Applied Low Energy Techniques at Universidad Austral de Chile's School of Architecture.

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ABSTRACT: The purpose of this paper is to show how theories of a passive and low energy concept of architecture have been applied in one of Chile`s Universities. These new theories involve the design of natural cooling and natural heating taking into consideration an adaptive approach to thermal comfort. Recently, these techniques have been established at *Universidad Austral de Chile´*s School of Architecture.
By doing a comparative analysis of the theoretical formulation and the comfort measurements gathered in the building, it will be shown how this school concept fits among the new architecture of passive system and low energy usage. The results have shown that compared to an average building in Chile under the same conditions, the School of Architecture has up to 70% less energy consumption in the winter time and using night cooling, overhang sun shading and natural cross ventilation techniques, optimal comfort conditions during the summer were achieved without the need of mechanical cooling and ventilation.

Conference Topic: Case study
Keywords: Nighttime cooling, thermal mass, overhang, chimney effect, cross ventilation, buffer zone, air tightness

1 BACKGROUND

The School of Architecture of Austral University in the south of Chile was established only 3 years ago (2000) by a multi-disciplinary team consisting of architects, anthropologists, geographers, engineers and environmental professionals. The vision of the founders was to develop a new generation of architects with skills in designing urban constructions that reflect a full consciousness of the impact on society, economy and the environment.

With the development of modern materials and construction techniques, the last few decades have seen buildings constructed that use sophisticated and high-energy intensive technologies to "solve" most of the problems caused by not paying attention to energy consumption and environmental impact. The negative anthropogenic effects, including those of the modern building industry, on the environment is widely reported and accepted as fact. The new energy crisis, polluted and crowded cities, environmental impacts, global warming, ozone layer depletion, problems with availability of resources are driving low energy building design. There is resurgence within the built environment profession to return to the simple design techniques of the past while still using the modern construction methods and materials, with the intention of reducing these impacts.

In the design on the new faculty building, simple, inexpensive and old concepts, "rescued" from the past, were applied. These kinds of techniques from before the industrialization era were almost forgotten by architects and engineers. A good and efficient way of assisting this essential "relearning" process is to educate the new architect generation in a simple and friendly building that can be seen and touched. This way the simplicity of these methods can be experienced in every hour of education and not only taught from text books, internet, physical and computer models. This creates within the new generation of architects, an all-important self-confidence that that these techniques are not only plausible but also extremely effective in providing indoor comfort and low energy consumption while creative designs and ideas can still be realised.

The construction of the building started in April 2002 and the building was occupied in March 2003.

2 THE CONCEPT

How can buildings be designed compliant to the new demands without "spoiling" the architectural appearance? There is a very simple way to accomplish this. The architectural team should be aware of the low energy design concepts and thus they can be incorporated efficiently from the first stage. Often indoor air quality, thermal comfort conditions, low investment, minimum environmental impact and low operational cost (heating, cooling, ventilation, lighting, and electricity) are an afterthought of the conceptual design. When they are retrofitted to the initial concept there can only be compromises where no parties are totally satisfied. These compromises detract from both the architectural design and the performance, which should not be seen as separate goals. Should the techniques form an integral part of the building, there will be no compromises, only complementation. This is a true example of the old architectural concept of form following function.

It was with this mindset that the multidisciplinary design team approached this project. The building itself is the "energy system." Basic passive design concepts were included from the very first stage of the conceptual design.

Figure 1 : View of southern and eastern facade from across the river

The longest façade is orientated towards the north and the building has been placed so as to benefit from the evapotranspiration effect of the nearby river and vegetation. This orientation takes advantage of the free solar energy for heating during winter and at the same time simple shading avoids the direct solar radiation in summer as much as possible, negating the necessity of mechanical cooling or ventilation system. This is assisted with nighttime cooling via chimney effect (accompanied with enough thermal mass to store the coldness for the next "hot" day), cross natural ventilation during day, overhang shading and white color in roof and exterior walls.

The intention was to achieve: a comfortable indoor environment, a balance of initial costs through not installing mechanical cooling and ventilation equipment and reduction in the heating installation and investing this in the passive design architectural aspects, reduction in running costs through no energy costs for cooling and ventilation, low heating requirements in winter and low energy consumption for lighting through the use of effective day lighting.

