# SUSTAINABLE PASSIVE HOUSING FOR EMERGING COUNTRIES

**Ernst Müller**

University of Kassel, Kassel (Germany)

## 1. Introduction

Sustainable passive and solar housing, including passive cooling and passive solar heating here, is a promising strategy to improve thermal comfort in the Mediterranean climate of Central Chile with its hot and dry summers and cool, but sunny winters. Chile, together with Brazil and others, forms part of Latin Americas emerging countries with a rapidly growing economy, but still large quantitative and qualitative deficiencies in housing. The building sector represents an important part of that economic growth - both as a social necessity and through its energy consume and environmental impact, especially on climate change. Therefore it is important to develop concepts and tools for the design of sustainable houses and buildings considering the ecological, social and economic aspects of sustainability.

This work will present the latest results of the author's participation in an international scientific cooperation and the research for his PhD thesis with special emphasis on the analysis of the technologies that make sense from the viewpoint of appropriate technology and sustainable development.

## 2. Methodology

The evaluation of thermal building behavior is based on extensive parametric studies, both for a reference room (>500) and for complete (passive) houses (>100) with the thermal simulation program Derob-LTH. The simulations were realized with a test reference year for Central Chile with hourly climate data, prepared with an own methodology presented in (Müller, 2001). The hourly climate data for Santiago were obtained from measurements (see acknowledgements), the mean reference values, shown in figure 7 below, are from (Dirección Meteorológica de Chile, 1991) and (Sarmiento, 1995).

As thermostatically regulated central heating systems or air conditioning systems can rarely be found in the residential sector in Chile, passive here means the absence of mechanical heating or cooling systems without promising always perfect thermal comfort as would be expected in rich countries.

Thermal simulations with DEROB-LTH 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 $\theta_o$ 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 or period with N hours with especially written software according to the following definition:

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

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

Parallel to the thermal simulations, classic building code calculations were adapted and applied: simple building characteristics were calculated in a spreadsheet according to (German versions of) ISO or European building codes ((E DIN EN ISO 13790, 1999) and related ones), which are similar to, but more complete than local codes (NCh 853.Of91) and (NCh 1960.Of89); basic characteristics of local building materials were taken from Chilean code (NCh 853.Of91) when available; necessary characteristic values and correction factors in building codes were determined with special thermal simulations; special simple models for passive design aspects that are not considered in building codes, e.g. night ventilation, were established.

This way, the calculation methods originally created for the description of thermal behavior in winter and the determination of energy needs, were adapted for the new climate zone and extended to determine basic thermal parameters for passive houses with free-floating temperatures in the cold and hot period. Then these basic thermal parameters, that depend on the size of a building or room, were combined to calculate size independent secondary thermal parameters, the crucial thermal parameters. 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.

## 3. Results

### *3.1. Technical Results: Design Tools and Recommendations*

At first, correlations between basic thermal parameters of a reference room in a passive house and thermal simulations were determined, that are shown in figure 1 for the coldest winter month, July, and in figure 2 for the hottest summer month, January. The correlations 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. They are based on two 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 minimum comfort level of 19°C)
- "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 maximum comfort level of 26°C)

