The use of Simulation Software to Evaluate the Thermal Performance of Buildings in Brazil

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ABSTRACT

The traditional methods for the evaluation of the thermal performance of buildings are appropriate to winter conditions and are often used in standards that regulate energy consumption. However, they are not adequate to the evaluation of the thermal performance of buildings in tropical climates, predominant in Brazilian territory.

These questions are discussed in this paper, where a method is presented for the evaluation of the thermal performance of buildings in Brazil.

The evaluation criteria used in this method impose the application of detailed simulation software that is able to determine in reliable way the dynamic thermal behavior of the building.

INTRODUCTION

The way of designing as well as constructing buildings has been revealing a great influence of the climatic characteristics, resulting on an identity that is also a part of the culture of local people. The methods for thermal performance evaluation of buildings are also affected by this influence.

This work presents the results of a study that evidences the adaptation of those methods to the climatic characteristics. This information was used for the development of a method proposed to Brazil (AKUTSU, 1998), in a different way from the one traditionally employed in predominantly cold countries.

The main differences concern to the methods for calculating heat transfer between indoor and outdoor environments that, for the Brazilian climatic conditions, must be solved for unsteady-state approach. This fact implies in solving more complex equations and in a higher number when compared to steady-state approach. This situation necessarily drives to the use of simulation software. This aspect provoked, at a first moment, a natural reaction of the involved people that rejected such method by considering it unfeasible from the operational viewpoint. However, as time passed, more and more people have been adopting this method and adding efforts for making it a normalized procedure.

THE INFLUENCE OF THE CLIMATIC CONDITIONS

A decisive factor in the structure of the method for building thermal performance evaluation is, undoubtedly, the climatic characteristic of the construction site. This is reflected directly in the mathematical model used to determine the thermal exchanges between indoor and outdoor environments through the building envelope. The basic point, in this aspect, is to decide what can be treated as steady-state condition and what must be considered as unsteady-state.

This fact means, from the operational point of view, a clear distinction among what could be treated with very simple equations, of easy solution, generally manually (in the case of steady-state) and what must be solved with more complex systems of equations, with larger number of variables that is only feasible by means of simulation software (when it is considered as unsteady-state condition).

The methods for building thermal performance evaluation in heating conditions, adopted in laws, regulations or national standards, aim to reduce the energy consumption based on the limitation of heat losses by the building envelope. This is made by imposing minimum values for the thermal resistance of the building components and for the air leakage in the fenestration. Examples of these practices are found in national legislation, as in the case of France and Portugal , in state codes of energy conservation as in USA and in Technical Standards, as in Argentina and France. Even ASHRAE Standards series 90 and 100 privilege the use of thermal resistance as an element for the evaluation of the enclosure, allowing that projects that don't satisfy its restrictions be evaluated by means of simulation programs. The use of detailed simulation software to determine the thermal behavior of constructions is applied to large enterprises or in buildings with special characteristics.

The application of those concepts of building evaluation, based on thermal resistance, to humid climates does not produce good results, once in conditioned buildings the dehumidification parcels of the cooling load in the air conditioning systems are very high. Also in unconditioned buildings, the relative humidity is a decisive factor in the sensation of the occupants' thermal comfort that can not be neglected in the evaluation.

In hot climates, the intentional ventilation of rooms and the solar radiation, elements that are not properly considered in the evaluation methods based on steady-state approach, also produce significant influences on the thermal performance of buildings, mainly in those not conditioned. In this case, the "evaluation parameter" is not the energy consumption but the occupants' thermal comfort, characterized by the temperature, the humidity and the velocity of the indoor air and the mean radiant temperature of the room. The reliable determination of these variables must be done using more refined calculation tools that emphasize again, the need of the use of detailed simulation software.

BUILDING THERMAL PERFORMANCE INDICATORS ADEQUACY

The traditional methods for the evaluation of the building thermal performance adopt as indicator the parameter "thermal resistance” of the elements or the “overall heat loss coefficient" of the building. Thus, the evaluation approach indicate limit values for those parameters, defined in function of the type of building occupancy and the characteristics of the local climate. These indicators are applied, therefore, to the evaluation in winter conditions, where the objective is the limitation of the energy consumption used for heating purposes.

