Crucial Building Parameters as a Novel Approach for the Design of Passive Solar Houses in a Mediterranean Climate

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ABSTRACT: The efficiency of the design process for passive houses can be improved with a clear concept for a small set of crucial building parameters. This is especially important in developing countries where passive design is a promising but rarely applied strategy for improving comfort conditions.

This work is based on a large number of thermal simulations with a test reference year for the mediterranean climate of central Chile. Basic thermal parameters for a passive house with free-floating temperatures were calculated according to building codes. The identification of the most appropriate crucial thermal parameters permitted to establish empirical correlations between the stationary method of the building codes and dynamic simulations. These crucial building parameters represent size independent functions of the primary, but size dependent building parameters.

Additionally the influence of design alternatives on thermal comfort was analysed in detail according to the crucial parameters. This approach permitted a better understanding of the dynamic interaction of building design, climate and user behaviour and their importance for thermal comfort, which is resumed in design recommendations.

This way the results contribute to the design of sustainable buildings, which offer good thermal comfort at accessible cost using renewable energy.

Keywords: passive design, design assistance, technology transfer, comfort, sustainable building

1. INTRODUCTION

Passive design is a promising strategy for sustainable housing design both in developing and rich countries: it permits the improvement of thermal comfort at low ecological and economical cost.

This investigation was based on the mediterranean climate of central Chile. In this region thermostatically regulated central heating systems or air conditioning systems can rarely be found in the residential sector, so that standard calculation procedures, which assume constant interior temperatures and are focussed on energy consumption, are not appropriate for the evaluation of thermal or energetic quality. As this is a typical situation, passive here means the absence of mechanical heating or cooling systems without promising always perfect thermal comfort as it would be expected in rich countries.

Thermal simulations offer an adequate evaluation method for thermal comfort, but they are too complicate for the first stages of the design process and their use is too expensive for normal application. Therefore they were used as a scientific method to create simple and efficient design tools extending the application field of building codes for heated buildings to passive houses and the hot period. The design

analysis is presented with a novel approach, that permits a better understanding and optimisation of the complex design balance between the demands for the hot and cold period. It is based on the definition of a small set of crucial and easily understandable building parameters, that are size independent, so that it is possible to predict thermal behaviour and formulate general design recommendations.

2. METHODOLOGY

2.1 Climate

The simulations were run with a test reference year for Santiago de Chile, that had to be elaborated
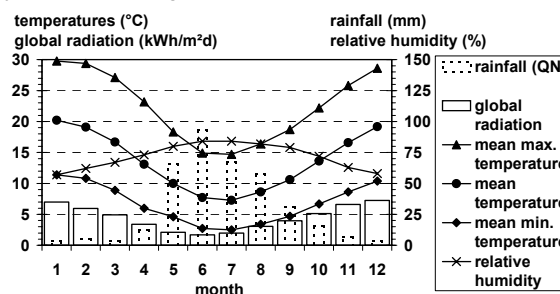

Fig. 1: Climate graph for Santiago de Chile (33.4°S)

with an own methodology [8]. The hourly climate data for Santiago were obtained from measurements (see acknowledgements), the mean reference values are from the National Meteorological Office [3] and [2].

The climate of the central region of Chile can be characterised as Mediterranean according to [1] and [4]. It's challenging because it combines thermal problems in summer (high maximum temperature and solar radiation) and winter (low temperatures) with a promising potential for passive climatization, especially due to its low night temperatures in summer and high levels of solar radiation in winter.
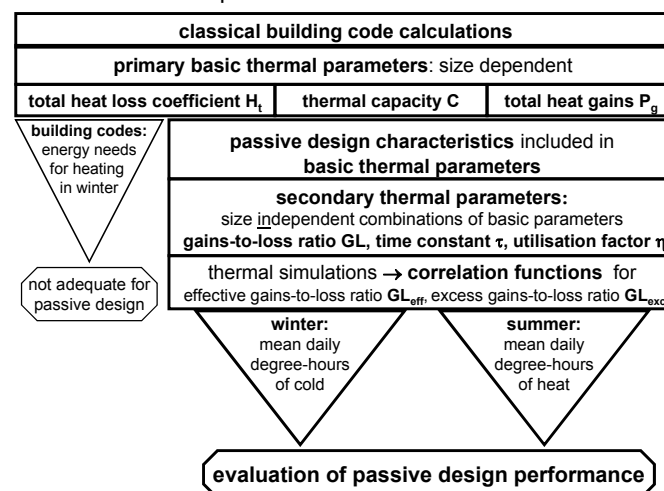
2.2 Thermal Simulations and Thermal Comfort