Figure 2 : View from the open plan model making space, showing the circulation area below and the three level's of lecture rooms and offices

However this should not be at the expense of elegance and useful space. The light four storey high glass envelope, which is used to capture the sun energy during the day and provides the mechanism for the stack effect ventilation, creates a high volume exhibition and function space as well circulation and meeting areas for between classes. The glazing gives both fantastic views of the picturesque surroundings, and great depth of day lighting, forming an almost utopian learning environment. The three inner stories of classrooms and office benefit from this natural lighting and ventilation while still providing acoustically separated areas. The open plan area above the classrooms that forms the apex of the natural ventilation is extremely suitable as a workspace for the students' model making.

There has been no balancing of the functional and aesthetical aspects of the building; rather they are seen to be developed to their full potential and compliment each other.

3 THE COMPUTATIONAL MODEL

It is important to note that due to the high cost of the licences, no commercial modelling software was available to assist with the design. A simple but relatively powerful excel spreadsheet was developed to estimate the result of incorporating various passive techniques in the design. Experience and observation served as a valuable tool in lieu of computational fluid dynamic (CFD) software. The spreadsheet will be developed further to form part of an educational package for the students. The next few paragraphs show some of the simple theory equations and data used as the basis of this spreads heet.

3.1 Transmission losses

Heating load [3]

$$P_{wall,\,roof,\,window,\,door} = U \cdot A(t_i - t_{DOT})$$

$$P_{ground} = U \cdot A(t_i - t_g) = U \cdot A[t_i - (\bar{t}_o + 3)]$$

where

$$U = \frac{1}{\frac{1}{hi} + \Sigma R_j + \frac{1}{he}}$$

where hi (total interior heat factor) = h_{cv} interior laminar or turbulant convective heat factor + h_r (radiant heat factor which varies acording to element material sellected)

$$h_{cv} = 1{,}32 \cdot \sqrt[4]{\frac{\Delta\theta}{H}}$$ *interior laminar convec tive heat factor*

$$h_{cv} = 1{,}74 \cdot \sqrt[3]{\Delta\theta}$$ *interior turb. convective heat factor*

where he (total exterior heat factor) = h_{cv} exterior laminar or turbulant convective heat factor + h_r (radiant heat factor which varies acording to element material sellected)

$$h_{cv} = 3{,}96 \sqrt{\frac{V}{H}}$$ *exterior laminar convective heat factor*

$$h_{cv} = 5{,}76 \sqrt[5]{\frac{V^4}{H}}$$ *exterior turb . convective heat factor*

and H = Height of the wall in which the elements are being considered
?? = Difference in temperature between the surface and the air

Extra heating load in summer due to solar absorptivity in walls and roof [4]

$P_{s\,abs.} = I\ a\ U\ A/\ h_e$

Energy load [3]

$$Q_{wall,\,roof,\,window,\,door} = U \cdot A \cdot S$$

$$Q_{ground} = U \cdot A[t_i - (\bar{t}_o + 3)] \cdot \Delta\tau$$

where

- U - heat transfer coefficient, W/m^2 K
- A -surface area, m^2
- t_i -designed indoor temperature, ºC
- t_{DOT} -designed outdoor temperature, ºC
- t_g -ground temperature, ºC
- t_o -mean annual outdoor temperature, ºC
- S -specific heating demand, degree-hours,Ks/yr
- $\Delta\tau$ -heating period, h/yr
- I -insolation in each surface, W/m^2
- a -solar absorptivity (0,83 for brick and concrete and 0,2 for white exterior painting)
- h_e -heat transfer factor for exterior surfaces (10-20 W/m^2 K, depending on wind velocity)

3.2 Ventilation losses [3]

$$P_{ventilation} = \dot{V} \cdot \rho \cdot c_p (t_i - t_{DOT}) \cdot (1 - \eta)$$

$$Q_{ventilation} = \dot{V} \cdot \rho \cdot c_p (1 - \eta) \cdot S$$

where:

- V -ventilation air flow, m^3/s
- ρ -density of air, kg/m^3
- C_p -specific heat of air, J/kgK
- η -efficiency of heat exchanger(in case of heat recovery)

3.3 Monthly heat losses

$$\overline{Q}_{month} = P_{total,max} \cdot \frac{t_i - \bar{t}_{month}}{t_i - t_{DOT}} \cdot 24$$

3.4 Natural Ventilation equations [1]

$$P_d = \frac{\rho V^2}{2}$$

$$\Delta p_{f,s} = \Sigma\zeta \cdot \frac{1}{2} \cdot \rho \cdot v^2$$

$$\rho = p \cdot M / (R_M \cdot T)$$

$$R_M = 8314.3\ J/(kmol \cdot K) \text{ and } M = 29\ kg/kmol$$

4 THE MAIN APPLIED BIOCLIMATIC CONCEPTS

4.1 Orientation and building placement.

The orientation and the placement of the building relative to the river, prevailing wind direction and vegetation takes advantage of the evapo-transpiration effect of the water and vegetation for cooling during summer.