In Brazil, the opposite situation prevails. The thermal comfort should be obtained for summer conditions. In this case, the simple adoption of the same procedure inverting the sense of the energy flux, supposing that the objective is just to reduce the heat gain due to the temperature difference between the indoor air and the outdoor air, is not enough. It is necessary to consider, at the same time, the other thermal exchanges that happen, as those due to: the air leakage; the solar radiation through glasses and its storage; the ventilation; the dynamic heat conduction trough opaque elements; the heat gains due to people, equipment and lighting; and the radiant heat exchange between indoor surfaces of the building elements.

In this way, the thermal capacity of the building cannot be despised and, therefore, the thermal resistance of the elements or the building overall heat loss coefficient is not enough to characterize the thermal behavior of the building.

In a study developed with the objective of clearing up these subjects, mathematical relationships among the parameters that characterize the thermal response of the building and those that characterize the thermal properties of the envelope were determined.

The analysis was done through the determination of the thermal response of a dwelling at a summer and a winter design day of São Paulo city, done through the software NBSLD (KUSUDA, 1976), adapted and implemented by the authors of this paper (AKUTSU, 1984; VITTORINO, 1994) to Brazilian conditions. In the analysis, 3 alternatives for the roofing (without ceiling, ceiling in concrete panel and ceiling in composed slab) and 30 alternatives for the walls were considered.

Initially, the dwelling was considered without artificial thermal conditioning and the hourly values of the indoor air temperature were calculated. Later on, the hourly values of the cooling load were calculated for the summer and the hourly values of the heating load, for the winter supposing that the indoor air temperature was maintained at a constant value (24°C in summer and 18°C in winter).

Then, the relationships among the parameters that characterize the thermal response of the building and those that characterize the thermal properties of its envelope were determined.

The parameters that characterize the building thermal response were:

- the maximum daily value of the indoor air temperature in summer;
- the minimum daily value of the indoor air temperature in winter;
- the maximum daily value of the sensible cooling load in summer;
- the total daily value of the sensible cooling load in summer;
- the maximum daily value of the sensible heating load in winter;
- the total daily value of the sensible heating load in winter;

The parameters that characterize the thermal properties of the building was:

- the thermal resistance of the external walls;
- the thermal capacity of the external walls;
- the average value of the thermal resistance of the external walls and internal walls;
- the average value of the thermal capacity of the external walls and internal walls.

The obtained results showed that a strong relationship exists (with average correlation coefficient ≈ 98%) between the values of thermal resistance of the walls and the maximum daily heating load, in the winter condition – see Figure 1. The same results were obtained for the total daily heating load. This shows that the thermal resistance of the walls is a good indicator of the building thermal performance in this climatic condition, when heating is used in the indoor. This fact confirms the correctness of the use of this parameter as normative element of building thermal performance in countries of cold climate, based on steady state approach.

Excluding this situation, the thermal resistance cannot be characterized as a good indicator of thermal performance of buildings, because in other combinations, only "clouds of points" that do not represent any type of relationship among the analyzed variables were observed. An example of this is shown in Figure 2.

Otherwise, a good correlation (correlation coefficient of ≈ 95%) between the thermal capacity of the walls and the maximum daily value of the indoor air temperature, was also observed – see Figure 3. This correlation shows that, for summer, it is possible to use the thermal capacity, instead of the thermal resistance, as an indicator of thermal performance of unconditioned buildings and reinforces that, for this case, unsteady state approach must be considered.

A good correlation between the cooling load and the analyzed indicators was not obtained. Also, for the daily minimum temperature in winter, a good correlation was not obtained. In these cases, computer simulation for the determination of the thermal response of the building, that is the valid process for any situation, must be used.

The conclusions presented here do not refer to buildings which enclosures present excessively different characteristics to each other when the effect of the internal partitions could be signficant on the thermal performance of the building.

Situations where the thermal capacity of the walls is “eliminated” by the use of thermal insulation materials were also not contemplated. In this case, the thermal capacity to be considered in the calculation should be pondered in a way that considers the presence of insulation.