Thermal simulations with the program DEROB-LTH are the main reference and method here. They permit the hourly determination of interior operative temperatures, defined as the mean value of indoor air temperature and the indoor surface temperatures weighted by their respective areas. Operative temperature θ_o is a much better comfort indicator than air temperature, especially in badly insulated constructions with sometimes extreme surface temperatures. From these simulation results, mean daily degree-hours of heat Gh_{26o} and mean daily degree-hours of cold Gh_{19o} could be calculated in (Kh/d) for each month with N hours according to the following definition:

$$Gh_{base} = \left\{ \sum_{i=1}^{N} (\theta_o - \theta_{base}) \times 1h \right\} \times 24 / N \quad (Kh/d)$$

The index of Gh_{26o} and Gh_{19o} indicates the base temperature and the use of operative temperatures.

classical building code calculations		
primary basic thermal parameters: size dependent		
total heat loss coefficient H_t	thermal capacity C	total heat gains P_g

building codes: energy needs for heating in winter

not adequate for passive design

passive design characteristics included in **basic thermal parameters**

secondary thermal parameters: size _independent_ combinations of basic parameters **gains-to-loss ratio GL, time constant τ, utilisation factor η**

thermal simulations → **correlation functions** for effective gains-to-loss ratio GL_{eff}, excess gains-to-loss ratio GL_{exc}

winter: mean daily degree-hours of cold

summer: mean daily degree-hours of heat

evaluation of passive design performance

Fig. 2: Basic concept for new design tools and crucial building parameters

2.3 Development of Crucial Building Parameters

The development of the crucial building parameters was an essential part of that of simple design tools and can then be resumed as follows:

1. Adaptation of classic building code calculations: simple building characteristics were calculated in a spreadsheet according to (German versions of) ISO or European building codes ([7] and related ones), which are similar to, but more complete than local codes ([5], [6]); basic characteristics of local building materials were taken from Chilean code [5] when available; necessary characteristic values and correction factors in building codes were determined with special thermal simulations; special simple models for passive design elements that are not considered in building codes, e.g. night ventilation, were established; monthly climate data were calculated from the TRY. This way, the calculation methods originally created for the description of thermal behaviour in winter, were adapted for the new climate zone and extended to passive houses in the cold and hot period. These first steps permitted the calculation of the primary basic thermal parameters, that depend strongly on the size of a building (see Fig. 2, 3.1).

2. Extensive thermal simulations (>500) for a wide range of design parameters in a passive room with free floating temperatures were realised: the simulation parameters, e.g. heat transfer coefficients, were adapted as far as possible to the building codes, but no simplifications were made to the simulation model itself. The building parameters in the simulations were selected to cover the spectrum of common Chilean constructions and possible improved designs with local building materials.

3. Thermal performance: mean daily degree-hours of heat Gh_{26o} for the hottest summer month (January) and of cold Gh_{19o} for the coldest winter month (July) were calculated from simulation results with an especially written software.

4. Regression analysis was realised with different models to obtain a mathematical correlation between simple building characteristics and comfort conditions determined by simulation; some input parameters were optimised to obtain maximum correlation. The definition and selection of the most appropriate thermal parameters in this step was essential here - it permitted to establish empirical correlations between the stationary method of the building codes and dynamic simulations. These crucial building parameters represent size independent functions of the primary, but size dependent thermal parameters.

5. The whole calculation process and the regression functions were implemented in a spreadsheet for easy application, documentation and distribution.

2.4 Design Recommendations

The design recommendations were based on traditional methods like the analysis of solar graphs ([9], [10], [11]), extensive parametric studies with thermal simulations of complete houses including special elements for passive climatization (e.g. winter gardens, Trombe walls; see [9], [10], [11]) and special analysis of the thermal simulations for the tools.

