Wall Building

Wall Building Technical Brief

Building Advisory Service and Information Network

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Recommendations and Methods for Thermal Improvement of Dwellings in Central Chile

Introduction

Thermal comfort and energy saving in the building sector are still relatively new issues in Chile and Latin America and are rarely taken into account in building design: even a factor as important and cost-free as the orientation of a house with regard to the sun is ignored. 64% of the energy used in Chile in the commercial, public and housing sectors is lost[1]. As shown in various studies[2], thermal comfort is generally low, both in winter and summer, and heating loss in winter is immense. Thermal quality also diminishes proportionally to socio-economic levels, so that low-income families face the double problem of high heating costs and poor thermal comfort, which in addition causes health problems. For these reasons, the thermal and energy quality of houses constitutes a significant element in the area's future sustainable development process in terms of housing.

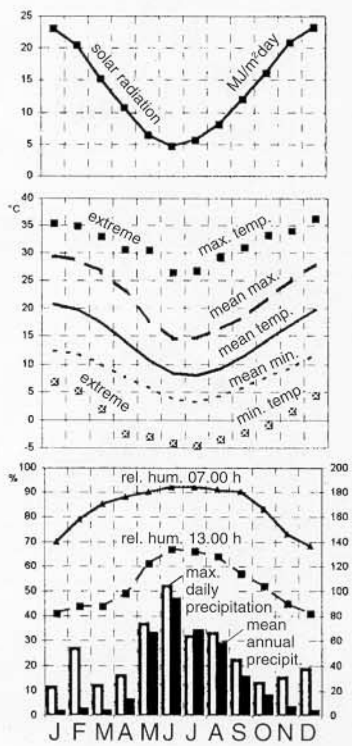

Figure 1 Climatic chart of Santiago

This document intends to contribute to this task by:

- explaining elementary processes of interaction between climate and housing;
- proposing simple architectural design recommendations for Central Chile;
- presenting analysis and design methods that can be applied to other areas.

Due to Chile's great climatic diversity, the Central Region was chosen for this study, more specifically the inland area with Santiago and its Metropolitan Area, which accounts for 40 % of the Chilean population.

Design methods

Traditional design methods and the climate of the Central Region

Climatic charts give a quick monthly overview of average temperatures, average and absolute extremes, maximum and minimum relative humidity, global solar radiation and precipitation. Figure 1 shows the significant daily and annual thermal variations in the Santiago area, showing the problem of very hot summers and cold winters. Solar radiation is high, causing thermal comfort problems in summer, while in winter the sun can make a valuable contribution to heating. Relative humidity poses no major problems, except in poorly ventilated dwellings in winter.

One of the most interesting traditional methods is the use of the Mahoney diagrams (ref. Koenigsberger, 1973), which characterize thermal stress for each month, primarily based on temperature and humidity extremes to arrive at general design recommendations. The primary indicators are thermal mass in summer (Figure 2, A1) and protection against cold in winter (A2).

Other traditional design methods include:

- bioclimatic diagrams of Givoni, which graphically depict monthly climatic extremes, along with the thermal comfort range for the parameters of temperature and humidity together with design, heating and cooling recommendations;
- solar and shade diagrammes, which trace the position of the sun throughout the year to facilitate the location and sizing of solar collectors and shading elements.

The main advantage of these methods is their quick, simple application, but they lack information related to climate and the architectural project, leading to poorly detailed and inaccurate design recommendations. Consequently, they are most useful in simple cases and in initial analyses.

Diagnosis: (°C)	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max.	29.4	28.7	26.7	23	17.9	14.4	14.5	16.2	18.4	22	25.1	28
Day comfort: upper	28	28	28	28	25	25	25	25	25	28	28	28
Day comfort: lower	21	21	21	21	20	20	20	20	20	21	21	21
Monthly mean min.	12.4	11.8	10.1	7.6	5.7	3.7	3.2	4.3	5.9	7.8	9.5	11.8
Night comfort: upper	21	21	21	21	20	20	20	20	20	21	21	21
Night comfort: lower	14	14	14	14	14	14	14	14	14	14	14	14
Thermal stress: day	H	H	O	O	C	C	C	C	C	O	O	O
Thermal stress: night	C	C	C	C	C	C	C	C	C	C	C	C
Indicators:												
Arid: A1	1	1	1	1						1	1	1
Arid: A2					1	1	1	1	1			

