A computational application to assess thermal and luminous comfort under tensioned membrane structures

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ABSTRACT: This paper presents a computational application that allows choosing membranes and sizing them for tensioned structures in order to provide thermal and luminous comfort. The membrane thermo-luminous characteristics database was developed through field researches and lab researches using spectrophotometer. The computational modeling consists of: thermo-physiological balance, radiation model, calculation of sky temperature, calculation of surface temperatures of ground, vegetation and membrane. The Heat Load index was adopted for assessing thermal comfort. Concerning luminous comfort, membrane transmission and the contribution of the uncovered sky were considered. The final result is a computational application, with data of 27 different kinds of membranes and climatic data of 57 Brazilian cities, which assesses the thermal and luminous comfort of a given environment, considering: dimensions, activities, membrane, surrounding characteristics and city. The assessment is done hourly for a typical day of each month of the year. Software validation was done through positive comparisons with results of empirical data gathered in field researches.

Keywords: tensioned membrane structures, thermal comfort, luminous comfort, computational application

1. INTRODUCTION

This paper presents a computational application that allows choosing membranes and sizing them for tensioned structures, considering: dimensions, activities, type of membrane, surrounding characteristics and city. The objective is to provide thermal and luminous comfort.

The application database has data of 27 different kinds of membranes and climatic data of 57 Brazilian cities.

2. METHODS

The membrane thermo-luminous characteristics database was developed through: field researches of solar transmittance using Kipp & Zonen CM6B piranometer, and luminous transmittance using Li-COR LI-210SA photocells, following ASTM E1084-86 [1]; field researches of solar absorption using Type J thermo couples and globe thermometers, following Domingues [2]; lab researches using Cary 500 UV-Vis-NIR spectrophotometer, following ASTM E903-96 [3].

The computational modelling consists of: thermo-physiological balance by Blazejczyk [4]; radiation model by Kuwabara [5]; calculation of sky temperature following Bliss [6]; calculation of surface temperatures of ground, vegetation and membrane (respectively by: IRC [7], Karvonen [8], and EDSL [9]).

The Heat Load index, by Blazejczyk [4] was adopted for assessing thermal comfort.

Concerning luminous comfort, membrane transmission and the contribution of the uncovered sky were considered through the criteria of NBR5413 [10] and DIN5034 [11].

3. DATA BASE

The data got in the field and lab research were gathered together with the fabricant technical information generating the software database.

Transmission data were obtained in field research under solar radiation and reflexion data were obtained through lab research using spectrophotometer. It was also used for determining the luminous transmission. Table 1 shows the results found.

The group classification, which is presented in the table, is not presented in the software, but it is used for internal operating purposes. The groups are: Group 1 – Samples with high transparency and low diffusivity; Group 2 – Samples with blackout; Group 3 – Samples with low transmissivity and high diffusivity; Group 3a – Samples of the group 3 with no luminous transmissivity; Group 4 – Samples not tested; the information were taken from catalogue.

Table 1: Thermo-luminous database of membranes available on the software.

		SOLAR			LUMINOUS	
Sample	Group	Trans	Refl	Abs	Trans	Refl
1	3	13,9	73,9	12,2	9,8	81,7
2	2	8,0	65,4	26,6	0,0	74,3
3	3	13,7	71,5	14,9	11,1	79,5
4	1	56,1	33,8	10,2	47,0	35,7
5	1	28,5	29,1	42,4	31,2	28,2
6	3	8,1	75,5	16,4	5,4	83,3
7	2	0,0	47,0	53,0	0,0	48,1
8	3	2,0	62,6	35,4	0,8	66,4
9	3	8,8	71,1	20,1	6,3	78,0
10	3	17,4	70,6	11,9	15,4	78,0
11	2	1,2	59,3	39,5	0,0	58,1
12	3	8,3	71,2	20,6	5,4	77,8
13	3a	2,3	50,0	47,7	0,0	40,0
14	3a	2,3	46,9	50,8	0,0	27,3
15	1	31,8	62,4	5,7	17,5	71,2
16	1	51,4	47,9	0,7	32,1	50,2
17	3	5,4	66,3	28,3	2,6	72,2
18	3	7,2	79,8	13,0	5,0	88,8
19	3	8,8	75,2	16,0	5,7	83,6
20	2	0,0	75,2	24,8	0,0	85,8
21	3	9,0	79,6	11,5	6,6	88,6
22	4	6,0	76,0	18,0	15,0	-
23	4	1,0	70,0	29,0	7,0	-
24	4	13,0	73,0	14,0	8,0	-
25	4	16,0	73,0	11,0	8,0	-
26	4	21,0	71,0	8,0	15,0	-
27	4	18,0	73,0	9,0	13,5	-