METHOD FOR BUILDING THERMAL PERFORMANCE EVALUATION

The method presented here for building thermal performance evaluation contemplates two modalities: unconditioned and conditioned buildings. In the first case, the evaluation consists of verifying if the indoor environment satisfies a group of requirements established in function of the human demands for thermal comfort. When the building is conditioned, the verification is made on the demand for thermal loads. Also in this case, the evaluation for unconditioned buildings should be considered a situation that can happen when the air conditioning system is shut off.

In both cases, the demand levels are defined when setting down the human demands of thermal comfort and the typical climatic conditions.

The evaluation process is composed by the following stages:

a) characterization of the human requirements for thermal comfort;
b) characterization of the typical climatic conditions;
c) characterization of the construction and its occupation;
d) determination of the thermal behavior of the construction;
e) evaluation of the thermal performance of the building.

In the evaluation of a conditioned construction, stages “a”, “b” and “c” correspond to the definition of the data that compose the necessary information for the execution of stage “d”, which corresponds to the calculation of the room thermal loads. The results obtained in stage “d”, together with the evaluation criteria, constitute the necessary data to the execution of stage “e”.

For unconditioned constructions, stage “d” corresponds to the determination of the indoors thermal comfort conditions, being used, for that, the information defined in stages “b” and “c”. The data defined in stage “a” and that obtained in stage “d” together with the evaluation criterion constitutes the necessary information to the accomplishment of stage “e”.

SIMULATION SOFTWARE

The calculations are made using simulation software that considers the dynamic characteristics of energy and mass transfers that occurs in the building.

Nowadays, there are many simulation software to perform this calculation with the necessary reliability for the evaluation of the thermal performance of buildings available in the market. Among them, we highlighted the following software, for its adaptation to the proposed method: the NBSLD program; the DOE-2 program; the BLAST program; the ESP-r program

There are several other programs available, some of then developed for air-conditioning enterprises, like Carrier or Trane, others developed in universities, based in manual calculation procedures, that use more simplified mathematical models and are not adequate to be employed in this method.

EVALUATION CRITERIA

The evaluation criterion for unconditioned buildings classifies the thermal performance in function of its behavior in summer and winter design days, respectively, according to levels "A" (thermal comfort during all the day), "B", "C" or "D" (thermal stress), being adopted as evaluation parameter, the indoor air temperature. So, for summer level "B" is assigned for "non confortable during some hours of the day, but the indoor air temperature lower than outdoors'", and level "C" when "maximum indoor air temperature is higher than outdoors' maximum".

For the conditioned buildings, the criterion consists on comparing the thermal loads, determined for the design days, with standard reference values.

We still do not have such values determined for Brazil. In the absence of those values, the method provides the comparison among several available design alternatives or even the comparison with a building considered as a standard.

APPLICATIONS

To illustrate the application of the evaluation method, two study cases are discussed: a dwelling and an industrial building, that are typical in Brazilian south area, both in a summer design day in São Paulo city. In these buildings, it is not common the use of artificial thermal conditioning systems. Sketches of these constructions are presented in Figures 4 and 5.

In dwellings, satisfactory thermal comfort conditions are sought by the adaptation of the building design to the local climatic conditions, using techniques of the passive conditioning, like walls with appropriate thermal inertia, shading of windows, openings that favor ventilation when necessary, etc.

In industrial buildings, the same concept also prevails, but the main purpose is to avoid thermal stress conditions for the workers. It is generally used natural ventilation and simple alternatives for the reduction of radiant loads, as the painting of the exterior surface of the roofing in clear colors.

The dwelling is a two-story house with external walls in ceramic hollow blocks, 14 cm of thickness, internal walls in ceramic hollow blocks, 9 cm of thickness, both with mortar finish in the two sides; roofing composed by ceramic tiles and ceiling in massive concrete, 8 cm of thickness, accompanying the roof. The upper story floor is in massive concrete, 12 cm of thickness, wooden laid.