3. Crucial Building Parameters

3.1 Determination of Crucial Building Parameters

The basic thermal characteristics of a house can be described by three primary thermal parameters, including the characteristics of passive design here:
♦ total heat loss coefficient H_t in (W/K)
♦ effective thermal capacity C in (Wh/K)
♦ total heat gains (solar, opaque, internal) P_g in (W)

The limited space only permits a brief resume of thermal calculations. More details can be found in [10][1] and the respective building codes. The disadvantage of these parameters is that they depend on the size of a building or room, so that they are not apt for the comparison of analogous designs with the same use and thermal characteristics (elements, materials, orientation etc.), but of different size. Therefore they had to be transformed to create size independent thermal parameters.
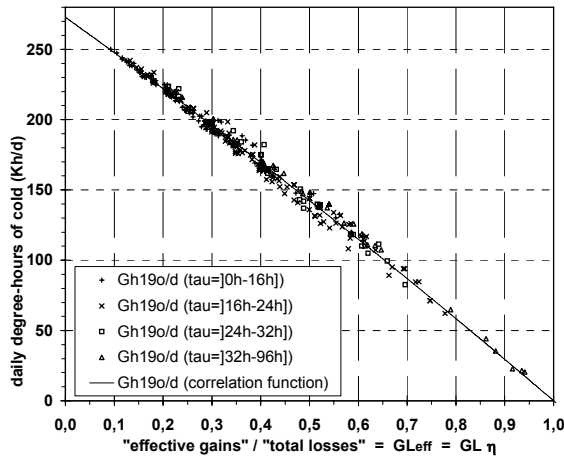
Fig. 3: Correlation for daily degree-hours of cold for winter (July), indicating time constant τ (h)

In **winter**, the relation of effective gains to total losses GL_{eff} is successful (θ_e = external temperature):

$$GL_{eff} = GL\ \eta = P_g\ \eta\ /\ (\ H_t\ (\theta_r - \theta_e)\ );\quad \theta_r = 19°C$$

The utilisation factor η is calculated according to [7] as a function of the gains-to-loss ratio GL and the time constant τ of the room or house:

$$GL = P_g\ /\ (\ H_t\ (\theta_r - \theta_e)\ )$$
$$\tau = C\ /\ H_t$$
$$\eta = (1 - GL^a)\ /\ (1 - GL^{(a+1)})\ \text{ for } GL \neq 1$$
$$\eta = a\ /\ (a+1)\ \text{ for } GL = 1$$
$$\text{with }\ a = a_0 + \tau\ /\ \tau_0$$

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[1] A similar, but further extended version with correlations for the complete hot and cold season will soon be published as part of the PhD-thesis of the author.

The parameters a_0 and τ_0 were determined by optimisation of regression. Quadratic regression between daily degree-hours of cold Gh_{19o} and GL_{eff} is very good and shown in Fig. 3 ($a_0 = 0.4$, $\tau_0 = 8h$; $r^2 = 0.9922$).

Each data point in Fig. 3 and Fig. 4 represents a design example, the indication of the time constant (or other design parameters) does not affect the correlation, but shows that there is no systematic deviation from the correlation function related to the indicated parameter and it is correctly represented in the model. Moreover, a correlation of certain parameter values with comfort conditions is helpful for design recommendations.

In **summer**, a correlation of daily degree-hours of heat Gh_{26o} with the excess gains $P_g (1-\eta)$, which are not useful for the compensation of heat losses at the reference indoor temperature θ_r, was promising, using the relation of excess gains to total losses GL_{exc}:

$$GL_{exc} = P_g\ (1 - \eta)\ /\ (\ H_t\ (\theta_r - \theta_e)\ );\quad \theta_r = 26°C\ \text{here}$$

Cubic regression of Gh_{26o} with GL_{exc} offers the best correlation as shown in Fig. 4 ($a_0 = 0$, $\tau_0 = 6h$; $r^2 = 0.9814$).
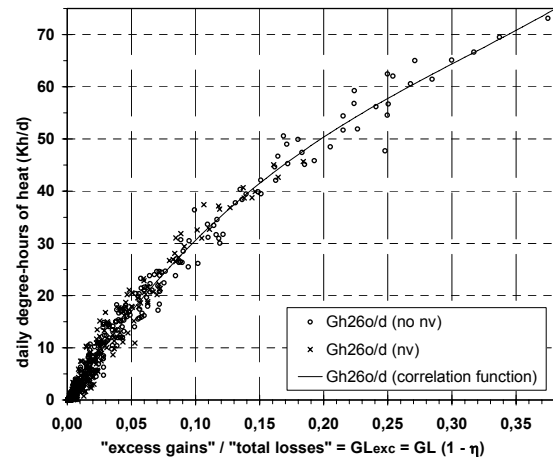
Fig. 4: Correlation for daily degree-hours of heat for summer (January), indicating night ventilation

