An adaptable urban house designed for the southern Brazilian climate – emphasis on summer and winter thermal comfort

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ABSTRACT: The climate in southern Brazil is characterised by mild winters and hot-humid summers which requires the design to be adaptable to the often conflicting summer and winter requirements. In the residential sector, air conditioning consumption is still low, but it has been growing significantly along with an increase in people's purchasing power which emphasizes the importance of encouraging a change in construction practices [1]. The aim of the research is to design a residence that combines traditional and contemporary techniques and technologies, along with a smart design, providing acceptable summer and winter thermal comfort. This was pursued by considering the advantages found in some precedents, such as, passive heating and cooling strategies that respond to the climate; and by controlling the relationships between buildings and outdoor spaces to ensure a response to the different seasons. Environmental design approach is found to go far beyond the quantification of energy consumption through the use of different materials or strategies.

Keywords: environmental design, thermal comfort, passive strategies, adaptable design

1. INTRODUCTION

To reduce energy consumption, the adequacy of the architectural standard is the item that requires the lowest investment and provides one of the highest energy savings.

Finding successful means of energy reduction and a solution to the environmental effects of air conditioning is a strong requirement for the future. Possible solutions include the adaptation of buildings to the specific environmental condition of cities in order to incorporate renewable energy technologies efficiently to address the radical changes and transformations of the radiative, thermal, moisture and aerodynamic characteristics of the urban environment. This involves the use of passive and hybrid cooling and heating techniques to decrease cooling and heating energy consumption and improve thermal comfort.

2. OBJECTIVES OF THE BUILDING

2.1 Project Brief

It is a house designed for a family of 4 to 5 people that enjoy being outdoors and having freedom in the house. The average size required is around 200 m². The programme is composed by Living Room, Barbecue Room, Kitchen and Study Room - mostly occupied during the whole day; 3 Bedrooms - occupied during the night; Laundry, Bathrooms and Garage - occasionally; and Swimming Pool - summer.

2.2 Conceptualization

According to the study of the built examples some conclusions were drawn, such as the importance of the engagement of the architecture with the environment, about rethinking the way that people live and how the design should respond to the climate [2].

The house should be adaptable, able to be changed according to the seasons, responding at the same time to the climate and to the occupants' attitudes and expectations of comfort. In winter it should be more compact and well insulated to keep the internal and solar gains inside the house and save energy when mechanical heating is needed, but at the same time it should be able to be more permeable in the summer and be fully integrated with the outside.

3. DESIGN GUIDELINES

3.1 Chapecó's Climate

The context of this work is the city of Chapecó, which is located in Southern Brazil, in the west of Santa Catarina State at Latitude 27°14' S, Longitude 52°37' W and Altitude 668 m.

The following description of the climate of Chapecó is based on 10 years of hourly meteorological data recorded in Chapecó's airport processed through the Software Meteonorm [3].

3.1.1 Dry bulb temperature

The annual mean temperature is 19.2°C. The hottest month is January, presenting a mean temperature of 22.8°C and the coldest is June, with a mean temperature of 13.5°C. The annual mean daily range of temperature is 9.3°C. In January, the mean maximum temperature is about 28°C and the mean minimum is 16.9°C, producing a daily range of temperature of about 11.1°C. In June, the daily swing of temperature is also about 11.1°C, ranging from a minimum mean of 7.9°C to a maximum mean temperature of 19°C.

It was observed that during the winter, or even in the summer, there are periods of heat and cold, respectively.

3.1.2 Relative air humidity

The annual mean relative humidity is 73%. The months with the highest average relative humidity are May and June (around 78%) and November is the month with lowest average (around 68.6%).

3.1.3 Wind speed and direction

The annual mean wind speed is 2.5 m/s. March is the month with the weakest winds and September has the highest speeds, both average and maximum.

Wind frequency, relative to its direction, shows the north-eastwards and northwards directions as predominant throughout the year. The north-eastwards direction is predominant during summer and the northwards direction in August. The second highest frequency occurs south-eastwards in most part of the year, mainly in winter and in the months of June and September.

3.1.4 Cloudiness and Insolation

In Chapecó's climate, winter months feature lower cloudiness rates than during summer months.