4. INPUTS AND OUTPUTS

Initiating the software, the user must select a city. The database offers climatic information of fifty-seven different Brazilian cities. As a initial diagnose, the climatic classification of Mahoney [12] is presented, to provide a preliminary thermal sensation assessment (Figure 1).

Once the city is selected, it is possible to verify the following meteorological data: air temperature, relative humidity, wind speed, solar radiation, atmospheric pressure, and nebulosity (database: INMET, from 1961 to 1990).

For thermal comfort assessment, the following parameters must be set:

Activity [13]:
- Standing up
- Walking at 9 m/s
- Walking at 1,4 m/s
- Walking at 1,8 m/s
- Playing
- Climbing ramp of 5%
- Climbing ramp of 10%
- Climbing ramp of 15%

Clothing [14]:
- Short and T-shirt (0,4 clo)
- Trousers and Shirt (0,6 clo)
- Light Costume (0,8 clo)
- Classical costume (1 clo)
- User's configurable clothing

Clothing color [2]:
- Light colors: (absorption 0,2)
- Medium colors (absorption 0,5)
- Dark colors (absorption 0,8)

Pavement [8]:
- Asphalt
- Concrete
- Sand
- Argyle
- Ardose Stone
- Light Stone
- Light Granite
- Dark Granite
- Wood
- Grass

Once such parameters were set, the software assesses thermal comfort under open sky and under a chosen membrane.

First, a screen with all hours of the day, for a typical day of each month of the year, is generated, assessing thermal comfort in a general situation under open sky (Figure 2).

This first result is a reference for further comparison with the shaded situation by the membrane.

The next step is to choose a membrane, setting its size and the maximum, minimum and mean edge heights. Considering irregular geometries, approximations can be done to achieve a rectangular or circular format. This screen will provide thermal comfort assessment under the chosen membrane and configuration (Figure 3)

Finally, choosing the level of luminance required, a luminous comfort assessment is provided in the last screen of the program (Figure 4).