The correlations presented here permit the easy estimation of comfort conditions in summer and winter, based on adapted building code calculations whose basic concepts should be familiar to designers. The smaller part of thermal behaviour not covered by the building code calculations and the independent parameters GL_{eff} and GL_{exc} is mainly due to approximations and dynamic behaviour. These are responsible for the scatter of data points here.

But the two correlations have a second interesting significance, that goes far beyond the specific climate zone: they permit the identification of a set of three **crucial building parameters** which can be used both in the cold and hot period and are size independent:
♦ gains-to-loss ratio **GL**   (dimensionless)
  GL describes the relative size of heat gains compared to heat losses in the climate zone (at the selected comfort level θ_r).
♦ time constant τ (h)
  τ describes how fast a building reacts to varying

thermal influences and how long it is able to compensate them.

♦ utilisation factor η (dimensionless)
η describes how efficient a building is making use of passive and internal heat gains (at the selected comfort level θ_r).

As explained, the three crucial building parameters have an easily understandable significance for the thermal behaviour of buildings. They are especially useful for optimising building elements considering their effect on the crucial building parameters and for planning parametric studies that cover a desired range of thermal parameter values, e.g. reaching high / low gains-to-loss ratios in winter / summer and utilisation factors close to 1 for passive design.

On a higher level of abstraction, the dimensionless independent parameters of the correlations as well can be taken as a set of crucial building parameters:

♦ "effective-gains-to-loss ratio" **GL$_{eff}$**   (cold period)
GL$_{eff}$ describes the relative size of heat gains that are useful for thermal comfort, compared to thermal losses (at the selected comfort level)

♦ "excess-gains-to-loss ratio" **GL$_{exc}$**   (hot period)
GL$_{exc}$ describes the relative size of heat gains that are harmful to thermal comfort, compared to thermal losses (at the selected comfort level)

This set of two crucial building parameters describes and determines the largest part of thermal behaviour, summarising thermal design quality in one parameter for each season. Therefore, these two crucial building parameters are especially useful for a simple and fast evaluation of a complete design's expected thermal behaviour without or before running thermal simulations.

Both sets of crucial building parameters are useful for the designer to get a clear idea of how to optimise the thermal behaviour of his passive design as will be shown in the following with more detail.

3.2 Application for the Analysis of Thermal Behaviour

Correlation figures indicating certain parameter values can be useful to derive design recommendations: from Fig. 3 it can be seen that in winter designs with too small time constants below 16h show the worst thermal behaviour with very low values of the effective-gains-to-loss ratio GL$_{eff}$ and correspondingly high values of the daily degree-hours of cold Gh$_{19o}$; medium time constants from 16h to 32h can show a wide range of thermal behaviour (depending on their GL), but passive houses with GL$_{eff}$ over 0.8 and little problems with Gh$_{19o}$ can only be found among designs with large time constants over 32h. From Fig. 4 it can be seen that in summer the worst designs lack night ventilation, although night ventilation can have reduced efficiency (due to low thermal capacity and excessive gains) resulting in mediocre thermal behaviour; good thermal behaviour can be achieved with other strategies as well, but in lesser cases. Analogous graphs indicating other parameters can be found in [10] and were used for design recommendations.