Annual average cloudiness is 5.4 (part of the sky covered by clouds: from a 1 to 10 scale, that is, greater than 50%); also, cloudiness tends to increase from September to February, reaching 59% in January and February. May is the month with the lowest cloudiness rate and is the only one to fare below 50%.

3.2 Passive Strategies Investigation

To obtain some building design guidelines the result obtained was analyzed by applying the program developed at LABEEE (Laboratory of Energetic Efficiency in Buildings – Federal University of Santa Catarina – Brazil), based on Watson's and LAB's method (1983), thus allowing the crosschecking of all hourly climate data on the Bioclimatic Building Plan tailored to Chapecó [4].

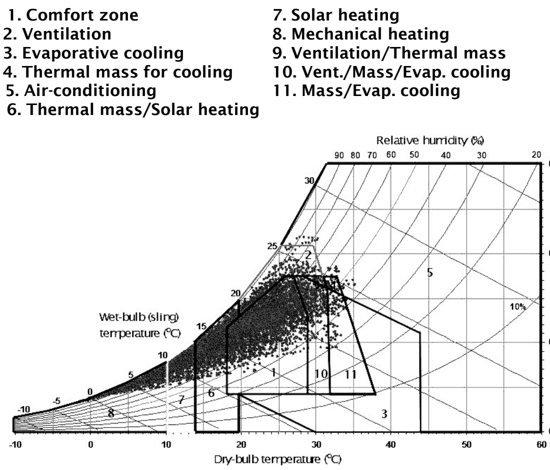

Figure 1: Chapecó's climatic year

4. DESIGN DEVELOPMENT

According to the local climate analysis the primary need is to increase winter heat gains and reduce summer heat gains during the day. This was attempted through a comprehensive set of actions that start on a large scale by controlling the relations between buildings and outdoor spaces.

In the design stage the advantages which were found in the three different houses' approach of designing and passive strategies that would respond to the climate were taken into consideration [2], as a result an adaptable house responding to the local climate is proposed.

4.1 Site layout and Building Form

As a starting point for the design, it was decided to separate the living area (daytime) from the sleeping area (night-time), thus more rooms could get the winter sun and have cross ventilation also allowing the buildings to be connected in winter and disconnected in summer which could lead to a more interesting site layout.

The sleeping area was located at the back of the site, consequently further away from the street and noise. It would comprehend the whole site's width (17 m) to ensure that all the bedrooms would face north. The living area would be more compact allowing 4 m setbacks at the sides to decrease the overshadow created by the neighbouring houses and walls and also for the creation of side gardens and courtyards that would allow the extension of the inside space when the outdoor temperature is comfortable.

The average distance found to ensure that the sleeping area would not be overshadowed by the living area was around 8 m (Fig. 2 and 3). It was considered that the first volume had an average height of 4.5 m, which is going to be used at the final project.

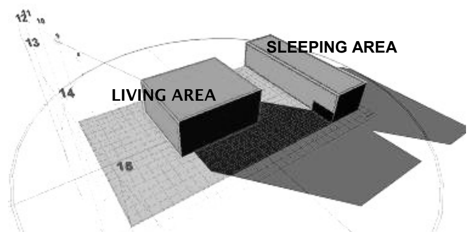

Figure 2: Shading study on June 21st at 9am

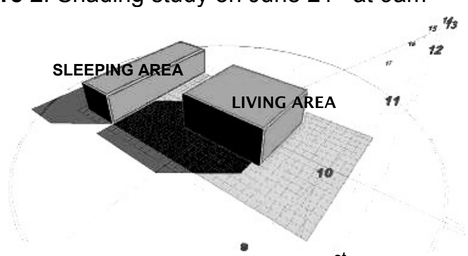

Figure 3: Shading study on June 21st at 3pm

4.2. Internal Layout

The house was designed with an internal layout where the main rooms such as barbecue room, living room and bedrooms are facing north as they are the rooms that will be most occupied at daytime and evening in winter. The study room, the second most used space, is facing east, and kitchen and laundry facing west as they also can be shaded in summer. Openings are not placed on the south façade as it does not have any solar gain in winter and in the summer it gets some sun, and the south façade might require extra insulation to avoid loss of heat gains.

