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Thermal Simulation of Ambients with Regard to Ventilated Attics

E L Krüger*, O D Corbella**

* M.SC. Energy Planning - COPPE/UFRJ, Rio De Janeiro, Brazil, Student at the Institut für Industrialisierung des Bauens Hannover, Germany

** Full Professor at the Architecture School of the Federal Univ of Rio De Janeiro, FAU/UFRJ, Predio da Faculdade de Arquitetura - 4 Andar, Sala 433 Cidade, Rio De Janeiro, Brazil

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by Eduardo L. Krüger (Ph.D. Student at the *Institut für Industrialisierung des Bauens* - Universität Hannover, Germany) and Oscar D. Corbella (Full Professor at the Architecture School of the Federal University of Rio de Janeiro, FAU/UFRJ, Brazil)

ABSTRACT

The idea that internal temperatures can be reduced by ventilating the air-space between the ceiling and the roof (the attic) of a house, is widely acknowledged by Civil Engineers and Architects. This phenomenon was evaluated through three softwares (CASAMO-CLIM, COMFIE and SPIEL) which were designed for the analysis of the thermal performance of buildings, by comparing the results of all three. The prototype of a popular house in three different locations in the State of Rio de Janeiro (Brazil), at Ilha do Governador, Jacarépaguá and Teresópolis, was used for the evaluation of summer conditions.

It is understood that thermal comfort in hot climates is related to the energy consumption required for the artificial climatization of ambients, thus a reduction of this consumption can be attained if building techniques, aimed at the proper adaptation of the building to the local climate, are used, i.e. those employing passive solutions to achieve thermal comfort in the built environment.

The ventilation of attics for the three climatic situations studied resulted in a small reduction of the inside temperatures. It was verified, during this research, that this reduction was about tenths of a degree centigrade, for the most extreme climatic condition, at Governador. However, the utilisation of ventilated attics can help promoting an expressive reduction in residential energy consumption, if used alongside the adoption of other solutions of Bioclimatic Architecture, thus contributing to energy conservation in this area.

1. INTRODUCTION

The necessity of providing thermal comfort to the built environment is based on one of the prime tasks of architecture, i.e. the provision of shelter against the external conditions. At the very beginning of the History of Architecture, the idea was to have some kind of protection against rain, wind, cold or heat next to the obvious protection against wild animals and enemy tribes. Indeed, by the time of Ancient Greece, Aristotle (382-322 B.C.), Xenophon (430-350 B.C.) and Hippocrates (460-380 b.C.) had already incorporated the climatic factor within the existent building-code. Later on, Vitruvius, in the 1st Century B.C., proposed several guide-lines concerning the proper adequacy of constructions to the local climate. Thus, it could be said that the climatic factor is a decisive parameter for architectural design.

But somehow during the 20th Century the traditional examples of the vernacular architecture were put aside, when a widespread adoption of an internationalised architecture occurred, in places of different climatic conditions. One can observe the same building being built in New York, Rio de Janeiro or Jakarta. The cause for these discrepancies can not be simply summarised. Among many factors, cheap energy prices until the first oil crisis in the 70's, guaranteed the general use of artificial climatization of ambients.
This is particularly true of office-buildings, but average one-family houses in tropical conditions also show a lack of interest in the vernacular designs. The consequent favouring of imitations of foreign solutions also lead to "climate alienated" constructions, which normally result in uncomfortable

solutions also lead to "climate alienated" constructions, which normally result in uncomfortable ambients. In low-cost houses, the use of artificial climatization by air-conditioners remains a luxury. Furthermore, as a consequence of improper architectonic design, already unfavourable climatic conditions outside, are substantially worsened inside the ambient.

For warm-humid climates (which characterise the greatest part of the Brazilian territory, including the States of Rio de Janeiro and São Paulo), the most common passive solutions to achieve thermal comfort internally consist of reducing heat gains through solar radiation by protecting the openings of the envelope and promoting a good ventilation rate [1].

In this research, the effects of the ventilation of the attic of the prototype of a low-cost house were evaluated. The air-space between the ceiling and the roof of a house becomes a substantial heat trap, as a result of the transmitted long-wave radiation of the roof elements. By the ventilation of this air-space, the heat can mostly be dispersed. In this case, by reducing the air-temperature inside the attic, a lower amount of heat will reach the space below. This phenomenon was analysed by using computer programmes, which were designed for the evaluation of the thermal performance of buildings. For that purpose, the climatic conditions of three different locations at the State of Rio de Janeiro were considered.