(Note: H = hot; C = cold; O = comfort)

Figure 2 Mahoney diagram for Santiago (only Table 2)

Modern design methods

Modern design methods consider a much more detailed description of climatic conditions, architectural design, and building usage. This is now possible with computer programmes, which deliver detailed and relatively accurate results on the thermal and energy behaviour in a building. The drawback is its complexity and the great amount of information required, which demands more training and implementation time for each project. Nevertheless, its use can be justified for:

- innovative projects, eg passive design,
- large-scale projects,
- research (case studies; parametric studies; design guidelines and recommendations; development of simple design and sizing tools; bioclimatic design, passive use of solar energy, passive heating and cooling).

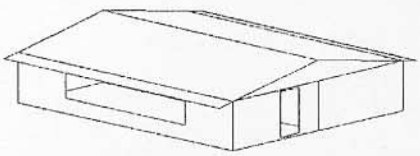

Figure 3 House at 15.00 h, 15 July

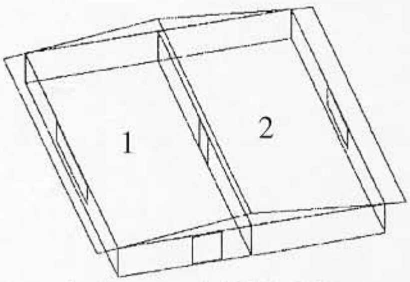

Figure 4 House at 14.00 h, 15 January

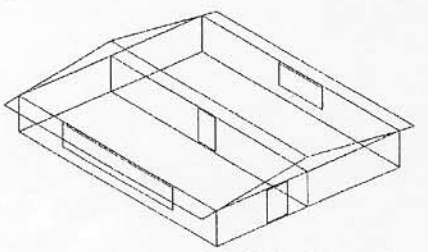

Figure 5 House at 14.00 h, 15 March

Parametric study

In order to quantify the design recommendations for the Central Region of Chile given in this paper, a small parametric study was conducted for low-income or medium-income houses under the climatic conditions prevailing in Santiago. A detailed simulation of the thermal behaviour of a house was performed with the DEROB-LTH programme, developed by the University of Lund (Sweden), as part of the author's postgraduate course in "Architecture, Energy & Environment – Tools for Climatic Design".

The simulation involved the western half of a semi-detached house, the most common form of dwelling in the Santiago suburbs. Based on this simple model passive house (without mechanical heating or cooling), different design parameters were applied to determine their effect on thermal comfort. The temperature differences in the various simulated scenarios were more important than absolute values, since various factors such as ambient temperature and user behaviour can change from one day or project to the next.

The design of the model house is shown in Figures 3 to 5 from the sun's position, showing the shading of the north façade in summer by the overhanging roof, with a shadow angle of 70°. The long axis of the house (9 x 7.2 m) has an east-west orientation. The living room window (1) correctly faces north, the bedroom window (2) faces south, and the loft (3) is non-habitable space. The main building elements are:

- floor: concrete
- windows: single glazing (common in Chile)
- roof: corrugated galvanized iron sheets
- ceiling: 12 mm plasterboard (in some cases with polystyrene insulation)
- doors: hollow wooden elements
- loft wall: 12 mm pine
- building partition wall: without heat transmission to the other half of the semi-detached house
- heavy construction walls (standard):
  - outer walls: cement rendering, 100 mm concrete, plaster
  - inner walls: 100 mm brick with plaster on both sides
- lightweight construction walls:
  - outer walls: 12 mm pine, 50 mm cavity, 10 mm wood fibre board
  - inner walls: 10 mm fibre board, 50 mm cavity, 10 mm wood fibre board

The material specifications were taken from the Chilean Standard NCh853.Of91; those not appearing in this standard are from Gut and Ackerknecht, 1993.