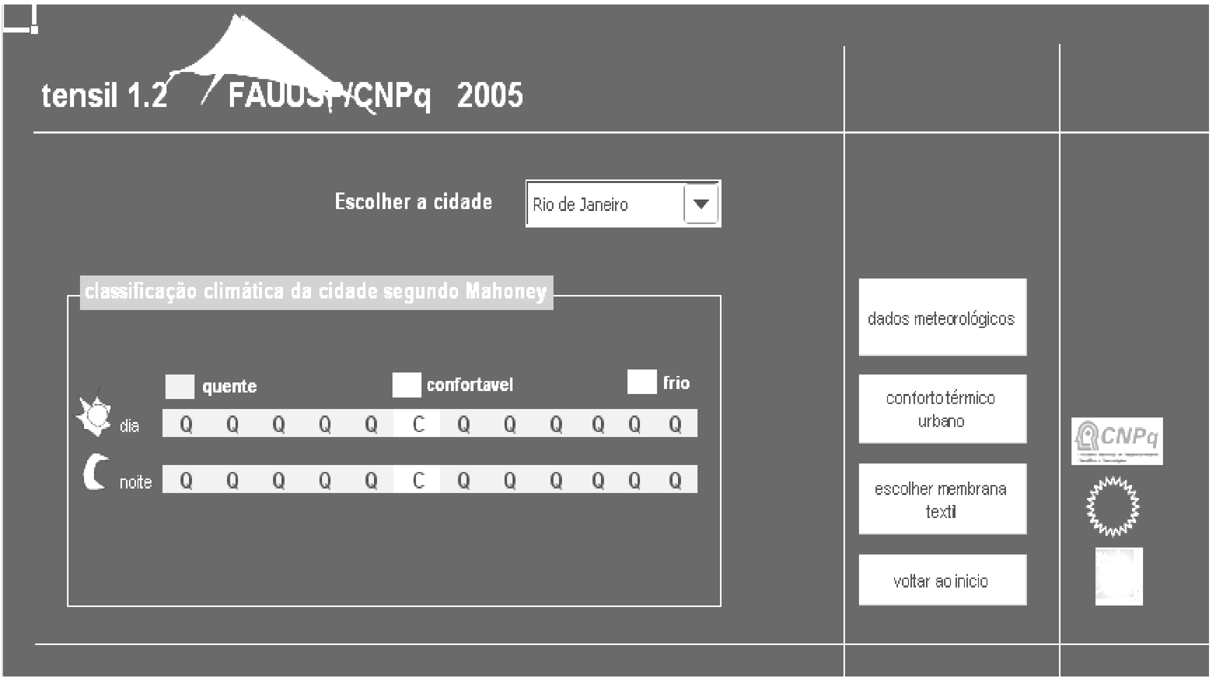


Figure 1 – Screen 1: choosing the city and viewing the climatic classification by Mahoney

