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# USE OF "COMFIE" COMPUTER SIMULATION TOOL FOR EVALUATION OF THERMAL PERFORMANCE IN HOUSING UNITS

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## ABSTRACT
This work deals with the use of the thermal simulation COMFIE tool, in the research project developed at Londrina State University / PR. In this research, 3 different building systems, represented by inhabited houses, are thermal-simulated and monitored. The obtained results are compared. The results allow us to verify the applicability and improve evaluation methods of thermal behavior of low-cost housing.

## INTRODUCTION
The computer simulation tool COMFIE (Passive Solar Design Tool for Multi-zone Buildings), developed by Centre d´Énérgétique, École des Mines de Paris, (PEUPORTIER AND SOMMEREUX 1992), allows the simultaneous thermal simulation of several zones of the same building, generating as a result, files of indoor temperatures, every hour throughout the year. This data base of indoor temperatures obtained by simulation, was adopted for the development of the methodology of the yearly hours of discomfort (BARBOSA 1997), in which a construction can be evaluated through the amount of hours a year that the indoor temperatures are out of the temperature range 18°-29°C, according to the comfort zone given in the bioclimatic chart of Givoni for developing countries of hot climate (GIVONI 1992).

Based on those principles, a research project at Londrina State University has been developed in which the main objective is to verify the applicability and enhancement of such methods in the evaluation of thermal behavior at low-cost housing. The project proposes an experimental set in which temperature data are measured and recorded from inhabited houses, representing 3 different building systems.

The experimental recorded data (hourly collected during a year period) which will be referred to as monitoring from now on, are compared to computer simulation data obtained through COMFIE and used as a reference to verify the viability and fitting of criteria and requirements adopted by existing methods to evaluate thermal behavior of buildings.

The method developed by a research team at the UFSC (Federal University of Santa Catarina State) for evaluation of thermal behavior of constructions: Brazilian Bioclimatic Zoning and Constructive Guidelines for One-family Low-cost Houses, (LAMBERTS, 1998a), is being applied in the above mentioned research project. This method proposes a division of the Brazilian territory in eight relatively homogeneous areas concerning climate and, for each one of these areas, a group of technique-constructive recommendations was formulated which optimize the thermal behavior of buildings, through a better climatic adaptation.

This article presents the use of the tool –COMFIE- as a necessary resource to forecasting the thermal behavior of the 3 studied houses. The approached subjects are : elaboration of a climatic file, schedule of housing occupation, considerations on the equivalence of composed and heterogeneous constructive elements, and obtained partial results.

## METHODOLOGY
The work methodology adopted the following activities: initially 3 houses were chosen and prepared to be monitored. Afterwards, all necessary data for the computer simulation was gathered. Finally, after the processing of the data obtained from the monitoring and from the simulation, an analysis of the results was made and conclusions were drawn.

The 3 houses were selected in the urban settlement Prof. Hilda Mandarino in Londrina/PR, a low-cost pattern construction with areas up to 50m², and distributed in three types of constructive systems; 10 houses in the amianthus-cement system, 164 in traditional masonry and 193 in monolithic concrete. The selection of buildings eliminated points of trade and reformed houses, for they had lost their dwelling characteristics. From each type of existent constructive system in the group, one house was selected, taking into account housing characteristics such as, the entries and the similarity in the following factors: orientation of the front facade, orientation of roof planes, number of inhabitants and their ages work, and schedule of the dwellers.

The characteristics of each selected house are described as below :

1. The traditional building system house –built area of 22.74m²- lateral walls built in masonry of 10 cm hollowed ceramic bricks, very used in the region, each face endowed with 2cm layer mortar, so the walls are 14cm thick. The covering is a mixed type flagstone (concrete and ceramic bricks) under a roof of amianthus-cement tiles 5mm thick, in two planes, with maximum height of 1.24m. (See fig.1)

2. Amianthus-cement building system house- construction area of 48.82m², walls of corrugated foil of cement asbestos endowed by a 10 cm mortar layer. The covering is a 1cm thick wood ceiling and ceramic tiles in two planes, with maximum height of 1.49m. (See fig.2)