The utilisation factor η is a complicated function, but a crucial building parameter, which depends on the gains-to-loss ratio and the (relative) time constant. Therefore, three examples of this function are shown in Fig. 5: it can be seen that both for small (e.g. 0.2) and high values (e.g. 2) of GL, the utilisation factor approaches rapidly its maximum value[2], so that medium time constants (around 24h) can be sufficient in normal houses to make good use of passive heat gains and the potential to limit overheating in summer. When GL is close to 1, η approaches its maximum much slower and continues to increase with large time constants, so that they make sense with passive houses and their improved solar heat gains in winter (excessive heat gains are unrealistic and anti-economic in this climate zone in winter).
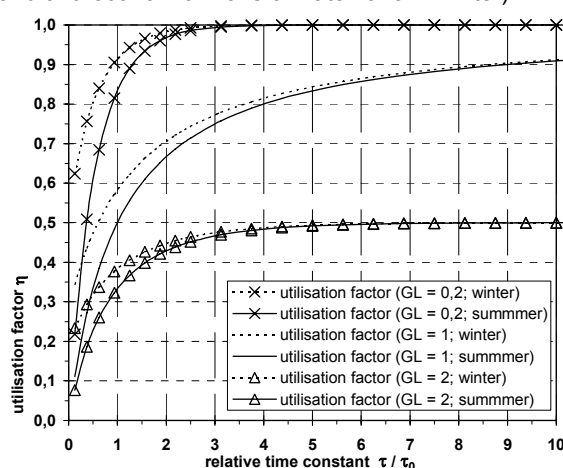

Fig. 5: Utilisation factor η, depending on gains-to-loss ratio GL, relative time constant

A more detailed analysis of the variation of thermal comfort according to crucial building parameters, the characteristics of building elements and main thermal aspects was possible by extracting information from the simulations realised for the tools: Each graph permits the analysis of thermal behaviour in the hot and / or cold period, of how it is influenced by a crucial building parameter or the construction type (wood panels, brick, rammed earth) and another parameter in different combinations.

Fig. 6 shows the variation of thermal behaviour with the time constant, that varies with insulation level and construction type (data points represent mean values for different orientations with identical τ) - illustrating the importance of the "crucial building parameter" time constant, as thermal problems decrease with increasing time constant for each insulation level. Moreover, the special importance of roof insulation in summer can be seen comparing the two series with and without it. The construction types involved are documented in Fig. 7 with exactly the same data and categories ordered according to their time constant presenting the projects explicitly, so that cases in Fig. 6 can be identified (e.g. the sequence of well insulated projects in Fig. 6 starts with "heavy floor (wood panel walls)" and ends with "passive house: heavy floor & walls (rammed earth)").
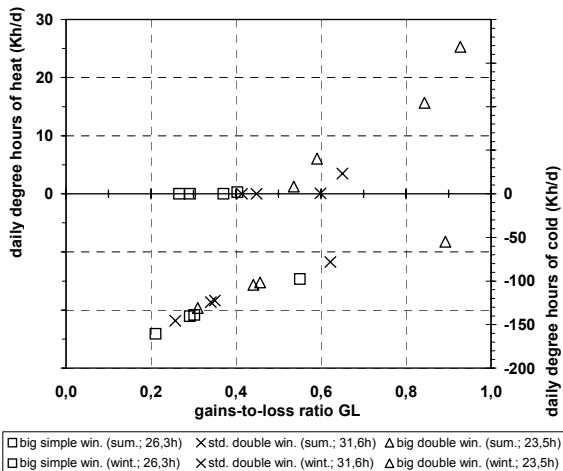
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[2]   for mathematical reasons:
$\eta_{max} = 1$ for GL ≤ 1, $\eta_{max} = 1/GL$ for GL > 1
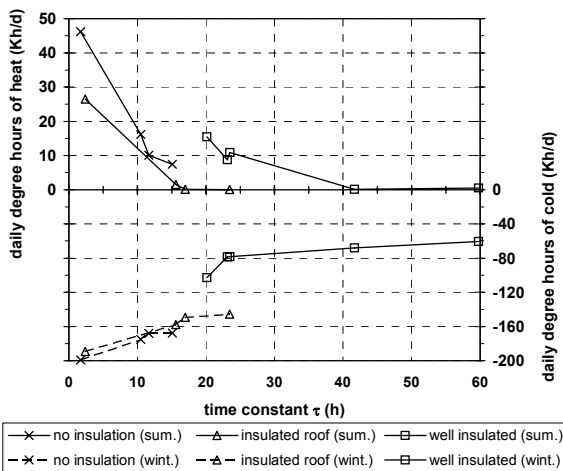
Fig. 6: Thermal behaviour in summer and winter: influence of time constant and insulation level
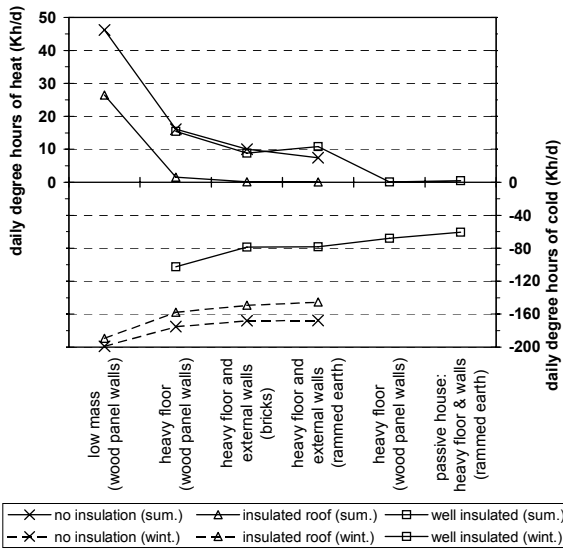