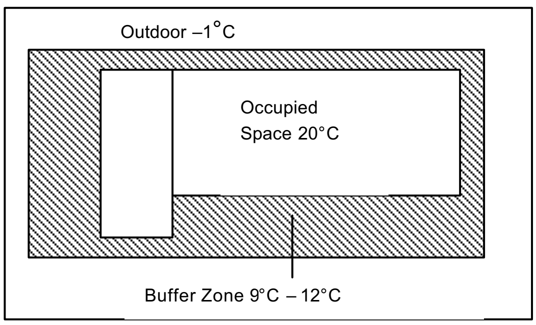

Figure 3: The zones within the building envelope

4.2 The different zones within the building.

The building has been divided into different zones with regards to both user function and comfort criteria. The floor area between the glass envelope and inner classroom/offices air concrete walls functions as circulation space. In addition it provides an exhibition and event area to east of the building. As these are areas where the occupants will have higher activity levels the thermal conditions can be less stringent when compared to the classrooms and offices (occupied space). This serves as a buffer zone in winter allowing the air entering the building to warm via trapped solar energy before entering the occupied zones.

Thus this zone will have a lower temperature than the occupied space but higher than the outside temperature. The workspace on top of the classrooms benefits from the warmer air rising in the building and with the highest level of activity and the added heat from the model making equipment the space has a higher temperature than the buffer zone but still lower temperatures than the classrooms.

4.3 Minimising heating demand in winter through thermal mass

The suns rays passes through the 500 m^2 of glazing on the north façade (the largest portion of glazing in the building) and is stored in the interior thermal mass (325 m^3 of heavy and air concrete). It is release evenly, reducing the required heating load.

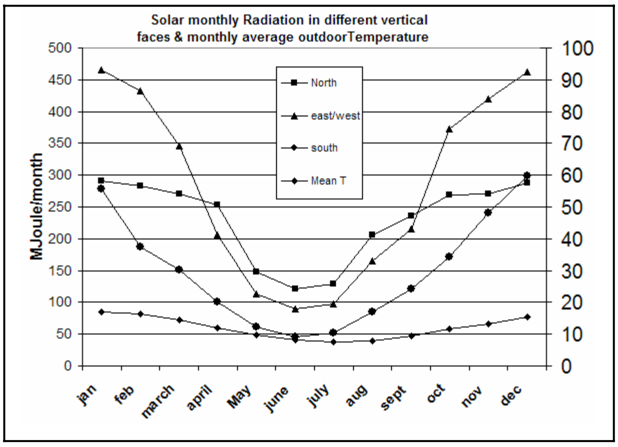

Figure 4: Solar monthly radiation in different vertical faces and monthly average outdoor temperature

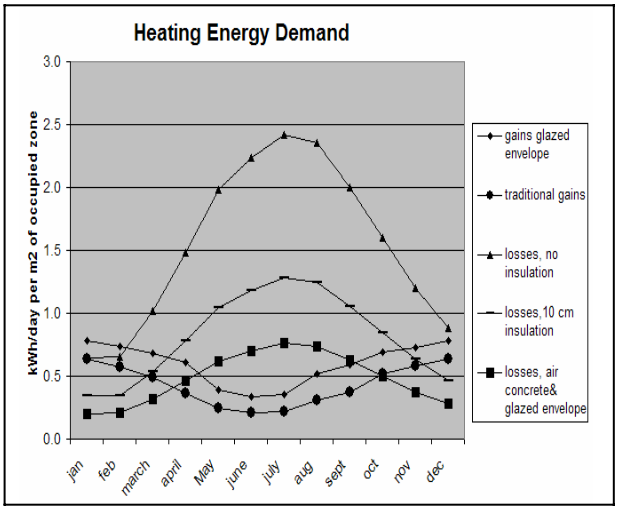

Figure 5: Heat energy demand

The buffer zone of the building is going to reach an intermediate temperature between the outdoor temperature (-1°C, design outdoor temperature DOT) and the design indoor temperature, 20°C, of the occupied zone. This indoor temperature is maintained with the assistance of a traditional central hydraulic heating system. Figure 5 shows how the use of an external envelope and internal walls of air block (estimated heating requirement of 38kWh/m^2 per year) is expected to reduce the heating load by up to 76% when compared to a common construction technique using 10 cm of insulation (estimated heating requirement of 158kWh/m^2 per year).