3. Monolithic Concrete building system house - area of construction of 22.74m², walls of 10 cm thick monolithic concrete. The covering is 10 cm thick solid concrete flagstone and 5 mm thick asbestos tiles, in two planes, with maximum height of 1.24m. (See fig.3)

## MONITORING

The houses were monitored, through the use of devices able to store temperature and humidity data , type HOBO TEMP/RH (See fig.4), installed in a wall at the central area of each house, from January to December 2000. Simultaneously data of temperatures and humidity were collected outside, through equipment installed in an external shelter (See fig.5), placed in the Campus of Londrina State University. HOBO TEMP/RH is a device with dimensions of 6 x 4 x 2cm, able to record and to store up to 5000 temperature and relative air moisture data. The period and frequency of measurements can be set according to need.

## COMPUTER SIMULATION

The use of the thermal simulation tool COMFIE was only possible through use of a climatic file and a schedule of seasonal occupation based on data collected from the dwellers of the monitored houses. The ventilation data, was given in the occupation schedule and represented by percentages of the maximum ventilation ratio per hour in one pattern week. The composed and heterogeneous equivalence of constructive elements were made considering the weight equivalence. The elaboration of these items is described below.

## CLIMATIC FILE

The climatic file is composed of climatic variation data of the region in the which the simulation will be performed. The climatic file of the COMFIE program requests data of dry bulb temperature, global, direct and diffuse solar radiation, hours of solar shine, relative air humidity and wind speed. Such data should be supplied per hour throughout the year, obtained as the reference climatic year of the area, gathering 52 weeks of data or 8760 hours for each considered variable.

In this work two climatic files were compiled; one for the simulations performed before the collection of data of a monitoring year (1996 file) and, after the collection of these data, another climatic file was set up with the collected data (2000 file). The year of 1996 was selected as the typical year or the reference year for the studied area within the historical period of 1979-1996 (BARBOSA, 1999). For this reason, a climatic file was set up for the city of Londrina, with the annual hourly data of the year of 1996. The data used to set up this file were supplied by the meteorological station of the Agronomic Institute of Paraná (IAPAR). Some data were not broken down into hours, thereby necessitating the use of software in order to obtain values to every hour of the year. After all the data were typed or copied onto multiple spreadsheets, it was possible to condense them onto only one spreadsheet, however COMFIE requests data in specific text format, necessitating the use of an algorithm for data conversion from the electronic spreadsheet (as Microsoft EXCEL) to data in text format. This climatic file was set up as shown in the table 1.

In the first column of the table 1, three characters indicate the city of the climatic file. On the second one, the dry bulb temperature is given TBS (x0,1) in Celsius. In the third one, the global solar radiation in J/cm², is given. The fourth one gives the diffuse solar radiation, in J/cm². The fifth column shows the direct solar radiation, in J/cm². On the sixth one, the hours of solar shine are shown since this data is not requested by COMFIE, one has decided to always adopt the value zero on this column. The seventh depicts the air relative humidity as a percent. In the eighth, the speed of the winds in m/s (x0,1) is given. The ninth column is the month in which such data occurred. The tenth column is the day, and finally in the eleventh column is the hour in which such data was recorded.

The compilation of the file of 2000 was made after the values of the temperature of dry bulb and the air humidity were obtained through the external shelter during the year of 2000. With this data, the 1996 climatic file was updated, and the values of the second column regarding bulb temperature dry TBS (x0,1) were changed as well as the seventh one with the relative humidity of the air, by the obtained values during the year of 2000.

Such a process was needed in 1996 as well as 2000 to convert the data from spreadsheet form (EXCEL), to text format.