The leisure area of the house would be on the roof of the ground floor as the swimming pool requires maximum solar radiation to heat the water (Fig. 5). The swimming pool also works as heat storage through its thermal capacity. The ceiling, which is cooled by heat conduction through the water, acts as a radiant/convective cooling panel for the space under it. Thus, the indoor air and radiant temperatures can be lowered without elevating the indoor humidity level.

4.3 Design Project - *Summer and Winter House*

The house proposed is adaptable through moveable devices. It can change its configuration through the occupant's interaction responding to the local climate and to the seasons change.

It was focused to design the versions of the house in summer and in winter as they are the most extreme seasons. Thus, in winter the house is more compact and well insulated to keep the internal and solar gains inside the rooms and save energy when mechanical heating is needed (Fig. 4). In summer it is more permeable and the relationship with the outside is stronger (Fig. 5).

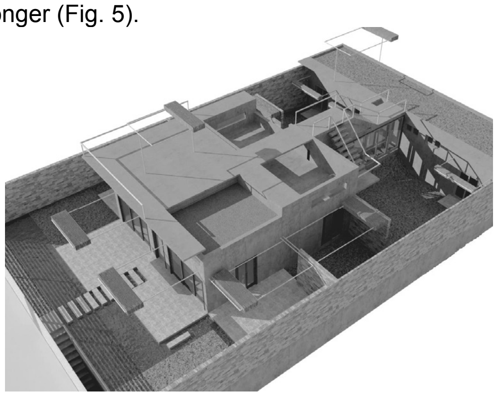

Figure 4: Winter House

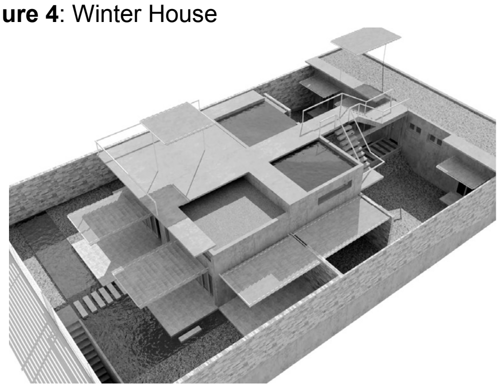

Figure 5: Summer House

The floor plans of the house are presented below with the strategies and the design elements pointed at the floor plans are explained (Fig. 6, 7, 8 and 9).

1. Thermal storage - water
2. Reflection - gardens
3. Thermal mass – stone (walls and floor)
4. Thermal mass – brick (walls)
5. Cross ventilation - sliding doors fully opened