The results of the study of the effects of two factors, are presented: the total shading of the window, with the use of external devices, and the increasing of the rate of natural ventilation from 1 air changes/hour (ACH), typical value for Brazilian common dwellings due to air leakage, to 5 ACH, that can be reached opening the window and the door when external wind speed is about 2,0 m/s.

The interior air temperature calculated values for three combinations of ventilation and window shading alternatives are shown in Figure 6. The temperature limits for "A", "B" and "C" levels and the hourly values of the exterior air temperature are also presented. In this case, the application of the method indicates that the construction under evaluation has potential to reach "B" level, if appropriately shaded and ventilated.

In case that level "B" for the thermal performance was not reached, or if one intends to reach level "A", it would be necessary to change the wall materials in order to increase thermal capacity.

The industrial building has an area of 2000 m^2 (50 m x 40 m), cemented floor, walls in concrete hollow blocks, 9 cm of thickness, internal faces with mortar finish, roofing in asbestos cement, 8 mm of thickness, windows with common glasses, 3 mm of thickness, with total area corresponding to 15% of the floor area. It is occupied by 65 people, performing light or moderate and occasionally heavy activities, operating equipment that liberate 20 W/m^2 (floor area). The artificial lighting system is composed by 32 luminaries with 4 fluorescent lamps of 40 W each one.

The calculated values of the wet bulb and globe temperature index (WBGT) for three ventilation rates: 0,1 ACH; 1 ACH and 10 ACH and the limit values of WBGT, imposed by Brazilian federal law, for continuous work of light, average and heavy activities are presented in Figure 7. These results show the need of continuous indoor ventilation, pointing out to the building planner the importance of the positioning of the openings according to the predominant direction of the incident wind.

These results were obtained using the adapted version of the program NBSLD (AKUTSU, 1984; VITTORINO, 1994).

CONCLUSIONS

The evaluation criteria of this method impose the application of detailed simulation software that is able to determine in reliable way the dynamic thermal behavior of the building, mainly due to the peculiar characteristics of the Brazilian climate. Fortunately, today, such need does not constitute a barrier for the definitive use of the method.

However, it is still notorious the need of the development of auxiliary tools, mainly oriented to the non-specialists users. In this sense, software must be developed to make the interface between a non-specialist user and the calculation program, in a way to turn it friendlier and of easy understanding. Other auxiliary tools, for the use in such software, are databases with thermal properties of building materials and files with climatic parameters of each site or region, which should be updated periodically.

On the other hand, even in situations in that the climatic conditions allow a simplified treatment for the evaluation of the thermal performance of the constructions, a significant potential exists to be explored in relation to the energy savings in the thermal conditioning systems, which will be also possible only by means of simulation software. With these software, other important aspects can be analyzed such as the effect of the thermal inertia of the construction and the indoor dynamic control of the temperature and humidity.

Finally, the results of the application examples show the importance of the use of simulation software as a building design tool since it is associated to adequate evaluation criteria.

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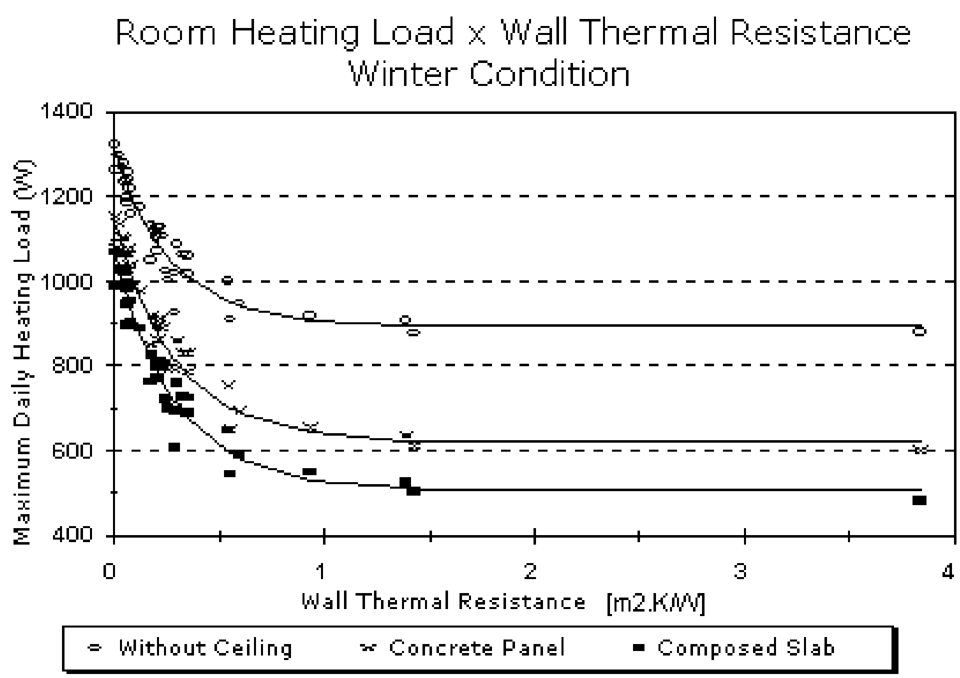