This paper will firstly give a brief description of the mechanisms related to the natural ventilation of ambients, concerning the achievement of thermal comfort standards. Secondly, the conditions for the simulations with the softwares are presented, followed by the simulations themselves and their results. Finally, some comments regarding the simulation results and the utilisation of the softwares are expressed.

2. NATURAL VENTILATION AND THERMAL COMFORT

There are two main goals related to the ventilation of internal spaces:
- the removal of excessive heat from the interior space (heat stored in walls and internal surfaces and the removal of internal hot air itself);
- ventilation for hygienic reasons, in which fresh air is permanently provided through openings at the building envelope.

However, under tropical climatic conditions, the natural ventilation of ambients is connected to the former, i.e., the removal of excessive heat and improvement of thermal comfort conditions internally. This is in general not easily achieved when high temperatures are to be found outside. In that case, selective ventilation may normally be the best solution.

The ventilation of the attic aims at a different objective. The primal task is neither increasing air movements in the ambient for immediate body cooling nor removing stored heat of internal surfaces by convection, but that of indirectly reducing the heat gains which are transmitted to the ambient through the ceiling.

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[1] As the temperature ranges remain considerably low in a daily and yearly schedule, i.e., permanently above comfort standards, the use of thermal inertia does not offer many advantages. In this respect, light constructions are mostly recommended, as these allow sufficient airflow (air-permeability) and do not absorb and retain heat.

Especially in one-storied houses, the roof is the building element which receives the highest amount of solar radiation throughout the year. If there is also an attic, the converted solar radiation into long-wave radiation is transmitted through the roof-elements and a heat trap is formed between the roof and the ceiling. When no ventilation is provided for this air-space, the inside temperatures rise far above the outside ones.

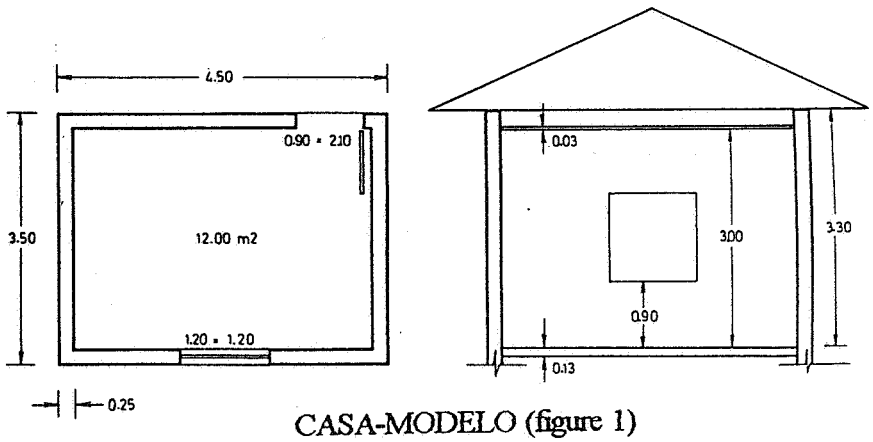
Through the ventilation of the attic, it is supposed that the inside temperatures of the attic may be reduced to a level the same as the rates of the outside air temperatures. This is partially achieved by renewing the inside air through the openings at the attic and partially by cooling the internal surfaces by convection and interfering at the radiation heat exchanges. After this temperature reduction is achieved, the heat transfer from the attic to the ambient below it is somewhat softened, thus a slight drop of the internal air temperatures is to be expected, increasing comfort conditions in the ambient.

Although the system is quite simple, its efficiency depends on the location and size of the openings. Furthermore, next to the natural ventilation by wind effect, one could take advantage of the stack effect, which consists of the natural upwards movement of hot air, if openings at different heights are provided. In this case, the heated air trap would also be slightly dissolved by the permanent air current from the lower to the upper openings.

3. THE PROTOTYPE: CASA-MODELO

The prototype (CASA-MODELO) which was used for the simulations consists of a low-cost house with an internal area of 12 m² and 3 m high, based on a proposed model by *Instituto de Pesquisas Tecnológicas de São Paulo* for similar studies [2].