Fig. 7: Thermal behaviour in summer and winter: influence of construction and insulation level


Fig. 8: Influence of gains-to-loss ratio (time constant) - insulated walls of rammed earth (heavy floor)

The influence of the gains-to-loss ratio GL, varied by orientation for different window types, is shown in Fig. 8 for a house with externally insulated walls of rammed earth and in Fig. 9 for a wood panel house.

The gains-to-loss ratio grows according to solar incidence, with reduced losses and growing window size. Time constant is indicated and varies only slightly with window size and quality so that it has no visible effect on thermal behaviour within each figure. For each construction type, thermal behaviour deteriorates strongly with growing gains-to-loss ratio in summer and improves clearly in winter, but is better with the larger time constants of the heavier constructions in Fig. 8.
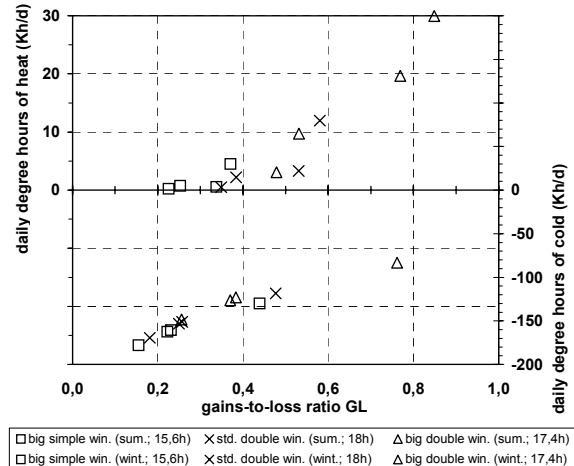
Fig. 9: Influence of gains-to-loss ratio (time constant) - wood panel house (heavy floor)
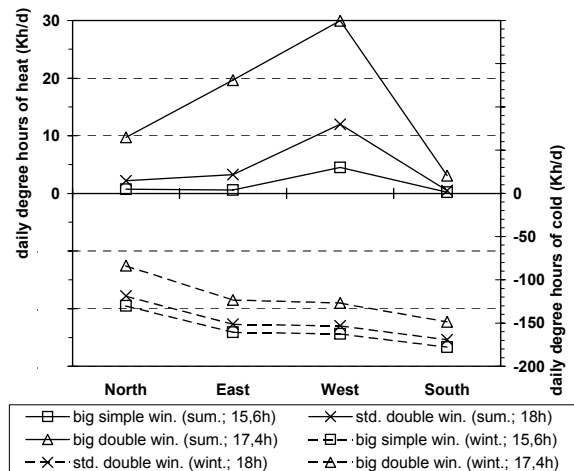
Fig. 10: Influence of orientation (gains-to-loss ratio) - wood panel house (heavy floor)

Fig. 10 shows the same data as Fig. 9, but sorted by orientation: it demonstrates clearly that north orientation offers the best results both in the hot and cold period. East and west orientation are critical in the hot period requiring special solar protection and south lacks solar gains in the cold period.

The graphs here are new, but more like Fig. 7 and Fig. 10 for different parameter combinations can be found in ([10], [11]) and were analysed for the design recommendations.

3.3 Resume of Systematic Design Recommendations

The crucial building parameters and extensive analysis permit a novel approach to the optimisation of passive design projects and the formulation of design recommendations, that can now be expressed

as recommendations for these parameters, based on an improved qualitative and quantitative understanding of thermal building dynamics:

♦ For the **whole year**, it is important to maximise the utilisation factor with a "sufficiently large" time constant, depending on the gains-to-loss ratio, in order to reduce both overheating in summer and cold in winter. Time constants over 16h are necessary and over 32h are recommendable. For the design this means large thermal capacity combined with a low heat loss coefficient.