The air infiltration was estimated at one replacement of air per hour (1/h) for the dwelling and 5/h for the loft. Internal heat gains in the habitable spaces were estimated for 4 people and their electric power consumption adding up to about 12 kWh/day. The simulations were made for the representative days of 15 January (summer), 15 April (autumn) and 15 July (winter). Climatic data are the same as those presented previously for global solar radiation and monthly maximum and minimum average temperatures which an auxiliary programme converted into hourly values.

The thermal behaviour of a standard case for the seasons of the year can be seen in Figures 6 to 8. In summer, due to outer temperatures above 30°C, overheating typically occurs in the afternoon, especially in room 1 facing north, but also in room 2 facing south, although both rooms are protected from direct solar radiation for most of the day by the roof. The loft reaches temperatures of up to 45°C in causing overheating of the other spaces as a result of the non-insulated ceiling and non-shaded diffuse solar radiation. Figure 7 shows temperatures near or within the comfort range in autumn in those spaces that are occupied during the daytime, so this season is less important. In winter the indoor temperatures are very low but thanks to solar and internal gains, especially room 1 generally remains above the outdoor temperature.

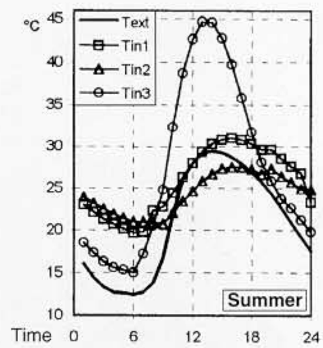

Figure 6 Standard case in summer

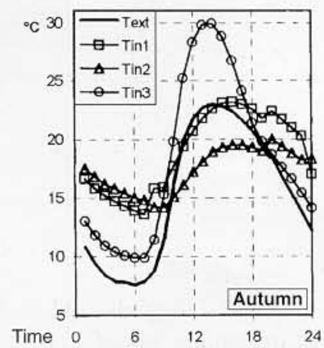

Figure 7 Standard case in autumn

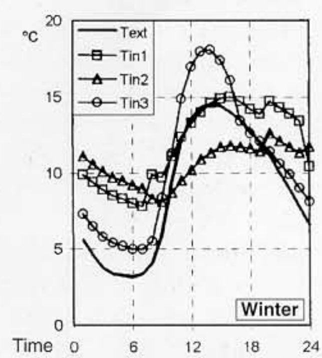

Figure 8 Standard case in winter

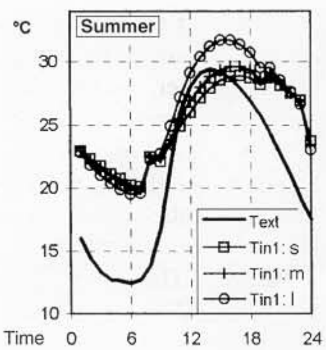

Figure 9
North-facing window, small, medium and large, in summer

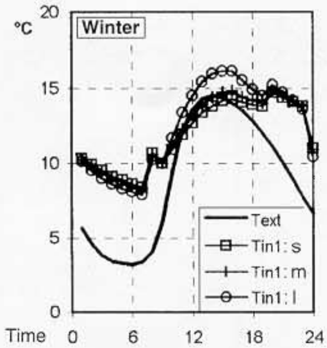

Figure 10
North-facing window, small, medium and large, in winter

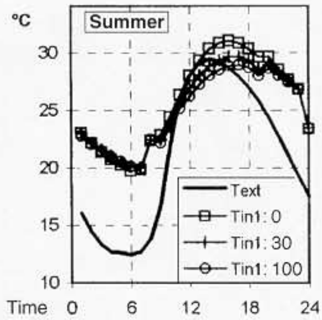

Figure 11
Ceiling (0, 30 mm, 100 mm) insulation in summer

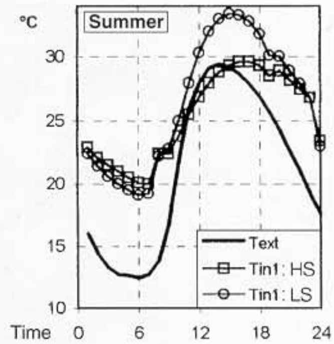

Figure 12
Heavy (HS) and lightweight (LS) structures in summer

Design recommendations

These design recommendations are based on the parametric study, the Mahoney chart for Santiago, the solar diagramme analysis and the literature referred to at the end.