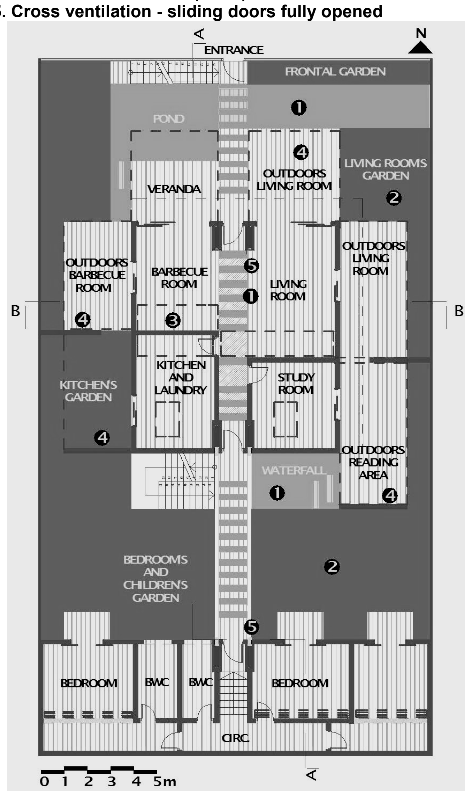

Figure 6: Ground Floor Plan – *Summer House*

1. Thermal mass and wind protection - concrete
2. Compactness - sliding doors fully closed

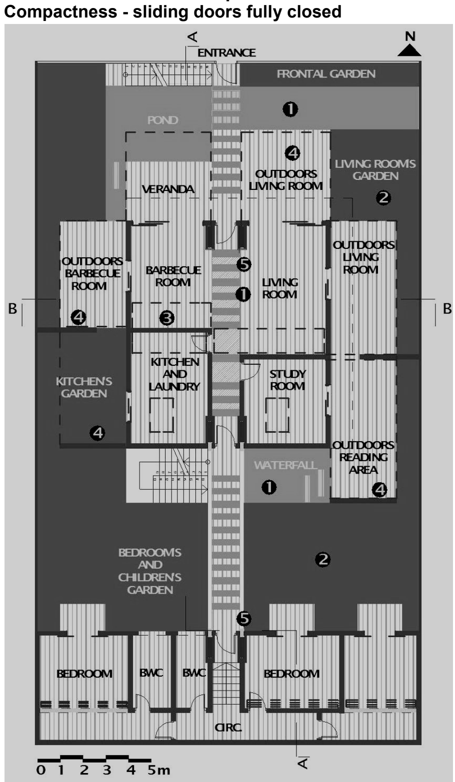

Figure 7: Ground Floor Plan – *Winter House*

1. Moveable shading device/night shutters - position: horizontal fully opened
2. Moveable shading device/night shutters - position: horizontal fully closed
3. Moveable shading device/night shutters - position: horizontal almost fully closed
4. Moveable shading device/night shutters - position: horizontal semi-opened
5. Reflection – green roof
6. Thermal storage - swimming pool
7. Fixed shading device

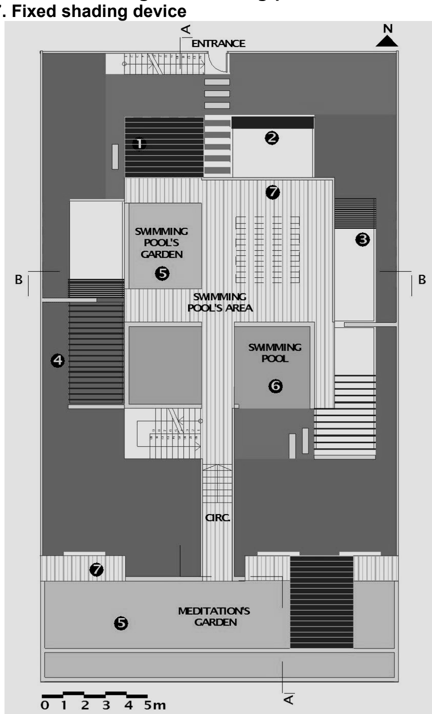

Figure 8: Roof Plan – *Summer House*

1. Solar heating - roof light
2. Thermal insulation – green roof

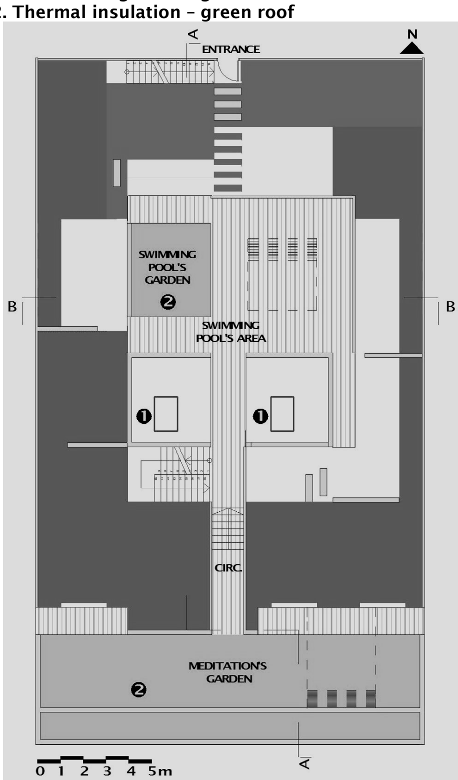

Figure 9: Roof Plan – Winter House

4.3.1. Thermal Mass

Thermal mass was applied through the brick and stone walls, concrete ceilings and floors (Fig. 6). It is a strategy suitable for summer, decreasing the peak of cooling loads and releasing, with a delay, the heat to indoors. In winter, the solar diurnal gain can be stored in the thermal mass and transferred into the building at night, when heating is required.

According to Balcomb [5], thermal mass is best increased by maximizing surface area rather than increasing thickness. Thus, thermal mass was also applied on the walls surrounding the building creating courtyards (Fig. 10 and 11). These walls can store some heat during the day and release it at night creating warmer and more comfortable outdoor spaces.