FIGURE 1: Calculated values of daily maximum room heating load as a function of the wall thermal resistance, in a winter design day.

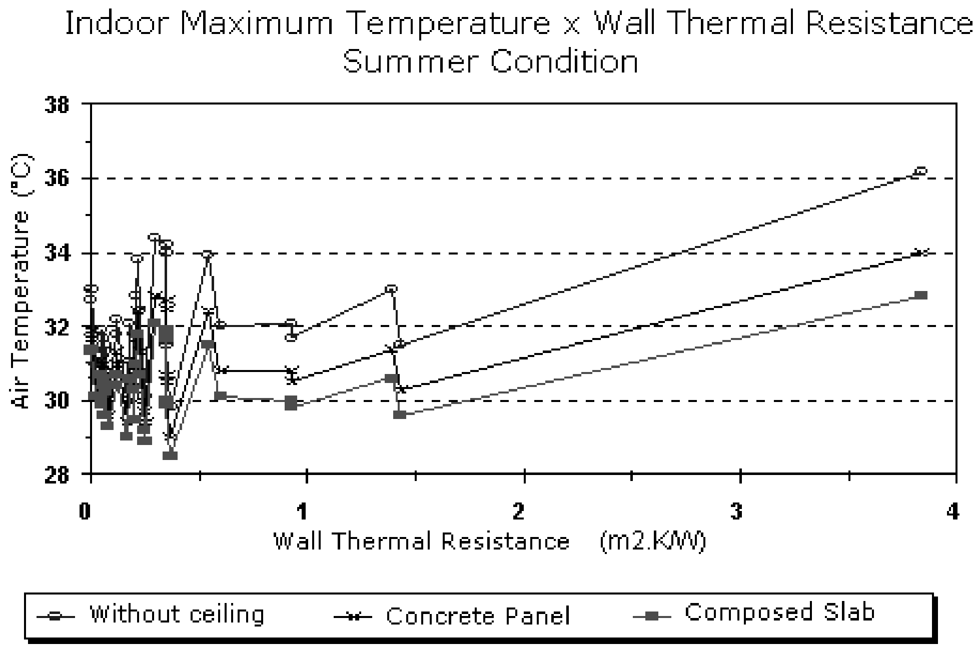

FIGURE 2: Calculated values of the daily maximum indoor air temperature as a function of the wall thermal resistance, in a summer design day.