Building form and orientation

Aim: To prevent solar gain in summer, but permit it in winter, to minimize heat loss.
Analysis: In summer, the north façade and its windows receive minimum solar radiation, as the sun rises in the southeast, passes near its zenith at midday (min. 10° distance) and sets to the southwest; in winter the north side receives the most radiation, the east and west receive less and the south façade the least, since the sun rises to the northeast, passes overhead due north (min. 33°) and sets to the northwest.
Recommendation: East-west orientation of the dwelling's long axis, with maximum façade facing north and minimum façade facing east and west; windows preferably facing north, few to east and west and minimum to the south; compact design.

Window size, solar protection

Aim: To prevent solar gain in summer, but permit it in winter, to minimize heat loss.
Analysis: In summer, insufficient control of solar radiation greatly overheats the inhabited spaces. Figure 9 shows the heat gain in summer in relation to window size. Despite shades, windows admit diffuse radiation and external heat by conduction. In winter (Figure 10), the day temperatures increase in proportion to the size of the north window, but with larger windows the temperature drops rapidly after sunset, especially with single-glazed windows, which lose more heat than the walls.
Recommendation: Use medium-sized windows on the north face with movable awnings for solar protection, small windows to the east and west with movable protection or a combination of horizontal and vertical shading, and minimum window area on the south side. Windows facing north with good movable solar protection and double glazing can be larger and more useful for passive heating in winter.

Thermal insulation

Aim: To prevent heat gain in summer, heat loss in winter through walls, ceiling, roof.
Analysis: A ceiling or roof without insulation loses more heat than a wall, and the heat in the loft easily spreads to all the inhabited spaces through an uninsulated ceiling. Furthermore, Figures 6 to 8 show how the loft temperature (Tin3) always remains above the outdoor temperatures at night, due to the heat it receives from the remainder of the house through uninsulated ceilings, representing a loss of energy in winter. Figure 11 shows the decrease of indoor temperatures in summer with the use of ceiling insulation. The energy-saving effect in winter is better understood by comparing the heat transmission (U) values (from Chilean standard NCh853 for expanded polystyrene), which are directly proportional to heat loss:

- 12 mm plasterboard ceiling without insulation, U = 4.06 W/m^{2}K;
- 12 mm plasterboard ceiling with 30 mm insulation, U = 0.97 W/m^{2}K;
- 12 mm plasterboard ceiling with 100 mm insulation, U = 0.35 W/m^{2}K.

Recommendation: Always install ceilings under roofs with at least 80 mm insulation in the Central Region (according to the first *mandatory* Chilean regulation for insulating ceilings/roofs, which is currently being drafted). According to the Ministry of Housing, the cost of this insulation is offset in the first winter by lower heating expenses. As a second priority, provide good insulation of walls through proper selection of materials and construction methods. The third priority is to use double-glazed windows.

Thermal inertia and construction mass

Aim: To reduce daily thermal fluctuation and daytime overheating in summer.
Analysis: The heavy structural elements of a building (ie concrete, brick or stone walls and flooring) absorb heat when the adjoining air temperature is higher than that of the material, and release heat when the temperature is lower, thus reducing the thermal fluctuation of the interior space (see Figure 12). This effect, called thermal inertia, is especially important in summer, when structures with high thermal inertia reduce (over)heating during the day and release heat at night, when outdoor temperatures are lower. In the winter, thermal inertia also helps to maintain a constant temperature indoors, but the effect is less essential than in summer. The effect of thermal inertia grows with increased daily temperature fluctuation, and is hence more important in the inland Central Region (eg Santiago) than in coastal areas, where the ocean's influence minimizes thermal fluctuation.
Recommendation: Use materials with high thermal inertia and apply thermal insulation on the outer facing of heavy elements.