The CASA-MODELO (figure 1) constitutes average brick walls (20 cm thick) which form only one ambient with an attic, separated by a 3 cm wooden ceiling. The roof is formed by ceramic tiles (1.5 cm thick) which offer a good thermal resistance. Wooden boards (3 cm thick) are used fo the floor. For a permanent ventilation of the ambient, two wooden venetian blinds (4.00x2.00 m) are provided at 2.70 m above the floor. At the same facades of this blinds, there is a wooden door and a single-glass window with wooden venetian blinds as well. External surfaces receive white finishes (including the roof). As for the internal surfaces, only the attic surfaces and the floor remain unpainted.



CASA-MODELO (figure 1)

[2] As this study is related to computer simulations, only the building data is considered as a basis for the simulations. It is not an experimental research, and no building has actually been built.

In the case of the attic, three situations were considered: firstly, without ventilation, and secondly and thirdly, with respectively two and four air-openings, protected by mosquito-nets.

With consideration of the climatic parameters, the adopted building orientation was preferentially North-South. However, for the best use of the wind effect (according to the existent average rates of wind currents), both wind- and sun-orientation were considered, allowing for heat losses by ventilation and less solar gains.

The occupation and utilisation of the CASA-MODELO are typical of a working-class couple, being basically nocturnal.

Three different locations were considered, representative of the basic climates of the State of Rio de Janeiro: Ilha do Governador (typical urban climate), Jacarépaguá (seaside climate) and Teresópolis (mountain climate). For these three locations, the basic climatic factors such as air temperatures, relative humidity, wind and solar radiation were collected for February (summer conditions).

4. SIMULATIONS

The three computer softwares which were used (CASAMO-CLIM, COMFIE and SPIEL) have been developed for the analysis of the thermal performance of buildings. They are run in small personal computers (PC's XT or AT) and are aimed at the design phase of the building activity and are aligned for the use of architects and civil engineers. The simulation results enable the planner to have a general idea of the building before it has actually been built. The main advantage of this evaluation method is allowing several variants of the same building to be tested, with regard to their thermal performance.

The basic data for the three programs have been summarised as follows:
- geographical data (latitude, hemisphere, height);
- meteorological data (radiation, albedo, wind direction and velocity, air temperature, relative humidity);
- building data (orientation, volume, areas, shadowed surfaces, materials, internal heat gains, ventilation rates, transmission, absorption and emissivity values).

After providing the program with these values, the simulation is run by finite differences and its results are offered as tables, diagrams and graphics, which make it possible for the architect to evaluate the comfort standards in the built environment.

4.1 CASAMO-CLIM

CASAMO-CLIM was developed by the *Centre d'Energetique de l'Ecole des Mines de Paris,* and its primal objectives are the evaluation of comfort conditions and the calculation of the existent charges of artificial climatization.

After the climatic and building data has been entered, the simulation is run for the desired time period and the results are shown in graphics (Givoni's Comfort Diagram and temperature curves) or in numbers (hourly values of the air temperatures, resultant temperatures -considering the heat wave emitted by the internal surfaces- and relative humidity for the studied ambient).

Considering the three situations (attic without ventilation and with two or four openings), for the three climatic zones, the results are summarised in the following tables.

table 1: CASAMO-CLIM Results for Governador

Zone: Governador Latitude: 22° 49' S minimal external temperature: 25.1°C maximal external temperature: 34.7°C		
variant	max. int. temperature (°C)	mean int. temperature during occupation (°C)
without ventilation at the attic	32.90	30.79
with 2 air-openings at the attic	32.90	30.76
with 4 air-openings at the attic	32.90	30.76

table 2: CASAMO-CLIM Results for Jacarépaguá

Zone: Jacarépaguá Latitude: 22° 59' S minimal external temperature: 23.4°C maximal external temperature: 31.4°C		
variant	max. int. temperature (°C)	mean int. temperature during occupation (°C)
without ventilation at the attic	29.70	26.89
with 2 air-openings at the attic	29.80	26.88
with 4 air-openings at the attic	29.80	26.91

table 3: CASAMO-CLIM Results for Teresópolis

Zone: Teresópolis Latitude: 22° 27' S Height: 874 m minimal external temperature: 18.2°C maximal external temperature: 28.6°C		
variant	max. int. temperature (°C)	mean int. temperature during occupation (°C)
without ventilation at the attic	27.70	26.35
with 2 air-openings at the attic	27.70	26.31
with 4 air-openings at the attic	27.60	26.28

Apart from an unexpected rise of the internal temperatures when the attic was ventilated in Jacarépaguá, the average tendency which was observed is a slight reduction of the internal air temperatures during the occupation of the ambient. These reductions are nevertheless insignificant and the program is not sensitive to variations of the air flow in the attic. In the case of Governador, for instance, the daily ventilation rate of the attic is risen from 73 up to 143 vol/h while nightly from 20 to 41 vol/h, which means an increase of 100%, and no temperature reduction was observed.
Though this program does not allow a precise understanding of the thermal behaviour inside the attic (for it presents the temperature curves and values only for the studied ambient), one may draw as a conclusion that a reduction is to be found, although not a very significant one.