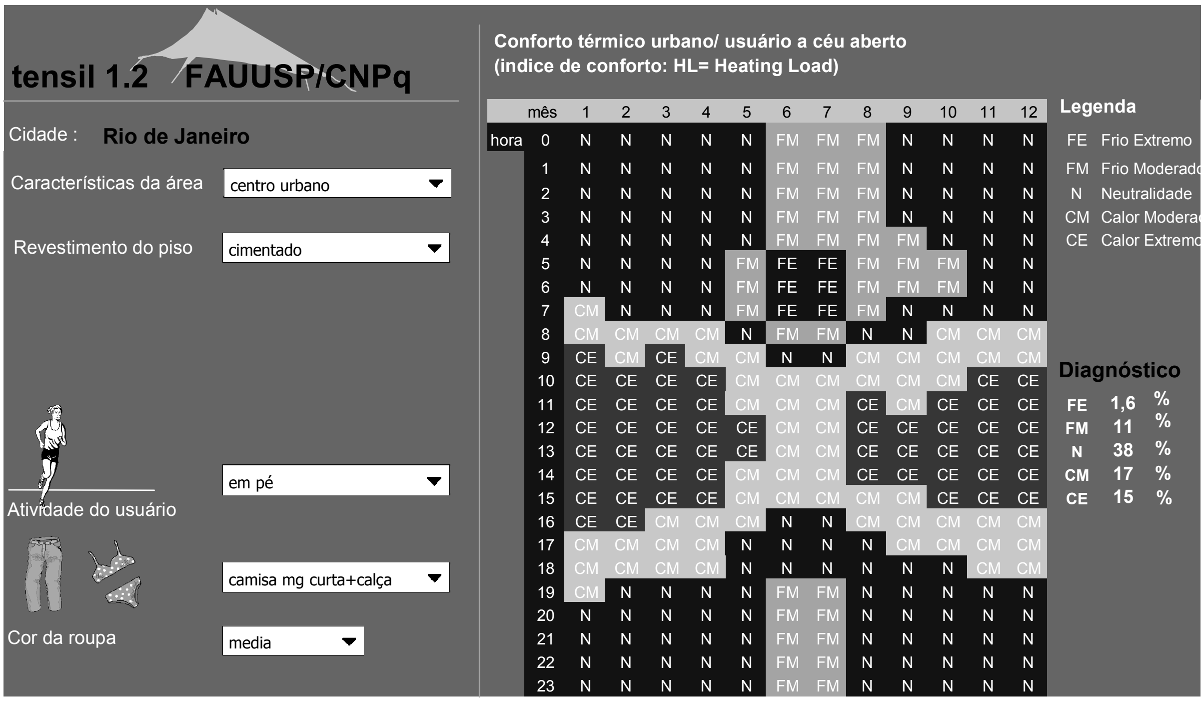
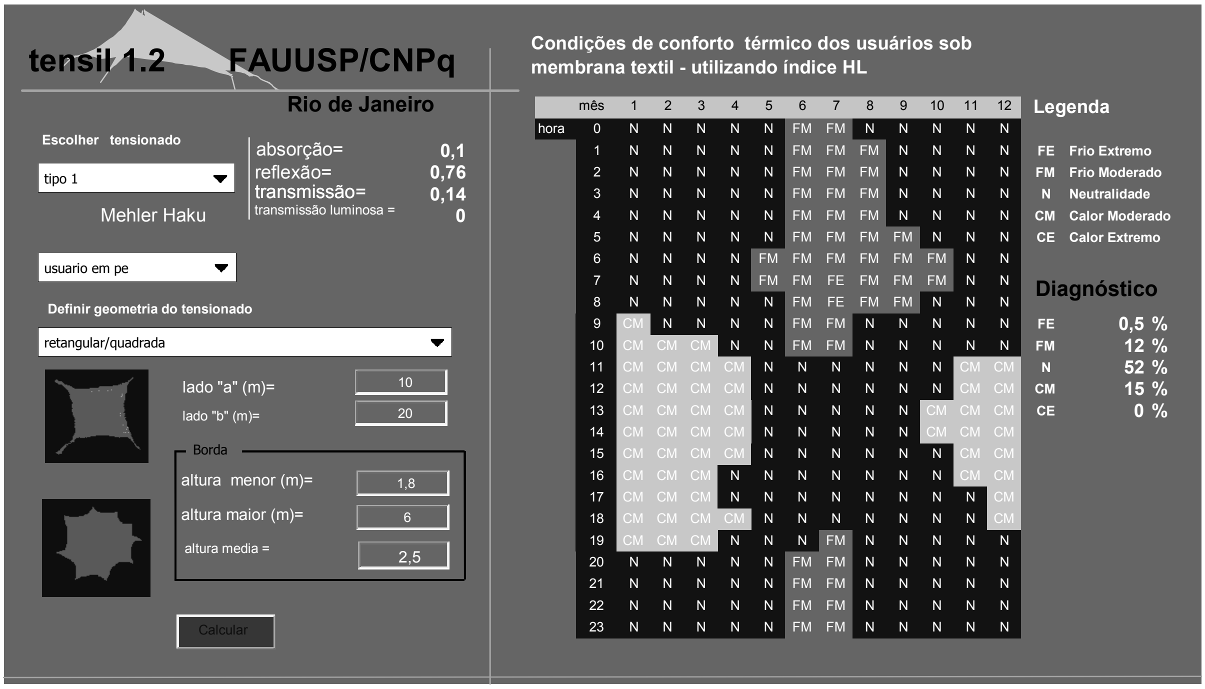
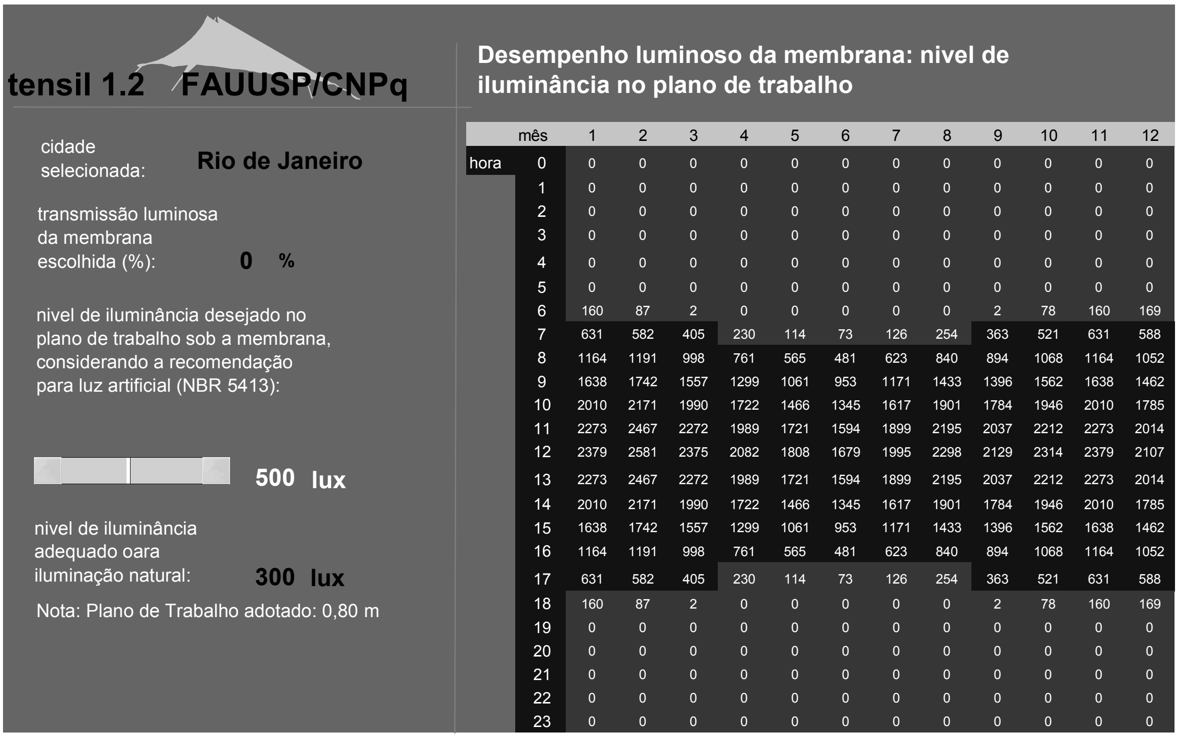