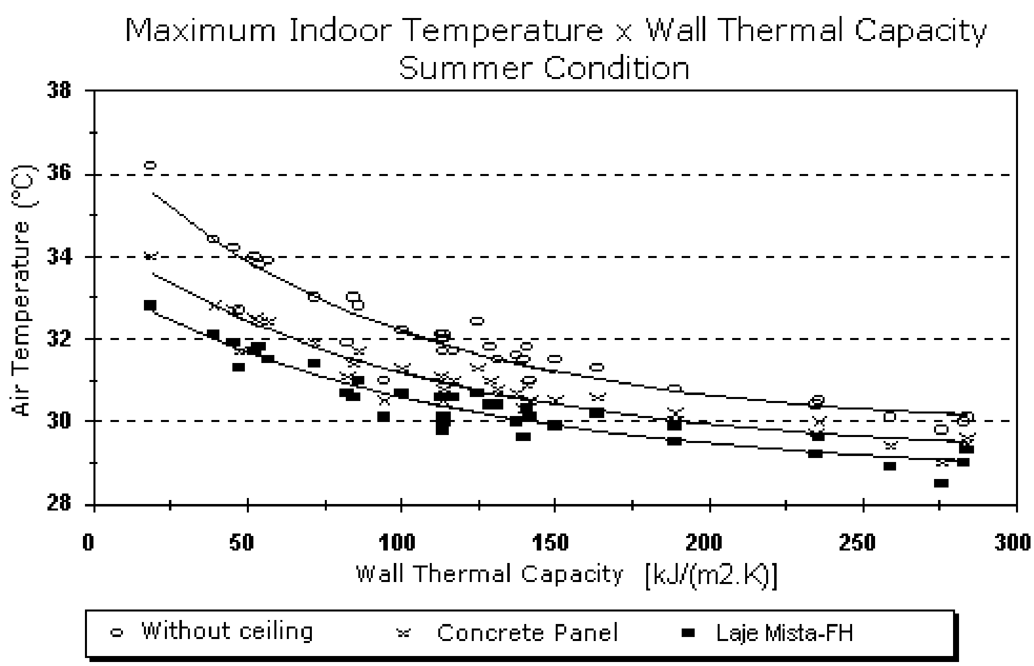

FIGURE 3: Calculated values of daily maximum indoor air temperature adjusted as a function of the wall thermal capacity, in a summer design day.

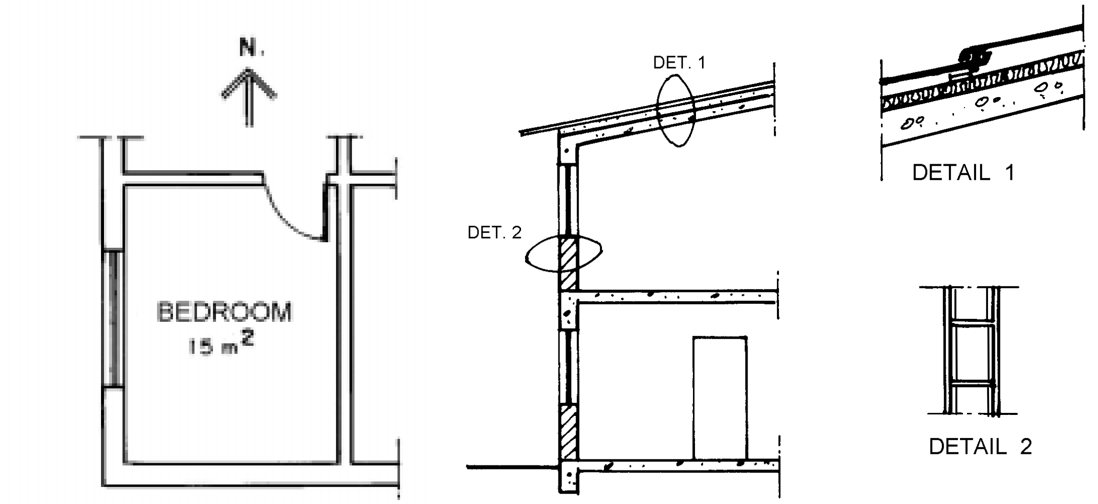

FIGURE 4: Sketch of the dwelling.