Figure 10: Barbecue Room's Courtyard – *Summer House*

Figure 11: Living Room's Courtyard –*Summer House*

4.3.2. Ventilation

Ventilation happens through the openings located at the occupant's level, providing comfort ventilation and located at a higher level in the bedrooms, barbecue room and living room (Fig. 12). However, as in these spaces there is a moveable insulated ceiling which can be closed decreasing the height of the room in winter, thus in winter the higher windows stay above the insulated wood ceiling and closed (Fig. 19). All the openings, with the exception of the kitchen and study rooms, are facing northwards which is the main wind direction.

Figure 12: Barbecue Room's openings and shading devices – *Summer House*

4.3.3. Shading Devices/Night Shutters

The shading devices applied in the design are mostly moveable allowing the occupant to control the penetration of direct solar radiation and also daylighting levels, to control direct gain passive heating, maximising useful gains while avoiding overheating. They are more used in summer, however, it was observed that during the winter, or even in the summer, there are periods of heat and cold, respectively. Therefore, within the same season, days may occur with characteristics of the opposite season consequently if the devices are moveable they can also provide shade for the lower winter sun.

As the configuration of operable shading devices can be changed, their performance can be much better than that of fixed devices. They are composed of fins that can be rotated in both directions and if they are not in use they can be folded to one side (Fig. 13). The horizontal and vertical shading devices also work as night shutters and as insulators for the walls covering its whole extension (Fig. 14).

Figure 13: Different configuration of shading devices

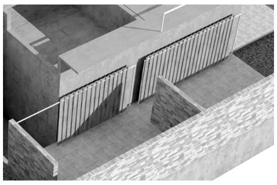

Figure 14: Different configuration of shading devices

The higher windows of the living room, barbecue room and bedrooms are also shaded to avoid unwanted heat gains in summer. The shading devices are fixed, and are the floor of the Swimming Pool's Area and the sits of the Meditation's Garden.

According to insolation studies on the 21st December, the sun just heats the northern surfaces between 10.30 am and 2.30 pm, before and after that it is towards the South, so the shading devices needed are quite small (Fig. 15).

According to Shaviv and Capeluto studies [6], the winter performance of the thermal mass is very sensitive to the roof's insulation and the better it is the less energy is required for heating. On the other hand, this is not the case in summer, when the better the roof's insulation, the more energy is required for cooling. This is because the poorly insulated roof allows night cooling by heat conduction and by long wave radiation. Consequently, higher transmittance in the roof is recommended.

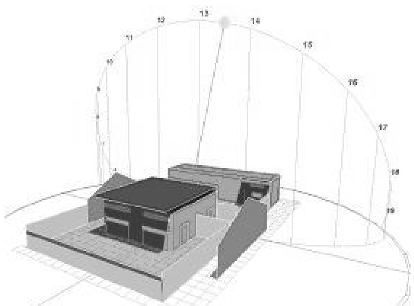

Figure 15: Fixed shading devices for higher windows

Thus, besides the function of shading the higher windows the floor of the Swimming Pool's Area is partially suspended shading the roof below from the Living and Barbecue Rooms. It also allows some cross ventilation as it is open on both sides (Fig. 16). In winter it is closed to avoid the contact of the roof with the outside temperatures (Fig. 17).

Figure 16: Suspended roof – *Summer House*

Figure 17: Suspended roof closed – *Winter House*

4.3.4. Swimming Pool and Ponds

Water is used on surfaces outside and inside the building as it has a very high thermal capacity, about twice that of common masonry materials and also has the advantage that convection currents distribute heat more evenly throughout the medium also providing some evaporative cooling. The water way inside of the house in summer is partially open and with moveable glass sheets, so it is possible to see the water through it (Fig. 20). In winter this floor is replaced by insulated wood panels, becoming fully closed. The same happens at the water way that connects the living area to the sleeping area.

The water that circulates around the house and from the waterfall is not the same as that from the swimming pool as one of the requirements for the swimming pool is to have its water heated, so it should be fully under the sun and not in movement.

The swimming pool was located above the kitchen and the study room, thus their roof can be cooled by evaporation and the ceiling then acts as a passive cooling element for the space below. The ceiling, which is cooled by heat conduction through the water, acts as a radiant/convective cooling panel for the space under it. Thus, the indoor air and radiant temperatures can be lowered without elevating the indoor humidity level.