Figure 2 – Screen 2: choosing individual parameters and assessing thermal comfort for open spaces



hora \ mês	1	2	3	4	5	6	7	8	9	10	11	12
0	N	N	N	N	N	FM	FM	N	N	N	N	N
1	N	N	N	N	N	FM	FM	FM	N	N	N	N
2	N	N	N	N	N	FM	FM	FM	N	N	N	N
3	N	N	N	N	N	FM	FM	FM	N	N	N	N
4	N	N	N	N	N	FM	FM	FM	N	N	N	N
5	N	N	N	N	N	FM	FM	FM	FM	N	N	N
6	N	N	N	N	FM	FM	FM	FM	FM	FM	N	N
7	N	N	N	N	FM	FM	FE	FM	FM	FM	N	N
8	N	N	N	N	N	FM	FE	FM	FM	N	N	N
9	CM	N	N	N	N	FM	FM	N	N	N	N	N
10	CM	CM	CM	N	N	FM	FM	N	N	N	N	N
11	CM	CM	CM	CM	N	N	N	N	N	N	CM	CM
12	CM	CM	CM	CM	N	N	N	N	N	N	CM	CM
13	CM	CM	CM	CM	N	N	N	N	N	CM	CM	CM
14	CM	CM	CM	CM	N	N	N	N	N	CM	CM	CM
15	CM	CM	CM	CM	N	N	N	N	N	N	CM	CM
16	CM	CM	CM	N	N	N	N	N	N	N	CM	CM
17	CM	CM	CM	N	N	N	N	N	N	N	N	CM
18	CM	CM	CM	CM	N	N	N	N	N	N	N	CM
19	CM	CM	CM	N	N	N	FM	N	N	N	N	N
20	N	N	N	N	N	FM	FM	N	N	N	N	N
21	N	N	N	N	N	FM	FM	N	N	N	N	N
22	N	N	N	N	N	FM	FM	N	N	N	N	N
23	N	N	N	N	N	FM	FM	N	N	N	N	N

Figure 3 – Screen 3: choosing and sizing membrane and assessing thermal comfort under it



hora \ mês	1	2	3	4	5	6	7	8	9	10	11	12
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	160	87	2	0	0	0	0	0	2	78	160	169
7	631	582	405	230	114	73	126	254	363	521	631	588
8	1164	1191	998	761	565	481	623	840	894	1068	1164	1052
9	1638	1742	1557	1299	1061	953	1171	1433	1396	1562	1638	1462
10	2010	2171	1990	1722	1466	1345	1617	1901	1784	1946	2010	1785
11	2273	2467	2272	1989	1721	1594	1899	2195	2037	2212	2273	2014
12	2379	2581	2375	2082	1808	1679	1995	2298	2129	2314	2379	2107
13	2273	2467	2272	1989	1721	1594	1899	2195	2037	2212	2273	2014
14	2010	2171	1990	1722	1466	1345	1617	1901	1784	1946	2010	1785
15	1638	1742	1557	1299	1061	953	1171	1433	1396	1562	1638	1462
16	1164	1191	998	761	565	481	623	840	894	1068	1164	1052
17	631	582	405	230	114	73	126	254	363	521	631	588
18	160	87	2	0	0	0	0	0	2	78	160	169
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4 – Screen 4: setting the required luminance and assessing luminous comfort under the membrane

5. SOFTWARE VALIDATION

Software validation was done through positive comparisons with results of empirical data gathered in field researches. This field researches took place at the Experimental Canteiro of FAUUSP (Faculty of Architecture and Urbanism of University of Sao Paulo), which can be seen in the following figure.