**Table 1 – Climatic file format ( first 24 hours of January first 1996)**

| 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th | 10th | 11th |
|---|---|---|---|---|---|---|---|---|---|---|
| LON | 230 | 0 | 0 | 0 | 0 | 58 | 40 | 1 | 1 | 1 |
| LON | 219 | 0 | 0 | 0 | 0 | 61 | 44 | 1 | 1 | 2 |
| LON | 212 | 0 | 0 | 0 | 0 | 62 | 49 | 1 | 1 | 3 |
| LON | 210 | 0 | 0 | 0 | 0 | 67 | 51 | 1 | 1 | 4 |
| LON | 207 | 0 | 0 | 0 | 0 | 70 | 45 | 1 | 1 | 5 |
| LON | 209 | 20 | 12 | 9 | 0 | 69 | 39 | 1 | 1 | 6 |
| LON | 222 | 90 | 31 | 59 | 0 | 60 | 43 | 1 | 1 | 7 |
| LON | 241 | 164 | 49 | 115 | 0 | 57 | 58 | 1 | 1 | 8 |
| LON | 221 | 230 | 64 | 165 | 0 | 52 | 28 | 1 | 1 | 9 |
| LON | 241 | 280 | 76 | 204 | 0 | 48 | 29 | 1 | 1 | 10 |
| LON | 260 | 313 | 84 | 229 | 0 | 42 | 26 | 1 | 1 | 11 |
| LON | 270 | 324 | 86 | 237 | 0 | 37 | 23 | 1 | 1 | 12 |
| LON | 283 | 313 | 84 | 235 | 0 | 34 | 14 | 1 | 1 | 13 |
| LON | 291 | 280 | 76 | 204 | 0 | 32 | 23 | 1 | 1 | 14 |
| LON | 289 | 230 | 64 | 165 | 0 | 30 | 19 | 1 | 1 | 15 |
| LON | 290 | 164 | 49 | 115 | 0 | 31 | 28 | 1 | 1 | 16 |
| LON | 284 | 90 | 31 | 59 | 0 | 32 | 25 | 1 | 1 | 17 |
| LON | 277 | 20 | 12 | 9 | 0 | 34 | 28 | 1 | 1 | 18 |
| LON | 266 | 0 | 0 | 0 | 0 | 35 | 14 | 1 | 1 | 19 |
| LON | 258 | 0 | 0 | 0 | 0 | 39 | 8 | 1 | 1 | 20 |
| LON | 251 | 0 | 0 | 0 | 0 | 45 | 4 | 1 | 1 | 21 |
| LON | 246 | 0 | 0 | 0 | 0 | 45 | 9 | 1 | 1 | 22 |
| LON | 245 | 0 | 0 | 0 | 0 | 48 | 28 | 1 | 1 | 23 |
| LON | 243 | 0 | 0 | 0 | 0 | 50 | 35 | 1 | 1 | 24 |

## DWELLING OCCUPATION SCHEDULE

Each one of the houses received a detailed visit, and was thoroughly examined in order to set up the occupation schedule. Also, the necessary data for the elaboration of the projects for the computer simulation tool COMFIE was obtained.

The occupation set up is the numeric representation of the way the house is occupied and used by their residents. The important data for the occupation set up are: number of occupants, schedule of occupancy, the internal maximum ventilation ratio and the schedules of whether the openings (windows and doors) are open or closed, and the existence and schedule of use of appliances and other heat generators. All this information is organized in data schedules during the seven days of one pattern week and supplied in percentage in specific text format for COMFIE.

Along with the climatic variations due to the seasons of one year, changes in the habits and the way the residents use their houses occur. Thus, for greater precision, different occupation schedules were set up for each season. It was necessary, to obtain the data of a complete year, to perform a simulation for each season and these respective values are gathered to compose a spreadsheet with values of the whole year.

## CALCULATION OF THE EQUIVALENT THICKNESS OF CONSTRUCTIVE ELEMENTS FOR SIMULATION

The COMFIE simulation tool doesn't recognize the heterogeneity of constructive elements in more than one dimension. In the case of the holed brick wall of the traditional system in which heterogeneity occurs in three dimensions, it was considered an equivalent wall with seven homogeneous layers; the two external layers of endowing mortar 2 cm thick and three internal layers of solid brick of 1.2 cm each, separated by two layers of air of 2.7 cm thick with equivalent thermal resistance of 0.0940 m² K/W each one.(See fig.6)

In the case of mixed type flagstone coverings and concrete and ceramic blocks, an equivalence was made of a flagstone with five layers of homogeneous materials as follows; the superior layer of concrete with 3 cm of thick, then two layers of solid brick of 1,5 cm thick each a, separated by a layer of air of 3 cm thick, with equivalent thermal resistance of 0.0506 m² K/W in the summer and 0.0426 m2 K/W in the winter. The roof of inclined panels of tiles was considered to be one more layer in the constructive element of the covering.(See fig.7)

## ZONING

In order to simplify the methodology, the houses were considered with only one general internal zone and the walls were considered as capacitive internal walls.