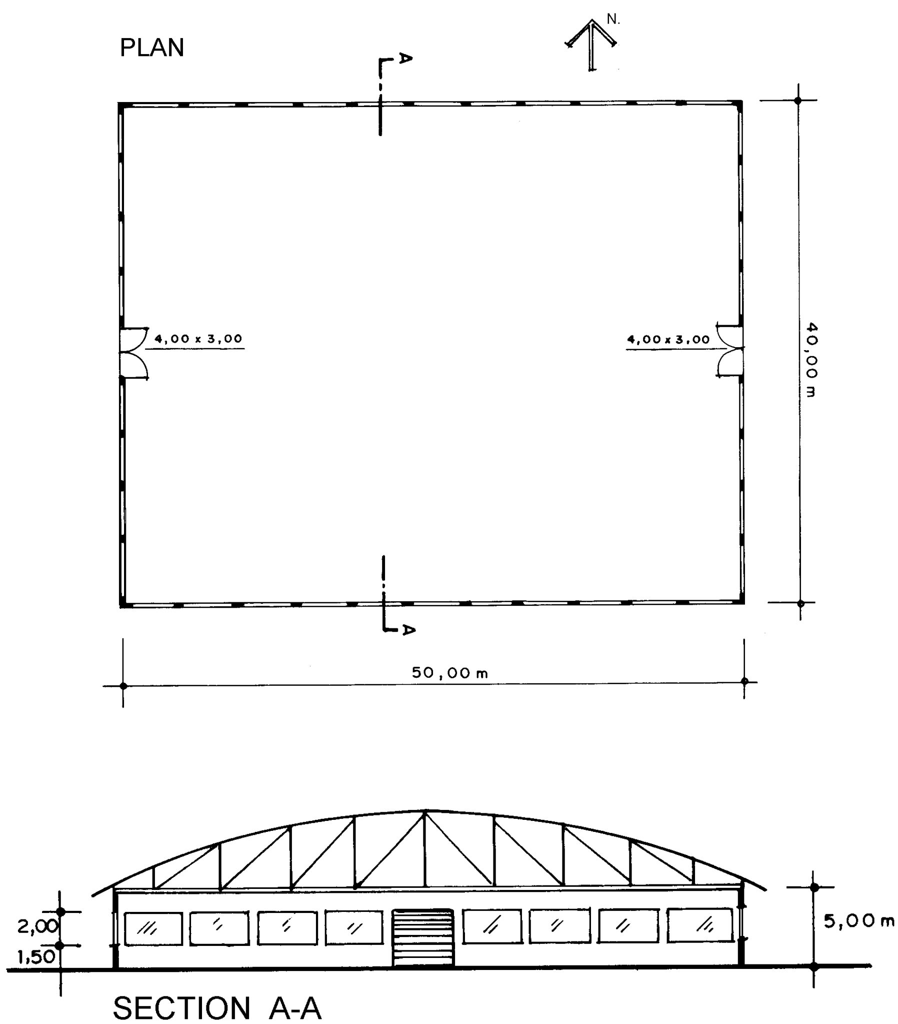

FIGURE 5: Sketch of the industrial building.