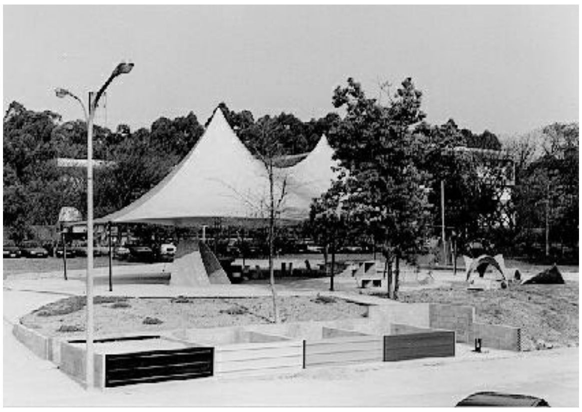


Figure 5: Experimental Studies at FAUUSP

The measures taken under the membrane were: air temperature, membrane surface temperature, ground surface temperature, and wind speed. External air temperature and humidity, wind speed and global radiation were also measured.

The data obtained allows verifying the prediction of the software. Initial data showed that the ground surface temperatures were over estimated by the software. It was observed that, when shaded, the ground surface maintain the same temperature as the mean temperature of the month, not changing in function of the air temperature under the membrane.

So, once the necessaries modifications were considered, the software predictions showed to be reasonable. The following figures bring comparisons between measured and calculated data.

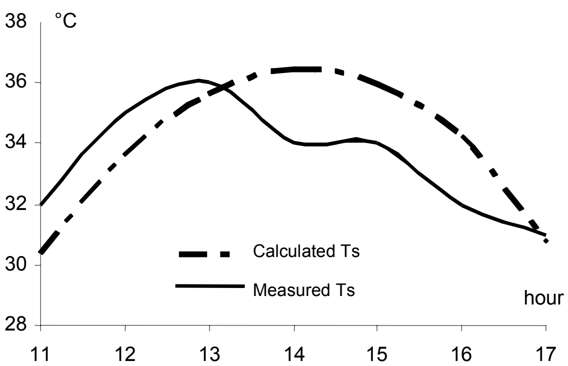


Figure 6: Calculated and measured membrane surface temperatures

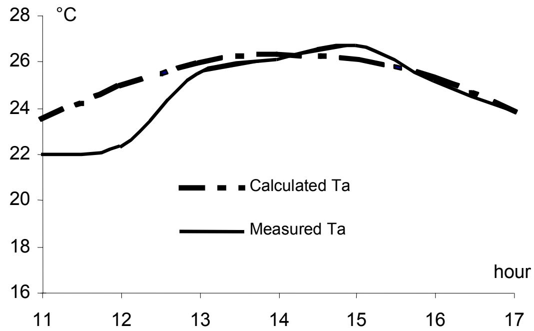


Figure 7: Calculated and measured air temperatures

6. FINAL CONSIDERATIONS

Considering further researches, we may mention: new field measurements for confirming the software validation; refining the measuring procedures in order to establish standards; natural ventilation studies, verifying its influence in the thermal behaviour of the membranes; bioclimatic studies considering membranes and their particularities; publishing further technical information in order to assure the recognition of the importance of thermal and luminous characteristics of the tensioned membrane structures

ACKNOWLEDGEMENT

The authors would like to thank the Conselho Nacional de Pesquisa e Desenvolvimento (CNPq), for the financial support in this research; the Laboratório de Micrometeorologia do Instituto de Astronomia, Geofísica e Ciências Atmosféricas da Universidade de São Paulo, for the meteorological data; the LACIFID of the Instituto de Física da Universidade de São Paulo, in the person of Prof. Dr. Shigueo Watanabe, for borrowing the spectrophotometer; and the engineers Thomas Schetty of Mehler Haku and Voldemir Braz Fakri of Ferrari, for the technical support and supply of membranes samples.

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