## RESULTS

The computer simulations were performed using the 1996 generic climatic file and with the elaborated climatic file from the 2000 year data obtained in the monitoring at the external shelter.

The graph in the figure 8 presents the hour-by-hour temperature curves, obtained by simulation and for monitoring in the 3 houses and in the external shelter, within the period of January to December of 2000. For better visualization, figures 9 and 10 show the same data, corresponding to a period of three days of summer and three days of winter extracted from the figure 8.

With the numeric values of temperatures obtained by computer simulation and by monitoring , the hours of discomfort are calculated according to (BARBOSA 1997). The table 2 presents a summary of these calculations for each house. The thermal characteristics of the 3 houses, were calculated according to (LAMBERTS, 1998b), and evaluated according to (LAMBERTS, 1998a). In this case the recommendations were the correspondents to bioclimatic zone 3 where the city of Londrina is located, according to data in the tables 3 and 4. The summary of the results of this evaluation is presented in the table 5.

**Table 2 – Calculation of discomfort hours according to (Barbosa, 1997), based on the results of simulation and on the results of monitoring in the 3 houses and in the external shelter**

| Number Hours of Thermal Discomfort in the Period of 1996 and 2000 | | |
|---|---|---|
| HABITATIONAL UNITS | WAY OF OBTENTION | HOURS OF DISCOMFORT |
| MONOLITHIC CONCRETE 1996 | MONIT. | 2206 |
| | SIMUL. | 2498 |
| % IN THE DIFFERENCE | | 13,24% |
| MONOLITHIC CONCRETE 2000 | MONIT. | 2206 |
| | SIMUL. | 2858 |
| % IN THE DIFFERENCE | | 29,65% |
| AMIANTHUS-CEMENT 1996 | MONIT. | 1911 |
| | SIMUL. | 1706 |
| % IN THE DIFFERENCE | | -10,73% |
| AMIANTHUS-CEMENT 2000 | MONIT. | 1911 |
| | SIMUL. | 2299 |
| % IN THE DIFFERENCE | | 20,30% |
| TRADITIONAL 1996 | MONIT. | 2711 |
| | SIMUL. | 4564 |
| % IN THE DIFFERENCE | | 68,35% |
| TRADITIONAL 2000 | MONIT. | 2711 |
| | SIMUL. | 4476 |
| % IN THE DIFFERENCE | | 65,11% |
| EXTERNAL SHELTER 1996 | MONIT. | 3680 |
| | SIMUL. | 2528 |
| % IN THE DIFFERENCE | | -31,30% |
| EXTERNAL SHELTER 2000 | MONIT. | 3680 |
| | SIMUL. | 3680 |
| % IN THE DIFFERENCE | | 0,00% |

**Table 3 – Recommended values to Bioclimatic zone 3 according to Lamberts (Lamberts 1998a)**

| Openings for ventilation A (in% of the floor area) | Shading of the openings |
|---|---|
| **Averages: 15% < A < 25%** | **To allow sun during the winter** |

**Table 4 – Recommended values to Bioclimatic zone 3 according to Lamberts (Lamberts 1998a)**

| External walls | Thermal Transmitance U (W/m².K) | Thermal delay (Hours | Factor of solar heat% |
|---|---|---|---|
| **Wall: Light built Reflective** | **U≤3,60** | **U≤4,3** | **U≤4,0** |
| **Covering: Light built Isolated** | **U≤2,00** | **U≤3,3** | **U≤6,5** |