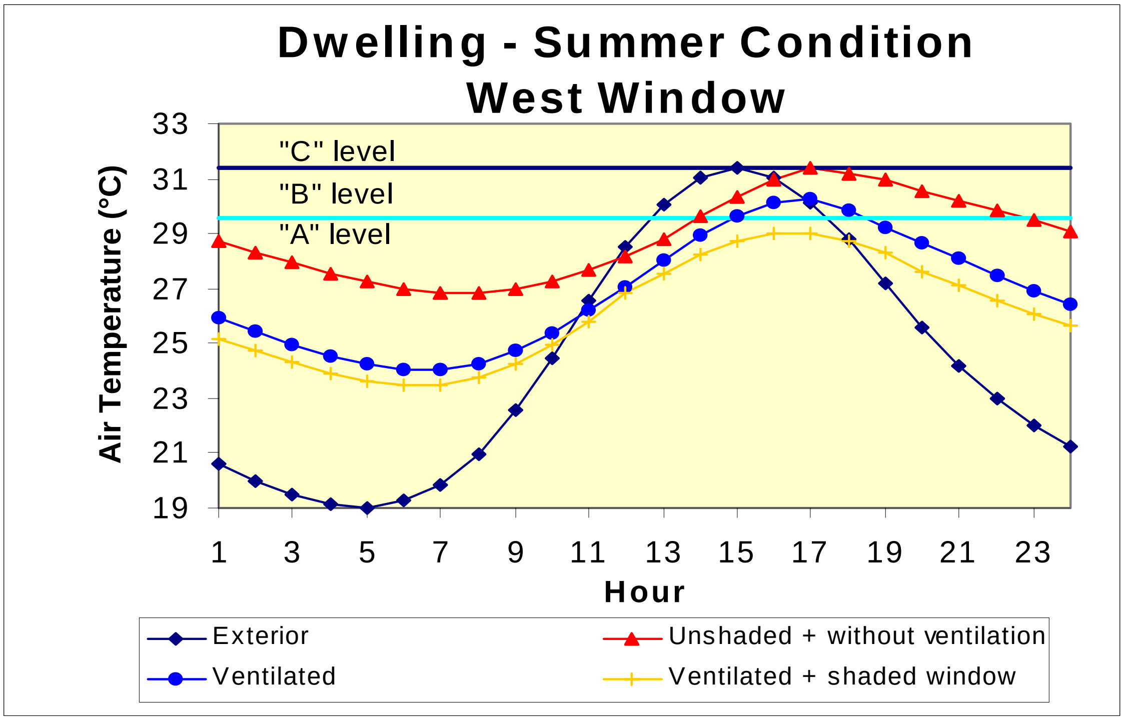

FIGURE 6: Hourly values of the outdoor and indoor air temperature calculated for the summer design day and the limit values for thermal comfort levels.

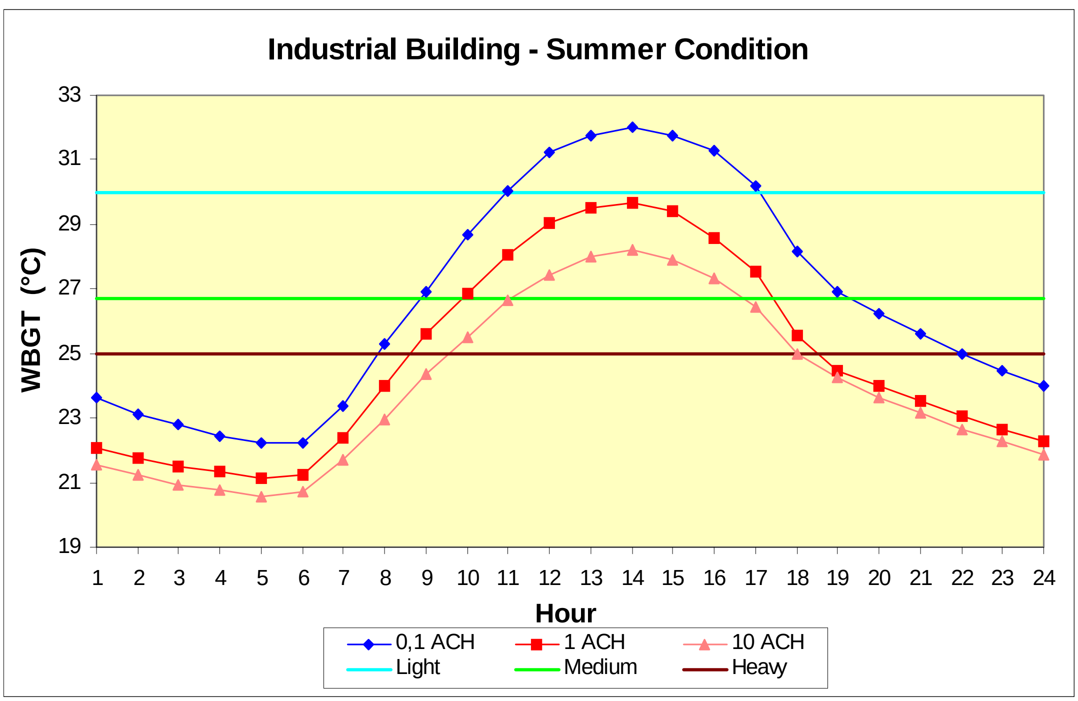

FIGURE 7: Hourly values of the Wet Bulb and Globe Temperature Index calculated for the summer design day and the limit values for light, medium and heavy activities.