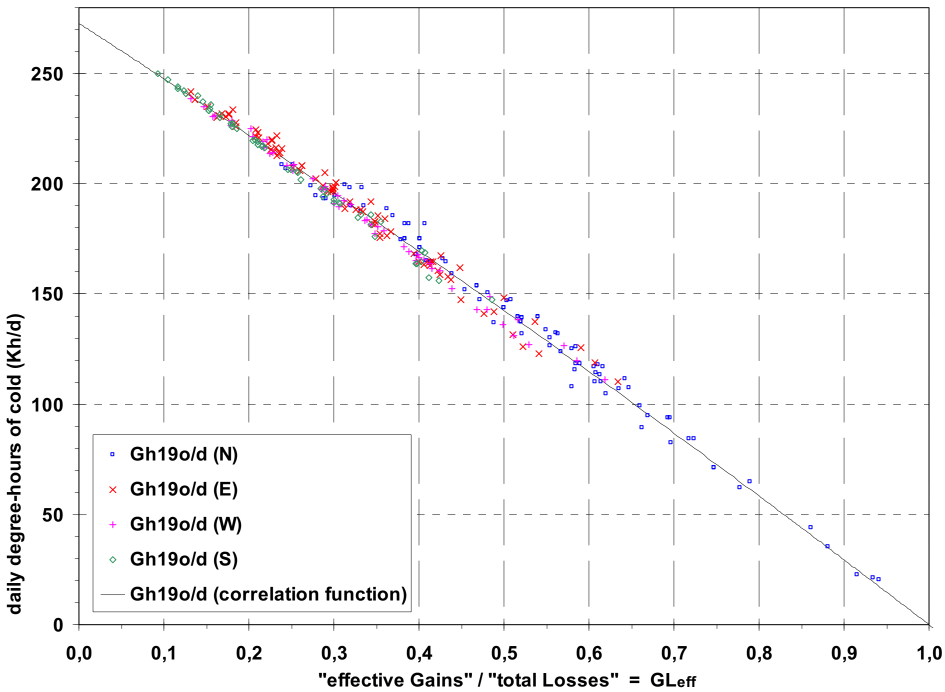


**Fig. 1: Correlation for daily degree-hours of cold $Gh_{19o}$ for winter (July), indicating orientation**

These crucial building parameters represent size independent functions of the primary, but size dependent thermal parameters in the building codes. Thus an improved understanding of the dynamic interaction of building design, climate and user behavior permitted systematic design recommendations for architects and civil engineers with a new approach based on crucial building parameters and thermal comfort, that were presented together with a summary of the calculation process by the author in (Müller, 2006).

The crucial building parameters and their extensive analysis permit a novel approach to the optimization of passive design projects and the formulation of design recommendations, that can now be resumed as recommendations for these parameters:

- in the cold period it is important 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 thermal mass permitting good utilization 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 important to minimize the excess-gains-to-loss ratio $GL_{exc}$; $GL_{exc}$ values of 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, 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 appropriate 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 making use of low night temperatures and reduces the temperature rise during hot days.

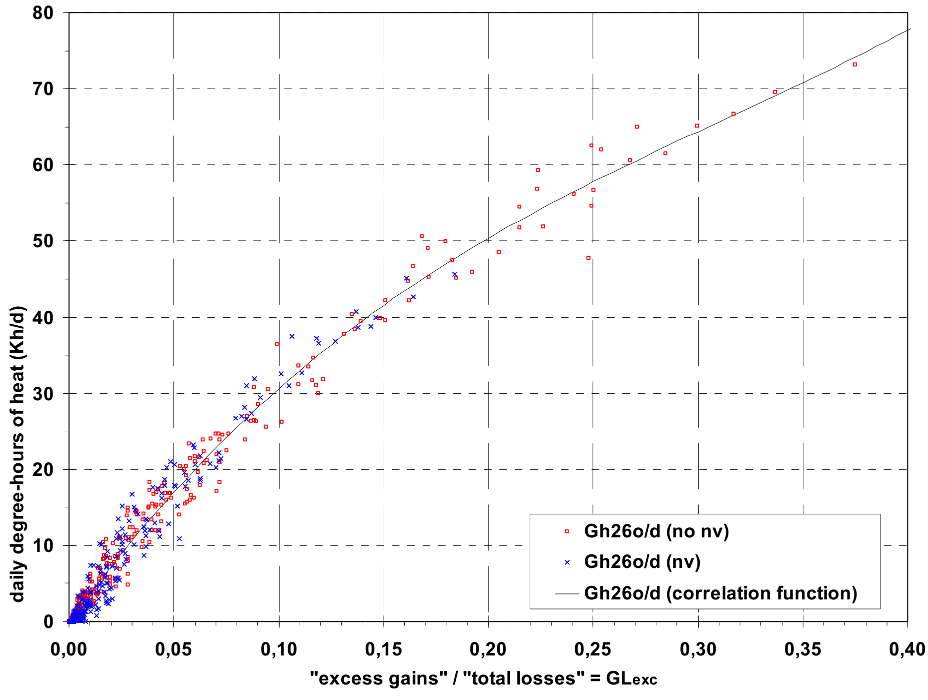


**Fig. 2: Correlation for daily degree-hours of heat $Gh_{26o}$ for summer (January), indicating night ventilation**

Marking different groups of cases according to important design parameters permitted to derive some design recommendations according to the resulting thermal behavior: in these examples, north orientation for the winter and the strategy of night ventilation in summer.

Based on the same simulation data, an analysis and recommendations for all important building elements and interesting strategies for passive heating and cooling were developed. One example is given here in figure 3 for different passive cooling strategies in summer: it shows the importance of thermal capacity in this climate with high daily temperature variations. Solar protection is essential as well and night ventilation is more effective than common increased ventilation during the whole day if the heat capacity is sufficiently high.