**Table 5 – Parameter values and thermal indexes calculated for each house according to (Lamberts 1998b) and established limits to Bioclimatic zone 3 according to (Lamberts 1998a)**

| Constructive systems→ Parameter of Evaluation ↓ | AMIANTHUS-CEMENT | MONOLITHIC CONCRETE | TRADITIONAL | LIMITS CONFORM LAMBERTS 1998a (ZONE 3) |
|---|---|---|---|---|
| % Area ventilat. / Area floor | 15,05 OK | 9,32 | 9,58 | 15% at 20% |
| Transmitance of the coverings (summer) | 2,01 | 2,16 | 1,77 OK | ≤ 2,0 |
| Transmitance of the coverings (winter) | 2,8 | 3,11 | 2,44 | ≤ 2,0 |
| Transmitance of the walls | 3,78 | 4,26 | 2,34 OK | ≤ 3,6 |
| Solar factor of the coverings | 6 OK | 3,6 OK | 3,2 OK | ≤ 6,5 |
| Solar factor of the walls | 4,5 | 5,1 | 3,3 OK | ≤ 4,0 |
| Thermal delay of the coverings | 1 OK | 4 | 4,8 | ≤ 3,3 |
| Thermal delay of the walls | 2,6 OK | 2,92 OK | 3,8 OK | ≤4,3 |

## ANALYSIS

The analysis determined the number of hours out of the temperature range of 18°-29°C which is considered the optimal comfort zone. Analyzing the results of temperatures obtained in the computer simulations with the two performed climatic files and monitoring, the following differences (c.f. table 2) for each constructive system were observed

1. The highest differences between computer simulation and monitoring results occurred in the traditional system house. This can be explained by the difficulties of the tool (COMFIE) to simulate heterogeneous walls in more than one direction.

2. Globally, the results of computer simulation were worse than the monitoring ones, that is to say, the houses are actually more comfortable then the simulation predicts

3. Even though the traditional house presented the higher number of items in accordance with

Lamberts´s method (Lamberts, 1998a), it is the most uncomfortable of all (see table 5).

4. The amianthus-cement house were the most comfortable among all houses studied in both simulation and monitoring methods.

## CONCLUSIONS

1. The simulation tool is more accurate for building systems in which the elements, walls and coverings are homogeneous and consequently there is no need to make approximation by equivalence of layers (see table 5: hours of discomfort to traditional masonry system).

2. The results show that the ventilation, more than materials used in walls and coverings, is the parameter responsible for the building system performance (see amianthus-cement house - table 5: ventilation area/floor area ratio).

## ACKNOWLEDGEMENTS

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Figure 1 - The traditional building system house