♦ In the **cold period** the strategy is to increase the effective-gains-to-loss ratio GL_{eff}; GL_{eff} values over 0.95 (at least 0.9) are sufficient for passive houses as low temperatures occur typically in the morning when lower temperatures are acceptable.

This requires reducing losses with insulation and increasing solar gains in an equilibrated way, combined with a high utilisation factor permitting good utilisation of passive gains. High solar gains during the day are only effective if they can be accumulated for colder hours. Especially recommended elements are large window areas of high quality for increased direct solar gains on the north façade, but winter gardens and Trombe walls for indirect gains are possible as well.

♦ In the **hot period** it is crucial to minimise the excess-gains-to-loss ratio GL_{exc}; GL_{exc} values up to 0.008 (max. 0.015) are recommendable.

This requires the limitation of solar gains and an increase of heat losses. The transmission heat loss coefficient is fixed and has to be small for winter comfort and time constant, but ventilation losses can be increased selectively with increased permanent or night ventilation. The seasonal conflict of recommendations for solar heat gains can be resolved with selective elements: proper north orientation of the main window areas with mobile shading or shaded by horizontal overhangs; such windows receive much less solar radiation in summer than in winter through the variation of solar declination. This is especially effective here at 33.4° latitude south with almost vertical incidence of solar radiation at noon in summer. A high thermal capacity permits effective night ventilation and results in a large time constant and a high utilisation factor (low rate of excessive heat gains).

4. CONCLUSIONS

This investigation demonstrated how the concept of crucial building parameters can facilitate a better understanding of the dynamic interaction of building design, climate and user behaviour and presents a novel approach to design recommendations and the efficient optimisation of passive solar houses. This way, it shows that in its essence passive design means the intelligent control of variable natural energy flows to improve thermal comfort.

The methods and results presented here can be useful to simplify the design process, for the preparation of parametric studies, the future extension of building codes to passive houses and the diffusion of passive design among students and professionals. I hope that this will contribute to the further diffusion of passive houses as an important element of sustainable development.

REFERENCES

[1] Norma Chilena NCh 1079.Of77, Zonificación climático - habitacional para Chile y recomendaciones para el diseño arquitectónico, Santiago 1977.

[2] P. Sarmiento M., Energía Solar, Aplicaciones e Ingeniería, Sistemas Pasivos, Valparaíso 1995.

[3] Dirección Meteorológica de Chile, Normales Climatológicas 1961 – 1990, Santiago 1991.

[4] Instituto Nacional de Estadísticas, Estadísticas del Medio Ambiente 1995 – 1999, Santiago – Chile 2000.

[5] Norma Chilena NCh 853.Of91, Acondicionamiento ambiental térmico - Envolvente térmica de edificios - Cálculos de resistencias y transmitancias térmicas, Santiago 1991.

[6] Norma Chilena NCh 1960.Of89, Aislación térmica - Cálculo de coeficientes volumétricos globales de pérdidas térmicas, Santiago 1989.

[7] E DIN EN ISO 13790, Thermal performance of buildings - Calculation of energy use for heating (ISO/DIS 13790: 1999); German version prEN 13790: 1999.

[8] E. Müller, Development of a Test Reference Year on a Limited Data Base for Simulations on Passive Heating and Cooling in Chile, Building Simulation 2001, Rio de Janeiro, August 2001.

[9] E. Müller, Desenvolvimento de Regras de Desenho Passivo para Edificações Habitacionais na Zona Central do Chile, ELECS, Canela/RS – Brasil, Abril 2001.

[10] E. Müller, Manual de diseño para viviendas con climatización pasiva. Building Research Institute - University of Kassel 2002, 60 p. (available from the author as pdf file in Spanish).

[11] E. Müller, Analise e propostas de desenho passivo para edificações habitacionais na zona central do Chile, VII Encontro Nacional sobre Conforto no Ambiente Construído ENCAC e III Conferência Latino-Americana sobre Conforto e Desempenho Energético de Edificações COTEDI; Curitiba – Brasil, 2003.