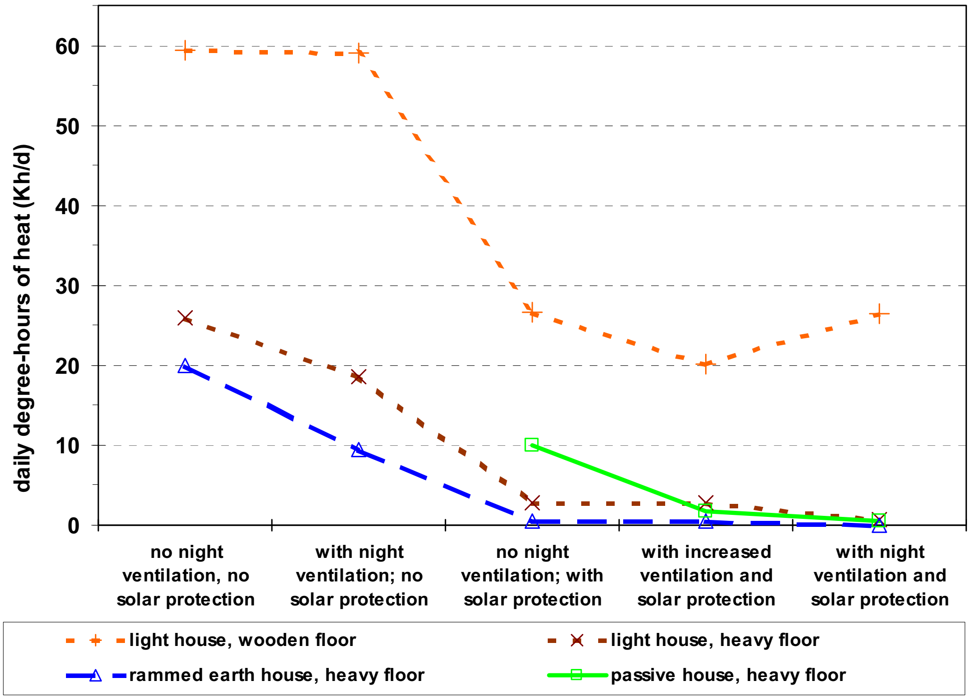


**Fig. 3: Analysis of different passive cooling strategies and thermal capacity**
**Santiago de Chile: daily degree hours of heat hot period (12~2, base 26°C)**
**thermal behavior of a reference room in a house (mean value for orientations N, S, W, E)**

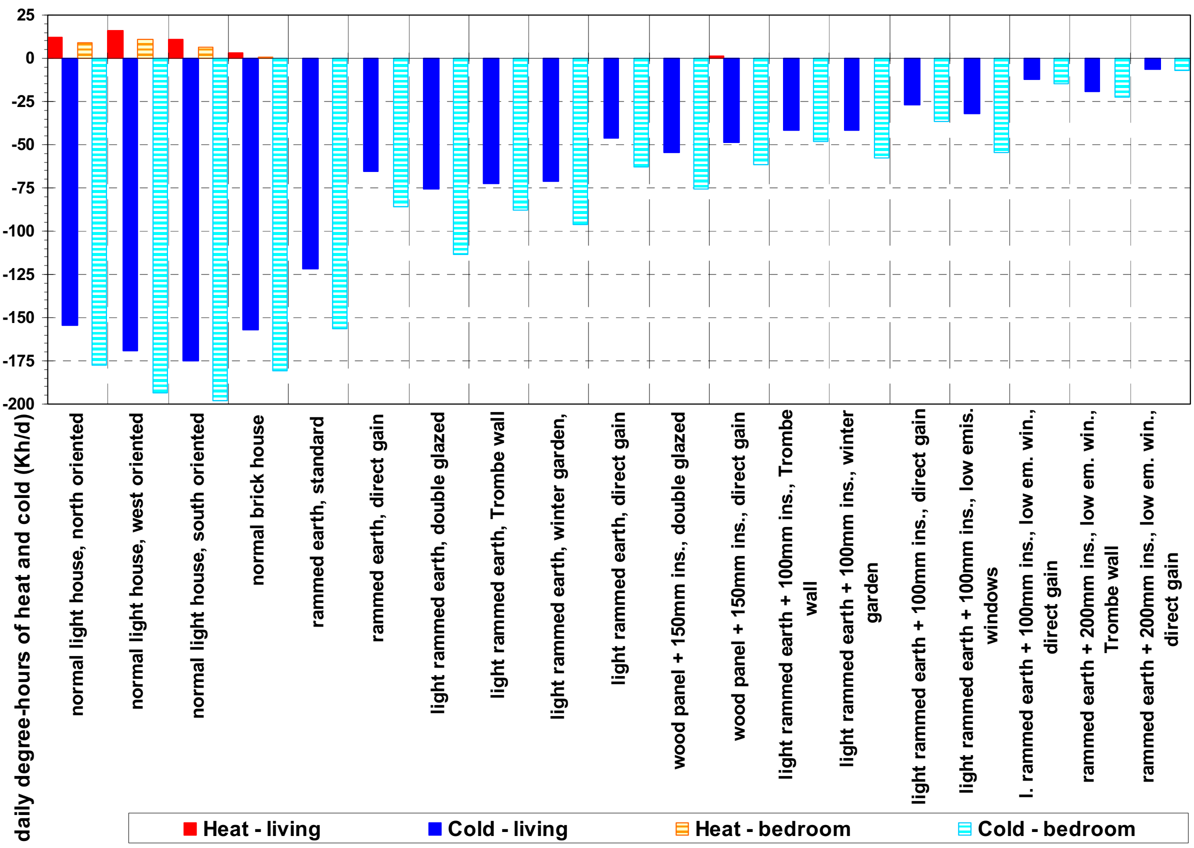


**Fig. 4: Comparison of thermal behavior of normal, improved and passive houses**
**Santiago de Chile: daily degree hours of heat and cold**
**hot period (12~2, base 26°C, >0) and cool period (5~9, base 19°C, <0)**
**for living room and bedroom [N, option: Trombe wall]**

Different designs of normal and thermally improved houses were simulated and analyzed and design examples for passive solar houses proposed. A few examples of their thermal behavior are compared in figure 4.