Ventilation

Aim: To take advantage of low night temperatures in summer to reduce daytime heat and prevent excessive heat loss due to infiltration of cold air in winter.
Analysis: Due to the dry climate, night temperatures in summer are relatively low and can be used for cross-ventilation to cool the house, by opening windows on opposite sides of the dwelling, as well as the interior doors. The positive effect compared with the standard situation in summer is clearly visible in Figures 13 to 15 for different spaces and window sizes in a house with heavy walls and 30 mm ceiling insulation, and with the air being fully replaced 20 times per hour from 19.00 h to 08.00 h. At night, indoor temperatures drop and almost match the outdoor temperature, without disrupting the night comfort range. Temperatures remain below the maximum outdoor values throughout the day, thanks to the thermal inertia, if the window is not too large, as in Figure 14. In winter, venti-

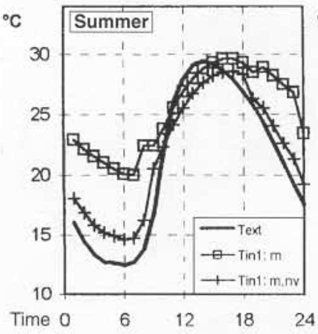

Figure 13
Night ventilation (nv) in room 1 with medium (m) window

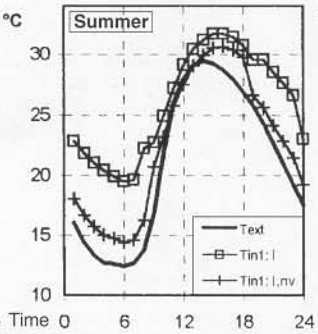

Figure 14
Night ventilation (nv) in room 1 with large (l) window

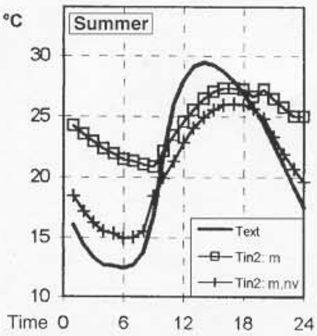

Figure 15
Night ventilation (nv) in room 2 with medium (m) window

lation exceeding the minimum necessary level for hygienic reasons (0.5 replacements per hour) leads to an undesirable loss of heat which reduces thermal comfort and increases energy consumption.

Recommendation: Facilitate cross-ventilation in summer when the outdoor temperature is lower than indoors, and reduce daytime ventilation to a minimum; keep doors and windows tightly shut in winter to limit ventilation to necessary levels for oxygen consumption and removal of humidity caused by persons and stoves.

Conclusions

The analyses and recommendations show that the thermal comfort and energy efficiency of a house can be significantly improved with simple, economical measures. These can be useful in the design, construction or renovation stages as well as in selecting a dwelling for future users.

Passive heating and cooling offer even more possibilities than those mentioned here, but the design process is more complex. Closer examination of design strategies and tools, their extension to other climatic areas, and the widespread application still needed, require greater research, training and dissemination efforts in future. Hence, the methods assessed in this paper, especially the thermal simulation, proved their efficiency and great potential for future thermal improvements in dwellings as an essential element for a process of sustainable development in Chile and Latin America.

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Building materials and construction technologies that are appropriate for developing countries, particularly in the low-income sector, are being developed, applied and documented in many parts of the world. This is an important prerequisite for providing safe, decent and affordable buildings for an ever-growing population.

But such new developments can do little to improve the building situation, as long as the information does not reach potential builders. The types and sources of information on standard and innovative building technologies are numerous and very diverse, making access to them difficult.

Thus, in order to remedy this drawback, Shelter Forum, GATE, ITDG, SKAT and CRATerre are co-operating in the Building Advisory Service and Information Network, which covers five principal subject areas and co-ordinates the documentation, evaluation and dissemination of information.

All five groups have a co-ordinated database from which information is available on Documents, Technologies, Equipment, Institutions, Consultants as well as on Projects and Programmes. In addition, printed material or individual advice on certain special subjects is provided on request. Research projects, training programmes and other field work can be implemented in co-operation with local organizations, if a distinct need can be identified and the circumstances permit.

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