Figure 2 - Amianthus-cement building system house

Figure 3 - Monolithic Concrete building system house


Figure 4 - HOBO TEMP/RH

Figure 5 - External Shelter

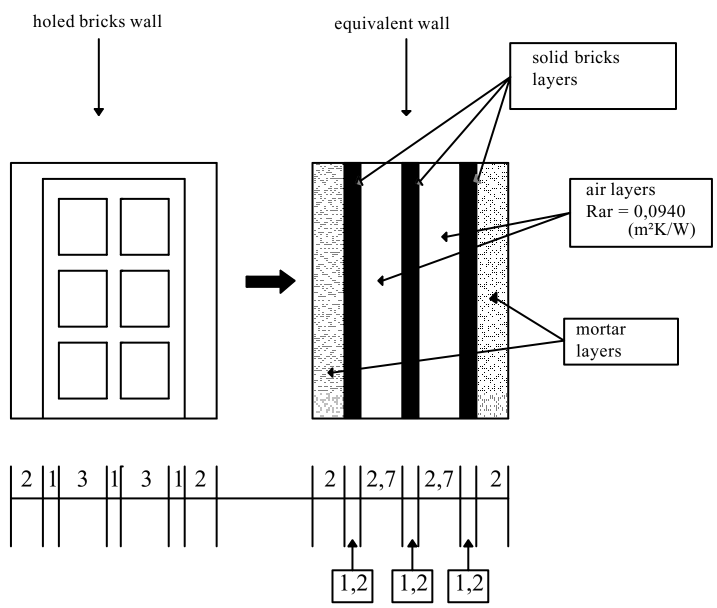


**Figure 6 - Equivalent wall**

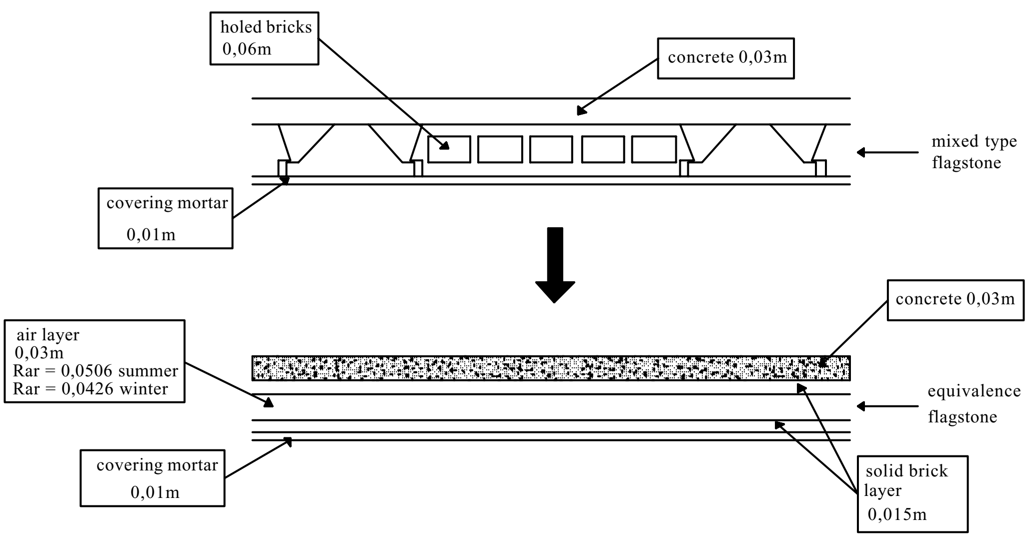