The designs of the houses are shown in figures 5 and 6, that were generated directly with the simulation program (orange/red: walls and floor seen from inside/outside, blue: windows, yellow: shading elements including thick walls).

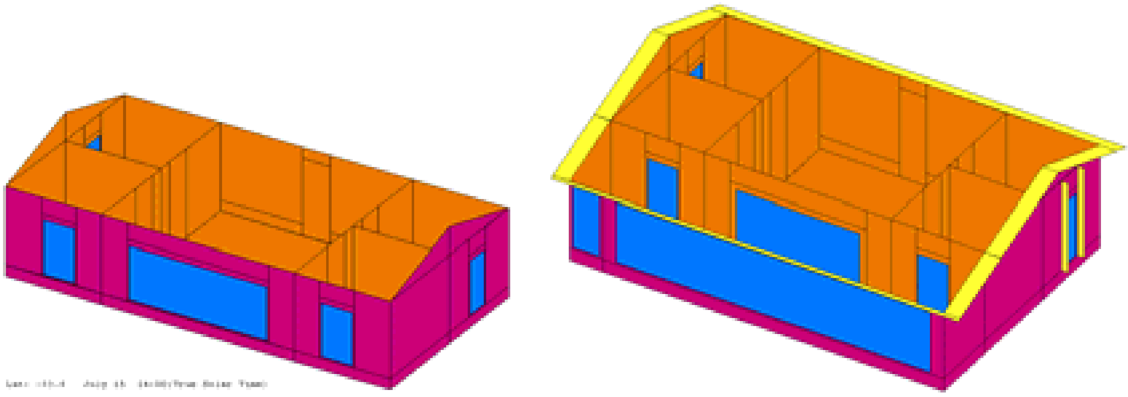

**Fig. 5: Normal House without shading devices (left); Passive house. made of rammed earth with winter garden in front (right) (shown without roof, front: north side; 15.7. 14:00 true solar time, seen from the solar position)**

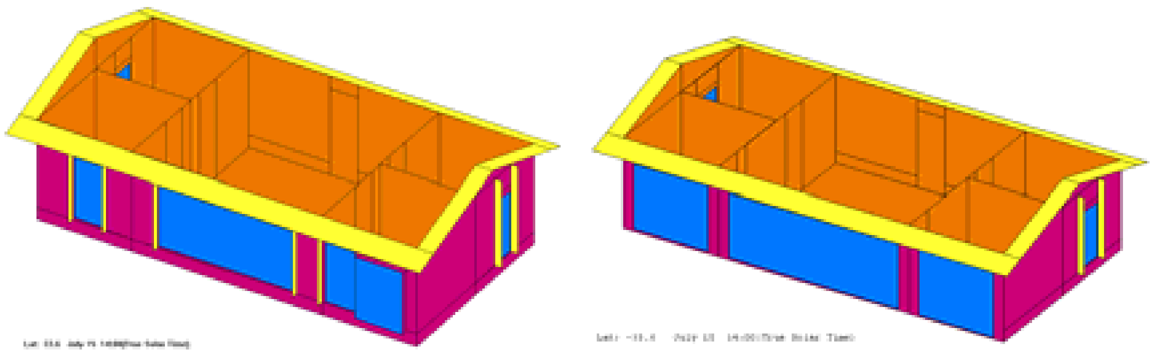

**Fig. 6: Passive houses, made of rammed earth: with Trombe wall (on right side; left graph); direct gain (right graph) (shown without roof, front: north side; 15.7. 14:00 true solar time, seen from the solar position)**

The thermal behavior of the different design proposals resumed in figure 4 shows: normal houses (light houses made of wood panels or brick houses without passive measures) show heavy thermal problems both in summer and winter; heavy standard houses made of rammed earth with shading and night ventilation resolve the problems in summer and improve the winter conditions (typical for Chilean vernacular architecture). Different proposals of passive houses, made of light rammed earth with better insulation and windows, demonstrate that, depending on the technical and financial effort, it is possible to design simple passive houses for Chile which can offer thermal comfort during the whole year.

Finally, the recommendations for thermally improved and passive house are resumed as a matrix of design recommendations with building elements and strategies for passive heating and cooling. Table 1 offers a simplified version here, organized according to the main aspects of heat exchange with the environment, solar gains and heat capacity for the cold and hot period. This way of presentation corresponds better to a design approach oriented in building elements and the analysis in the following chapter.