5.2 COMFIE

COMFIE is also a product of *Centre d'Energetique de l'Ecole des Mines de Paris* and it was designed for the thermal analysis of multizonal buildings.

As this program offers the possibility of studying several zones simultaneously, its results concerning the thermal performance of the attic allow a more precise understanding. However, the results are presented in form of temperature means and maximal and minimal values for each zone.

For the three climatic zones considered and for the three situations concerning the ventilation of the attic, the results are shown below:

table 4 : COMFIE Results for Governador

variant	mean int. temperature (°C)	mean int. temperature during occupation (°C)
without ventilation at the attic	30.87	30.81
with 2 air-openings at the attic	30.76	30.69
with 4 air-openings at the attic	30.72	30.67

table 5: COMFIE Results for Jacarépaguá

variant	mean int. temperature (°C)	mean int. temperature during occupation (°C)
without ventilation at the attic	28.00	27.20
with 2 air-openings at the attic	27.90	27.12
with 4 air-openings at the attic	27.88	27.12

table 6: COMFIE Results for Teresópolis

variant	mean int. temperature (°C)	mean int. temperature during occupation (°C)
without ventilation at the attic	24.50	24.18
with 2 air-openings at the attic	24.38	24.06
with 4 air-openings at the attic	24.33	24.03

The first thing to be noticed is a better sensitivity of this program towards the ventilation of the attic. Although the reduction of the ambient temperatures is still not very significant, through higher ventilation rates in the attic, the reduction of its internal temperatures is quite expressive, as it is shown in the following table.

table 7: COMFIE Results for Governador - Internal Temperatures in the Attic

variant	min. int. temperature in the attic (°C)	max. int. temperature in the attic (°C)
without ventilation at the attic	27.46	36.82
with 2 air-openings at the attic	25.93	35.29
with 4 air-openings at the attic	25.70	34.81

Thus, through these results, it can be concluded that the ventilation of the attic is not as effective as the ventilation of the ambient itself, though, an attic when present should be preferentially ventilated.

4.3 SPIEL

SPIEL was designed by *Ecothec Design Ltd.* (Sheffield, UK) for the analysis of the thermal performance of buildings and the calculation of the energy charge for the climatization of ambients.

The input data is similar to that of CASAMO-CLIM and COMFIE and the results consist of the daily temperature development and of the correspondent energy consumption during occupation (for lighting and climatization).

For the first situation (the unventilated attic), at Governador, the temperatures of the ambient and of the attic were practically identical. Allowing for the fact that the program had not considered the heat gains from solar absorption on the roof, several tests were conducted to verify this assumption.

In order to try to solve this problem, a fictitious "glass envelope" that is perfectly transparent and with a thermal conductance equal to that of the external surfaces was introduced to the model. For the most extreme situation, the unventilated attic at Governador, the temperatures of the ambient remained below those of the attic. However, when the attic was ventilated, the internal temperatures of the ambient rose, even though the attic presented lower temperatures than before.

It was then assumed that this program was designed for northern part of the northern hemisphere, where milder solar radiation is to be found. In this case, the great temperature differences between in- and outside (due to heating systems and insulated walls) turn the solar gains in opaque elements into an almost negligible factor.

5 CONCLUSIONS

While admitting that computer simulation by PC's is still a rudimentary tool to predict the precise performance of a physical phenomenon (an experimental analysis would be more recommendable), one can nevertheless infer what happens in reality.

In this research, small reductions of the internal temperatures were observed by the utilisation of two softwares (CASAMO-CLIM and COMFIE) when the attic was ventilated. Though the exact decrease of the ambient temperatures was left undetermined, it was noticed that this reduction is insignificant.

Nevertheless, as one of the various means to achieve thermal comfort in buildings using Bioclimatic Architecture, the ventilation of the attic could be efficient when applied alongside others such as shadings, building finishes with low absorption and cross-ventilation.

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