4.4 Passive ventilation strategy

The building uses the stack effect assisted by the wind to ventilate the envelope and cross ventilation for the classrooms and offices using air from within the well-ventilated envelope. The natural ventilation of the occupied zone is calculated to get a CO2 level lower than 900 ppm (10 l/s of air fresh per person). In the summer on both the north and south facades the bottom 3m of façade is raised allowing a large volume of air to enter the building for both cooling and ventilation. This rises due to the stack effect [1] and exits the building via ridge ventilators situated in the roof. In winter these openings are closed, and smaller traditional window openings are available to allow sufficient air intake for ventilation purposes only and to reduce heat losses.

4.5 Getting good thermal comfort in summer

The following simple building components where used to provide comfortable summer conditions without the need of mechanical cooling

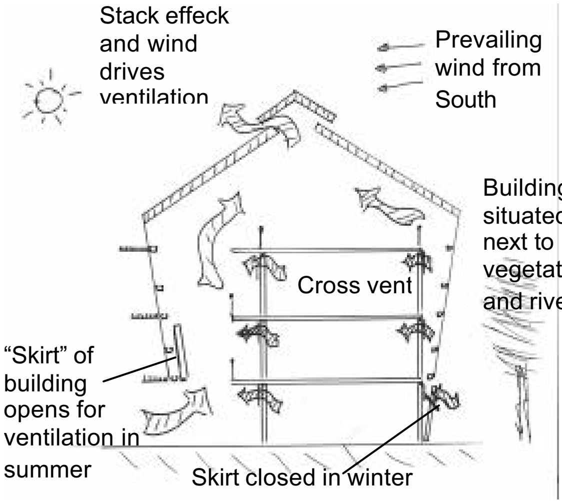

Figure 6: Ventilation strategies in the building

Overhang design

With North orientation is possible to avoid 100% of the direct solar radiation during summer with a simple design of an overhang. The solar movement graph [4] for the latitude of Valdivia (40 º South, app) was used to get the maximum altitude angle at noon in November (66 º). This parameter was determined the length of the overhang minimizing the solar energy in summer [3], [5] and maximizing it in winter. The result is 100% shadow in summer and 15% in winter.

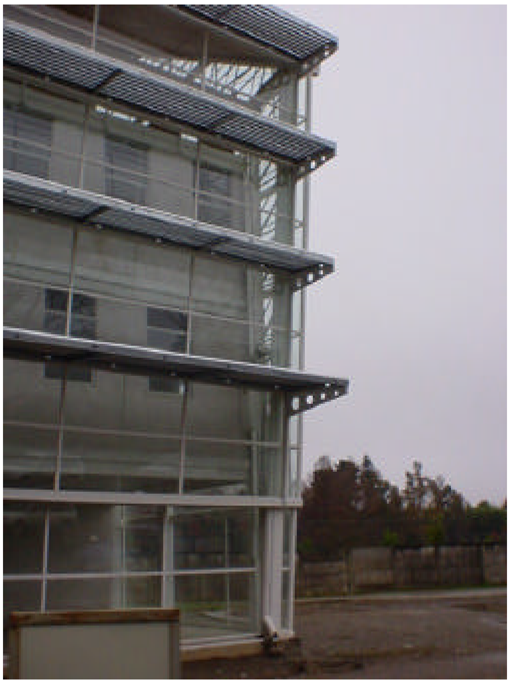

Figure 7: Overhang on the north facade

Nighttime cooling

The chimney effect in this building, as explained earlier, is also use in the summer at night to cool the structure of the building releasing the energy taken up during the day. 0,2-0,3 m/s of air movement is induced at night giving 3 to 4 ACH.

Modeling the thermal building behavior

To model the thermal building behavior in summer is more of a challenge than winter. It is necessary to model at least hour by hour, and the variables in associated are more complex, however a simple and fast thermal model, which needs hour-by-hour data, was created on Excel.

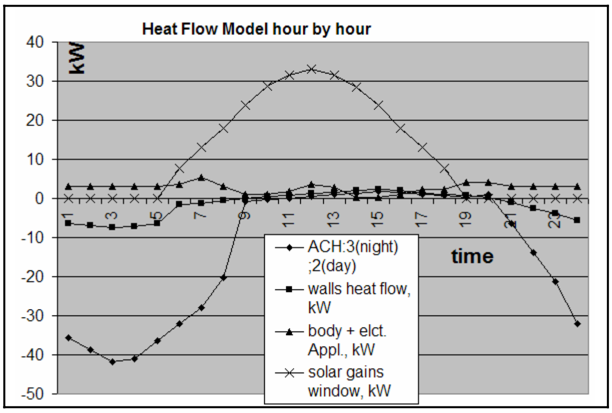

Figure 8: Heat flow model hour by hour

The variables are: solar radiation gains through windows, transmission gains, heat from human bodies, electrical appliances, ventilation gains during the day, ventilation losses during the night and extra transmission gains due to exterior solar absorptivity of building materials.