**Figure 7 – Equivalence of mixed type flagstone coverings**

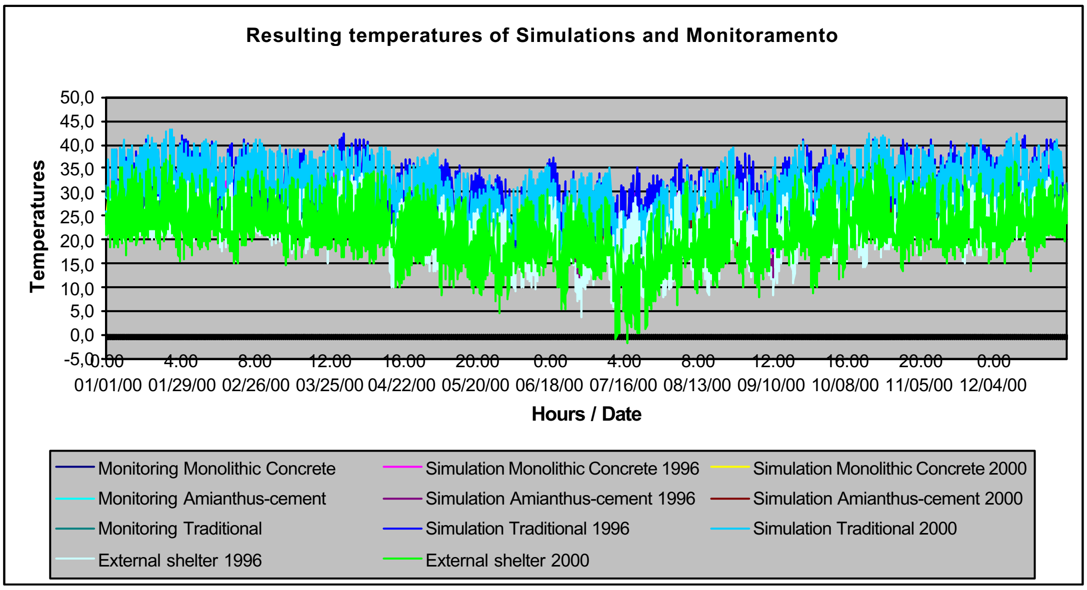


**Figure 8 - Hour-by-hour temperature curves**

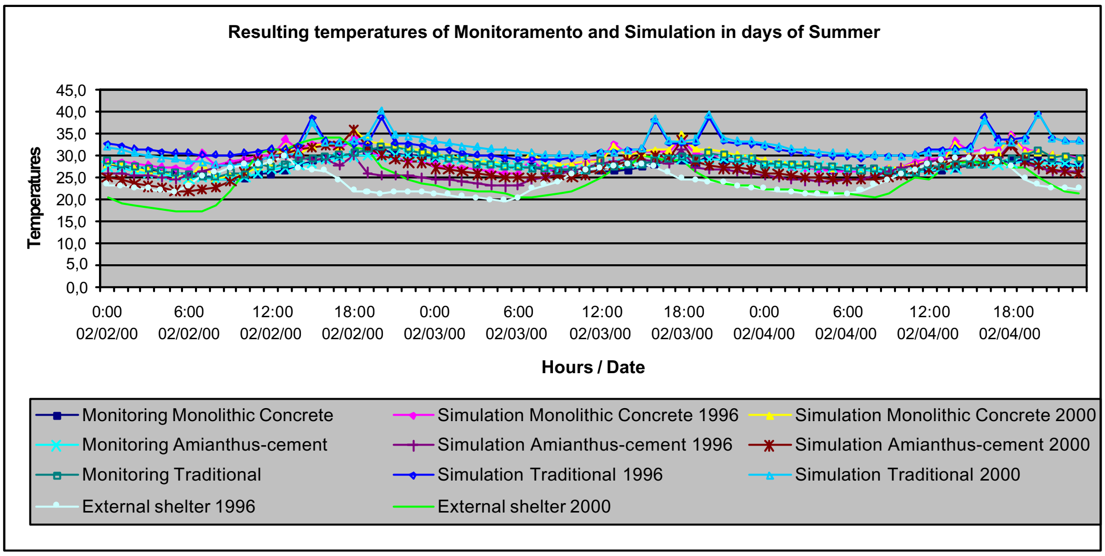


**Figure 9 - Period of three days of summer**

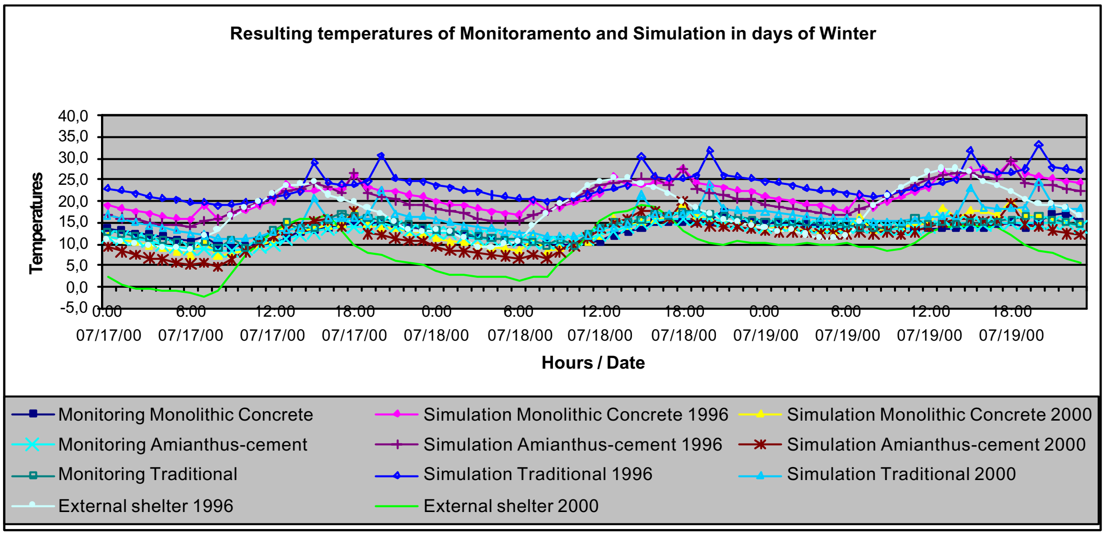


**Figure 10 - Period of three days of winter**