**Tab. 1: Simplified matrix of design recommendations for passive houses in a Mediterranean climate**
**(numbers indicate priority for each period)**
**innovative materials and strategies that require technology transfer and/or training**

| Design Aspect | Cold Period | Hot Period |
|---|---|---|
| Heat exchange with the environment:<br>▪ transmission<br>▪ ventilation | 1 reduce heat losses:<br>1.1 thermal insulation and windows with reduced heat losses<br>1.2 ventilation: sealing of windows and doors; avoid internal contamination from heating systems<br>1.3 adequate window size: depends on thermal quality and orientation of windows | 3 increase heat losses:<br>3.1 ventilation: permanent or night ventilation, cross ventilation, convection through adequate openings<br>3.2 heat conduction: floor / underground |
| Solar gains:<br>▪ transparent surfaces<br>▪ opaque surfaces<br>▪ indirect | 2 passive solar heating:<br>2.1 direct gains: windows<br>2.2 indirect gains: winter garden (buffer zone), Trombe walls | 1 protection from direct and diffuse solar radiation:<br>1.1 solar protection: fixed (N) and variable elements (N, W, E, S)<br>1.2 windows: orientation (N!) and size<br>1.3 winter garden: solar protection, ventilation<br>1.4 Trombe walls: solar protection, sealing<br>4 reduce opaque solar heat gains: thermal insulation (roof!), shape and orientation; surface colours |
| Heat capacity | 3 heavy building elements for efficient use of heat gains:<br>3.1 floor<br>3.2 walls (interior and exterior)<br>3.3 (ceiling: not in seismic zones) | 2 heavy building elements compensate daily temperature variation and permit efficient use of low night temperatures |

### *3.2. Sustainable Passive Housing for Emerging Countries - What Makes Sense and What Doesn't?*

Especially when you are working in international cooperation and with the intention to present proposals for sustainable development beyond experimental buildings, it is important to consider the type and level of technology that will work in the long run and on a larger scale in the specific regional social, cultural and economic context. Based on my long-time working experience in Chile, the investigation in/for Chile resumed above and my working experience with solar energy and a cooperative for the organization and realization of building cooperatives in southern Brazil, I want to discuss shortly the type of passive and solar houses that make sense for emerging countries and their sustainable development, considering aspects beyond thermal comfort and energy efficiency.

Besides climate, there are a number of technical and building code conditions affecting thermal design, e.g. disaster protection / earthquake resistance in Chile[1], that imposes limits on the design and the size of window openings. Especially if you are building with rammed earth, you have to take special care as described in (Minke, 2001). There are two interesting solutions for passive solar gains respecting seismic resistance, that were considered in the design proposals here (together with others that are less relevant for thermal design):

- avoid single walls and keep at least two wall elements joined together at an angle, so that they can stabilise each other; this still permits large window sizes for passive gains on the north façade and is considered in all proposals with rammed earth walls;
- Trombe Walls are thermally less efficient than direct gain windows, but offer the stability of massive walls if their ventilation openings are reinforced appropriately.

[1] in Brazil, earthquakes don't pose a problem in housing

Tab. 2: Social and economic data of Chile and Brazil, compared to other countries[1]

| | Gross Domestic Product GDP per capita | GDP per capita - Average annual growth rate | Net trade in goods and services | Carbon dioxide emissions per capita | Carbon dioxide emissions per capita | Human Develop-ment Index HDI[2] | Average annual HDI growth rate | Inequality -adjusted HDI[3] - Overall loss | Income Gini coeffi-cient[4] |
|---|---|---|---|---|---|---|---|---|---|
| | (US$) | (%) | (US$) | (tonnes) | (tonnes) | | (%) | (%) | |
| year / period: | 2008 | 1970–2008 | 2009 | 1990 | 2006 | 2010 | 2000–2010 | 2010 | 2000–2010 |
| **Chile**: | 10084 | 2.8 | 12.9E9 | 2.7 | 3.7 | 0.783 | 0.65 | 19.0 | 52.0 |
| **Brazil**: | 8205 | 2.2 | 6.0E9 | 1.4 | 1.9 | 0.699 | 0.73 | 27.2 | 55.0 |
| United States: | 46350 | 1.9 | -374.9E9 | 19.0 | 19.0 | 0.902 | 0.10 | 11.4 | 40.8 |
| Germany: | 44446 | 1.9 | 164.7E9 | 12.1 | 9.7 | 0.885 | | 8.0 | 28.3 |
| India: | 1017 | 3.6 | -69.2E9 | 0.8 | 1.3 | 0.519 | 1.66 | 29.6 | 36.8 |
| Developed OECD: | 40976 | 2.4 | | | | 0.879 | 0.31 | 10.2 | |
| Least developed countries: | 664 | 2.0 | | | | 0.386 | 1.72 | 31.9 | |

I have identified two complementary ways to systematize the evaluation of the appropriateness and viability for sustainable passive housing of the design recommendations and proposals that had resulted from my thermal analysis, including some preliminary considerations that had already influenced my selection of design alternatives for simulation and further analysis:

- the design proposals should comply with the three main aspects of sustainability as presented the resulting "main aspects of sustainable housing" outlined in figure 8 indicating the aspects I have focussed my own work on;
- it is helpful to analyse step by step and with more detail the whole process from the elaboration of design recommendations, design itself, the building process until final use and maintenance.