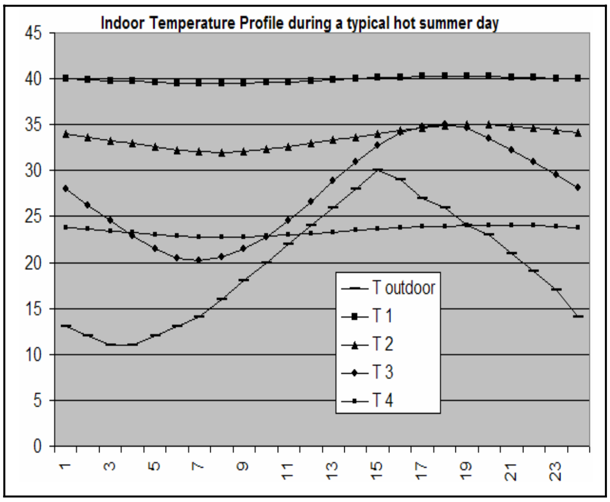

Figure 9: Indoor temperature profile during a typical hot summer day: T1 – Heavy construction without night cooling, envelope closed during the day, north orientation and overhang, T2 - Heavy construction, night cooling, west facing and overhang, T3 – Light construction, north facing without overhang. T4 – as constructed with heavy construction, night cooling, north facing, natural ventilation during the day

From Figure 8 it can be seen that the heat gain from solar irradiation during the day is of a similar magnitude to the losses through nighttime ventilation of 3 air changes per hour. Figure 9 shows how the use of the heavy structure uses the night cooling and natural ventilation during the day and the north facing main façade protected from solar gains through the external shading overcomes the gains during the day and keeps the indoor temperature at a comfortable and even level below 25°C. It is through the incorporation of all the passive techniques that this is achieved and with T1, T2, and T3 that incorporate only certain aspects, internal comfort cannot be achieved without assistance from a mechanical system.

5 COMPARISON OF CALCULATIONS WITH MEASURED RESULTS

5.1 Summer

From the time of occupation of the building in March 2003, there has not been an indoor temperature measured over 25°C even with outdoor temperatures of 32°C. There have been no complaints of in adequate ventilation and all in all there has been a very satisfactory indoor climate during the summer months.

5.2 Winter

As the building was newly completed and had not experienced a winter at the time of the writing of this paper, it is not possible to compare measured results with those calculate. It must be said though that it is expected that the building will **not** meet the designed performance. On a closer inspection of the finished façade it was found that the quality of the construction was extremely poor, with a 50mm gap around the whole perimeter of the building at the interface of the raisable 3m high façade and bad sealing between the actual glazing and frame. This results in inadequate air tightness and serious infiltration problems. It is expected that the heating system provided in the classrooms will have to be utilised for much longer periods that originally estimated and the energy consumption should be much higher.

At the time of writing the design team was looking at this challenge with the intention of doing some measurements and seeing what retrofit technique would be suitable.

6 CONCLUSION

This building showed significant reductions in cost at US$232/m^2 when compared to the previous building built on this campus at US$535/m^2. The passive design techniques utilised made a large contribution to this saving with the avoidance of installing costly mechanical cooling and ventilation equipment. Although it is unfortunate that the building will not meet the winter design conditions it is hoped that a solution for thiscan be found.

The software developed provided valuable insight into the affects of incorporating different passive systems into the building and when it is possible to carry out extensive measurements on the building, the accuracy of this will be confirmed. The designer of the excel spreadsheet is quite confident that there will be a close correlation between the software and reality.

It will also provide a valuable tool to the students. The advantage of this software that as it is in it's "raw" form the basics are not hidden by colourful interfaces, giving the students an understanding of what the software is actually calculating, it's limitations and the source of the inputs. And while it uses the same principals as commercially available software, it does take some time to get used to. However, the programmer will be looking into ways of making it user-friendlier without masking the basics with the intention of including it in an educational package for the students and architects interested in these techniques.

The most important conclusion drawn from this case study, shown in both the results of the excel model and the actually building is that although correct orientation, high thermal mass, shading, natural ventilation and night time cooling might weigh differently in their contribution to achieving a passively served building, this can only truly be achieved in the utilisation of all these techniques.

This building provides a resourceful and creative learning environment for the students and the principles used should be incorporated in further projects related to the department and university.

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