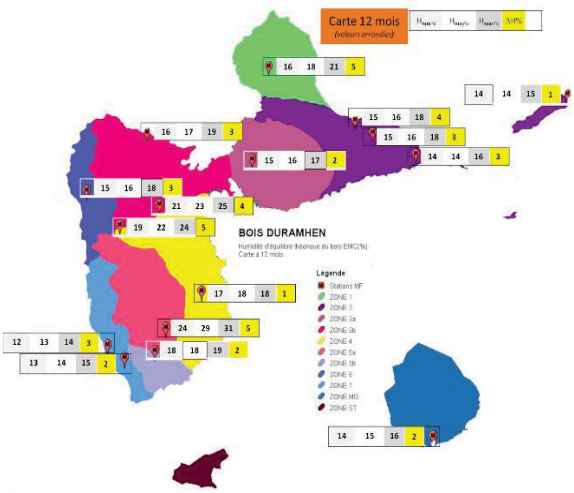

Figure 11: *12-months maps in Guadeloupe: extreme values of wood equilibrium moisture content (*EMC*, %) obtained for 16 weather stations [8]*

On most of the MF stations and different sites, the calculated and measured moisture content values fitted well within the MF Zone. In this case, service class zone could be clearly defined. In other zone(s), the service class determination had to be more detailed in order to propose a more precise mapping. The altitude is an important parameter, as well as the forest environment.

4.3 NATURAL DRYING WOOD AND MONITORING

Variations in *MC* below *FSP* are shown in Figure 12 for natural drying.

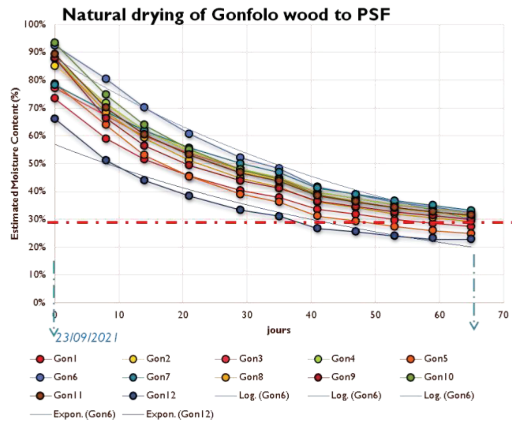

Figure 12: *Moisture loss tracking curves of Gonfolo (Q. rosea) wood (Cayenne) [10]*

Monitoring the humidity at different depths of the samples give information that can be used to monitor the drying of the wood below *FSP* (Figures 13, 14).

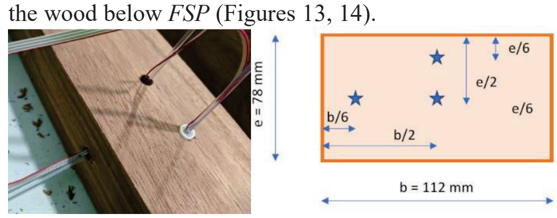

Figure 13: *Natural drying - Geometry, sensor position*

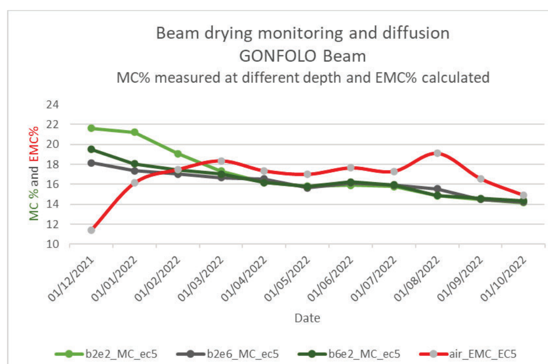

Figure 14: *Moisture content (*MC*, %) tracking curves of Gonfolo (Q. rosea) wood drying – equilibrium moisture content (*EMC*, %) calculated from local air sensor data.*

5 CONCLUSIONS

Results obtained by the different approaches, comparison of measurements, calibration of equipment led to a wide data base and gave interesting projections.

The work carried out confirmed the relevance of the abacus provided by the national appendix to Eurocode 5-part 1.1, to estimate the equilibrium water content of the woods most likely to be used for structural uses in the Guyanese context. However, a reservation must be made for the Ipe (*H. serratifolius*): because of its very high density this wood had probably not reached the hygroscopic balance: the reputation it has of being less hygroscopic than the usual species could not be invalidated by our tests. Independent observations at CIRAD Kourou nevertheless suggest a lower hygroscopicity of Ipe, as well as Goupi (*Goupia galbra*) but to a lesser extent, whose high density is likely to slow down the achievement of hygroscopic balance. Measurements by dynamic sorption method, with analysis of the kinetics of mass change to extrapolate equilibrium values, could be carried out in order to verify the results obtained.

For the 3 French departments thanks to the results obtained by the BOIS DUR-AMHEN projects, maps were built allowing wood builders to know the humidity conditions of their construction, Figures 9-11.

Professional rules will allow these results to be used and disseminated. Especially for French Guiana, the calculated and measured moisture content values show that certain areas can be considered with conditions of a class of service 2 (SC2), but some towns present conditions of a class of service 3 (SC3).

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