To start with, it's important to characterize the basic situation in the region with its social, ecological and economic situation, as far as it affects housing, and referring to table 2 and my local and regional experience:

**Economically**, both Chile and Brazil are emerging countries with growing economies and a medium sized GDP per capita. Both GDP and Human Development Index HDI are constantly growing and situated well above the least developed countries, so that both countries are now located in the second highest category "high human development" of the HDI according to (UNDP, 2010). However, economic resources are still very unevenly distributed as can be seen from the relatively high loss in the inequality-adjusted HDI and the high income Gini coefficients. Additionally, there exist large regional differences within the countries.
This means that there exist both the social need and the economic potential to improve living and housing conditions, but the thermal solutions have to consider the different economic possibilities of both lower /

[1] compiled by the author, taken from (United Nations Development Programme UNDP, 2010), except "Net trade in goods and services" taken from (The World Bank Group, 2011)
[2] "A composite measure of achievements in three basic dimensions of human development - a long and healthy life, access to knowledge and a decent standard of living. For ease of comparability the average value of achievements in these three dimensions is put on a scale of 0 to 1, where greater is better, and these indicators are aggregated using geometric means." (UNDP, 2010)
[3] "A measure of the average level of human development of people in a society once inequality is taken into account. Under perfect equality the HDI and IHDI are equal; the greater the difference between the two, the greater the inequality." (UNDP, 2010)
[4] "Measure of the deviation of the distribution of income (or consumption) among individuals or households within a country from a perfectly equal distribution. [...] A value of 0 represents absolute equality, a value of 100 absolute inequality." (UNDP, 2010)

middle class people and social programs. Economic restrictions on additional costs for improved thermal design and technical complexity are stricter than in rich countries.
The positive value of the net trade in goods and services[1] shows that a certain level of importation of materials is possible, though not desirable in the long run for economical and ecological sustainability.

**Ecologically** important and increasingly relevant for climate change, the economic growth is accompanied by a considerable growth of carbon dioxide emissions per capita in emerging countries, as can be seen comparing the levels for 1990 and 2006. Both living spaces and energy use in buildings for heating and cooling are growing with housing construction and increased income, making energy consuming devices more viable. This increases the importance of energy efficiency and passive heating / cooling in dwellings.

**Social** sustainability is the most complex aspect defining appropriate and sustainable housing and its implementation. Most fundamental is the satisfaction of basic needs for healthy and comfortable living space for all people, not only a privileged minority, with optimised and viable proposals according to personal needs and economic possibilities. The basic needs and conditions for thermal comfort in housing are the starting point of this work:

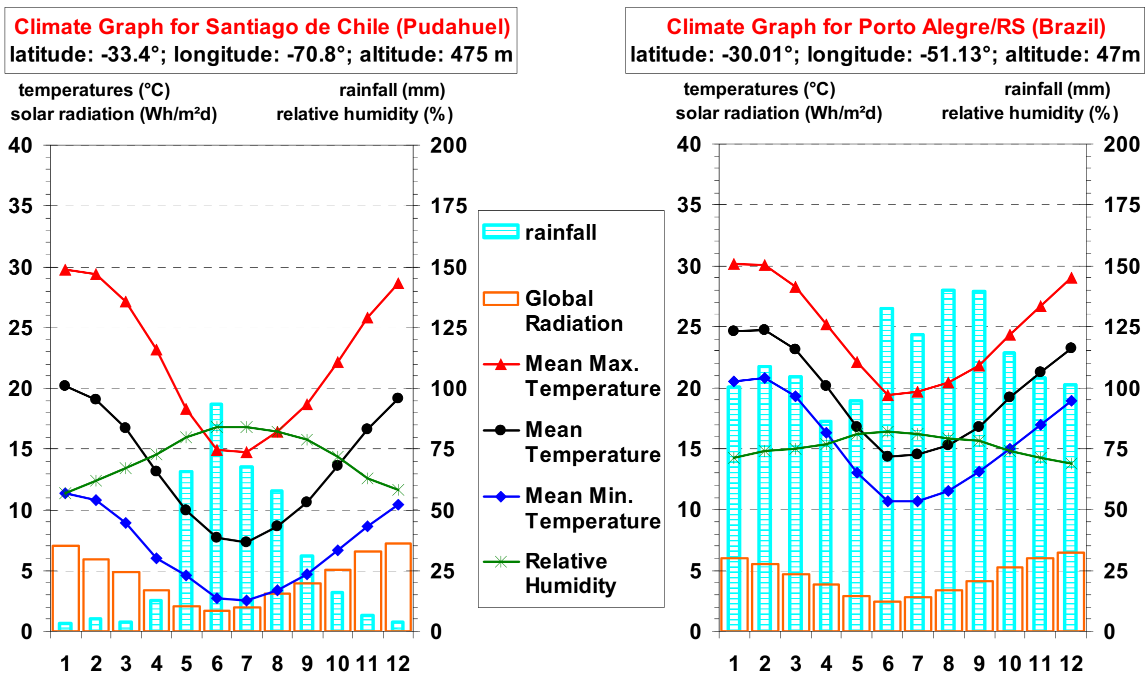


**Fig. 7: Comparison of climate graphs with monthly data for Santiago de Chile and Porto Alegre/Rs (Brazil)[2]**

In Chile, thermostatically regulated central heating or air conditioning systems offering constant interior temperatures can rarely be found in dwellings, so that the improvement of thermal comfort is more relevant than the theoretical reduction of energy use. Typical heating devices include mobile gas or "paraffin" stoves without exhaust pipe, that contaminate interior spaces directly; in (southern) rural areas simple wood stoves with chimney are common, but illegal in the metropolitan region of Santiago because of their contribution to smog problems. Even simple central heating systems and their components can rarely be found, so that there is no ample infrastructure for their installation and maintenance like in richer and colder northern countries. This is a strong argument to improve thermal comfort as far as possible with passive heating and cooling strategies, as the initial cost of implementing totally new (and not only improved) automated central systems would be prohibitive.
In Brazil with its hot and humid summers, compact and not very efficient air conditioning systems mounted below window openings are common in middle and upper class homes and can be used for electric heating in

[1] Brazil: positive 1983-2009, except 1995-2001; Chile: positive 1985-2009, except 1993, 1996-1998
[2] climate data from (Departamento Nacional de Meteorologia, 1992)

winter in southern Brazil, so that their energy consumption is high. In Chile with its warm and dry summers (in the central and north regions), air conditioning systems aren't common in private homes. Figure 7 offers a comparative overview of climate conditions in both regions.

The consideration of regional culture and living habits is important in the design process to avoid conflicts or technologies that end up unused. According to the frequently moderate outside thermal conditions in summer and winter[1], people in both countries are accustomed to pass a considerable part of their live at home changing between "interior" and "exterior" spaces (e.g. shaded terraces or backyards), so that perfectly hermetic houses with minimized infiltration, mechanical ventilation and heat recovery in winter enter in conflict with local living habits.

The participation of all affected people and important stakeholders in the process of adaptation, development and diffusion of technology is a fundamental element for social sustainability. The cooperation with local enterprises and the participation of local professionals, workers and users is essential for the success and diffusion of new technologies and can be improved through the cooperation and adaptation of "traditional" local organizations and social models, like Non Governmental Organizations (NGOs) in Chile or cooperatives and solidarity economy in Brazil. "Extension" activities of universities form part of the traditional university concept in Chile and Brazil (along with teaching and investigation) and the model of "technological incubators of popular cooperatives" (Incubadoras Tecnológicas de Cooperativas Populares[2]) linked to Universities are an interesting recent concept in Brazil. Education and training are, for example, an integral part of the concept of cooperativism or incubators and a strength of NGOs for non-professionals.

More details of social sustainability will be considered below.

In the following I want to realise a step by step analysis of the whole process of sustainable housing from the investigation, elaboration of design proposals, construction until final maintenance and operation.

According to the high level of some Universities in Chile and Brazil, there are no general limitations for **investigation** and the **development of design rules**, if funding is available from national programs or international cooperation. Interdisciplinary / transdisciplinary cooperation is essential because of the complex demands for the development and diffusion of sustainable passive housing from building physics, civil engineering and architecture to social sciences. For most climate regions, detailed analysis and recommendations for passive design have still to be realized in regional Universities and/or international cooperation. New and improved concepts for passive heating and cooling have to be integrated into the standard curriculum in architecture, civil engineering and building physics to be effective - the challenge is not only one of teaching new methods and designs, but of convincing students and professionals of their importance and viability. Moreover special courses and other activities oriented in professionals should be integrated into the activities of extension.

After the initial technical studies and especially during the first pilot and demonstration projects in every new region, the future users and social organizations concerned should be integrated into a partizipative design and implementation process.

The resulting technical and **design proposals** have to be economically accessible for a wide majority and easily adaptable to different sizes and economic levels. Typically an architectural design for economic houses in Chile is realized dozens or even hundreds of times identically (normally without consideration for solar orientation), as can be easily observed for example in the outskirts of Santiago de Chile. In Brazil as well, several identical houses are often realized as a single project or a gated community ("condomínio fechado") for security reasons. Ecological villages ("Ecoovilas" in Portuguese) are another model organized as cooperatives in Porto Alegre (Brazil) by the cooperative ARCOO (Architecture and Cooperativism)[3]. This way, the costs of architectural design are divided among many houses and may not be increased too much.

---

[1] high interior temperatures in summer in central Chile are more the result of strong solar radiation combined with bad thermal design than of extremely high outside temperatures, as the thermal simulations have shown;
even in winter in both regions, sunny days frequently offer some hours with comfortable outside conditions in the sun.