In the winter the swimming pool is empty allowing the entrance of light through the roof lights to heat the study room and the kitchen. The dimension and the location of it were done by shading studies (Fig. 18). According to the shading mask the roof light would get full sun between 10 am and 2 pm, before and after that it could be closed and very well insulated avoiding loss of heat to the outside.

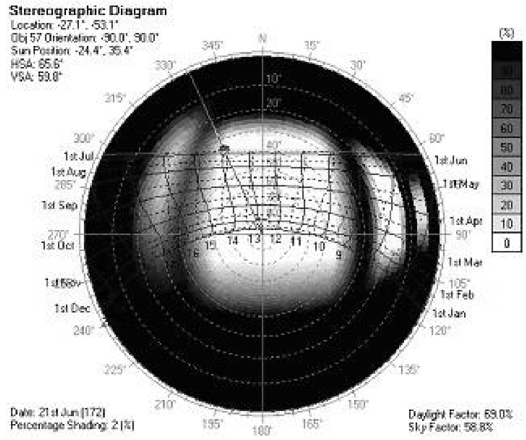

Figure 18: Shading mask of roof light in the kitchen – *Winter House*

4.3.5. Gardens

The roof is the building element which receives the most amount of sun, especially in summer, and that is more exposed to nocturnal cooling by radiation. Vegetation protects the roof from direct solar radiation and enhances its thermal behaviour providing a cooling effect in summer as green surfaces reflect sun radiation and storage heat causing a cooling effect. In winter it can be used for its thermal insulation effect though the air cushion within the vegetation and the fact that the cold wind does not hit the earth surface consequently protecting the surface below. Thus, grass was used on the Bedrooms' and on the Barbecue Room's roof (Fig. 8).

4.3.6. Solar Heating and Architectural Features

Solar Heating was applied at the design stage as storage element exposed to the indoor and outdoor spaces to store excess solar energy during the sunny hours and release it back during the night. This strategy was applied through the mass of the building fabric itself, floor, in the internal layers of external walls, internal partitions, on the roof and in the furniture surface area.

To improve the solar heat and internal gains of the building, a moveable ceiling and sliding doors were applied in the Bedrooms, Barbecue and Living Rooms. The moveable ceiling is composed of wood filled with insulation. There are 4 or 5 sheets of 1 m each that can be fully closed in winter leaving the room with a height of 2.6 m (Fig. 19) and in the summer they can be folded (Fig. 20), leaving the room with a height of 3.5 m. In the summer the height improves ventilation through the high windows (just visible in summer); in winter, the floor-to-ceiling lower height helps to keep the internal gains and solar gains in the room. They also have wood sliding doors that make it possible to isolate the rooms in winter (Fig. 19) and leave them open in summer increasing ventilation (Fig. 20).

The circulation from the living area to the sleeping area is also created by sliding doors that can be fully opened in summer and fully closed in winter, keeping the access between the two zones less exposed to the weather (Fig. 4 and 5).

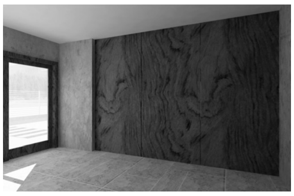

Figure 19: Moveable insulated ceiling and sliding doors – *Winter House*

Figure 20: Moveable insulated ceiling and sling doors – *Summer House*

5. CONCLUSION

The design of more enjoyable spaces and their interrelation in a more interesting way was pursued at the same level as the outside penetration/interference at the inside spaces, and, on its occupants interaction with the building's envelope and features.

In response to this, the design started by challenging attitudes in house designing, pointing out that the occupant should be in control of the house in such a way that he feels that he is interacting with the design, having the possibilities of achieving what he wants from the space, mostly by moving architectural features instead of switching on equipments. Its occupants can deliberately see very visible differences between "summer" and "winter" houses through a clear reading of the different devices.

It was found that environmental design combining passive strategies and the intention of achieving a quality design might be more efficient in the overall environmental design picture. The occupant's thermal and psychological comforts were placed as the main issues to be addressed and not energy savings, as the latter is a consequence of the two former considerations.

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