[2] see (ITCP-USP, 2005) and more information under http://www.cooperativismopopular.ufrj.br/english/metod_incub.php

[3] information under http://www.arcoo.com.br in Portuguese; the author E. M. has participated in ARCOO

This requires the development of simple and efficient design tools and concepts as those resumed before[1].
At the same time, the implementation of groups of houses offers the chance to reduce the effective cost for the development of improved, sustainable passive designs and include the necessary unobstructed access to solar radiation and eventually natural air flows into the definition of the individual construction sites and the arrangement of houses. The planning and construction of such settlements can be organized in a more partizipative, economic and sustainable way by housing cooperatives, eventually with (partial) self-construction. The essential process of participation and education constitutes an integral element of cooperativism and other forms of solidarity economy.

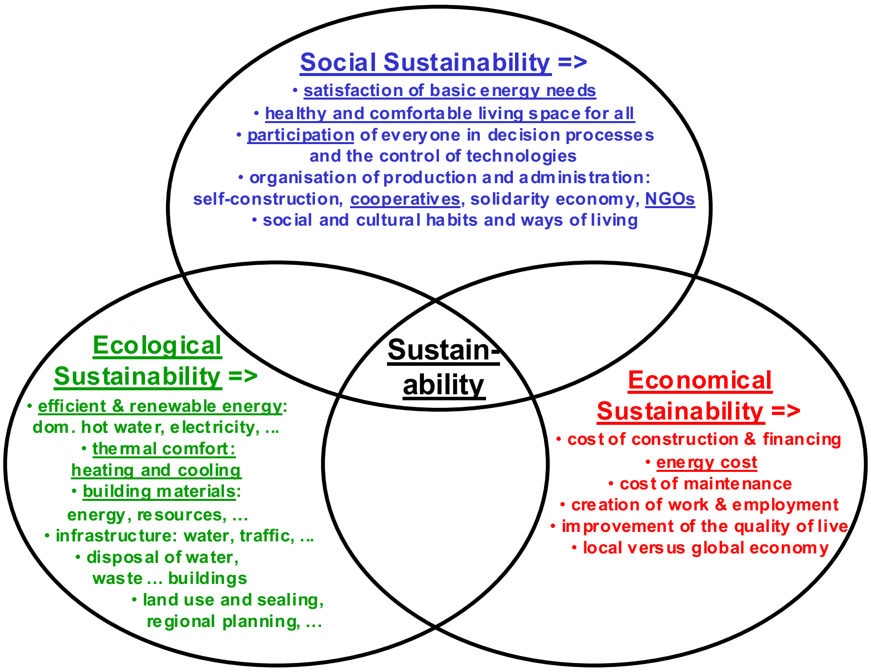


**Fig. 8: Main aspects of Sustainable Housing (own working experience underlined)**

The design and **construction** should give priority to locally and regionally available and traditional materials and their improvement, considering the high economic and energetic cost of transport and the support of local economy. Examples are (rammed) earth in Chile or bricks from sustainable regional production in Brazil. Rammed earth ("tapial") or mud bricks ("adobe") had been traditional building materials in Chile, but in recent decades have come out of use because of their lack of earthquake resistance without special care. Common insulation materials like polystyrene ("plumavit" in Chile), glass wool or polyurethane foam have been available in Chile for many years, but normally haven't been used in private houses with the exception of ceilings in recent years (MINVU, 2000). Both in Chile and Brazil, fixed and mobile shading devices are available, but often not implemented in an optimized way according to orientation and not as an integral part of thermal design including its implementation in construction.
In emerging economies advanced building elements like new sustainable insulation materials or highly efficient windows are viable if they are cost-effective and not too complicated to implement, as they can be imported initially (for prototypes or demonstration projects) and then be produced locally, when implemented on a larger scale, creating jobs and economic development. This requires a corresponding process of technology transfer, adaptation and development, that is already under way in other economic sectors. Reasonable additional costs for improved thermal quality and energy efficiency could be considered in housing programs or are at least covered by general building financing as they improve thermal comfort and living quality. Some design recommendations like proper orientation or ventilation strategies are even free but quite effective.
Participation and training of workers together with quality control for the realization of improved traditional techniques (like rammed earth) and new ones for the region (like insulation) are essential for their

[1] for more details see (Müller, 2002), (Müller, 2006), (Müller, 2007)

effectiveness, as local workers often don't have ample and formal professional training.
However, complex high-tech components like automated central regulation systems for passive or active (renewable energy) heating / cooling / shading / ventilation etc., controlled by sensors and computers, whose installation requires specialized and expensive experts, are especially critical and hardly economically viable for the majority of housing projects.
Cooperative models and other forms of solidarity economy for the production of building materials and elements, for construction as well as for the process of financing and training of workers can help to reinforce the social and economic aspects of sustainability.

The long-term **maintenance** is a typical weak point of technological development projects, if it is not very well organized or too expensive due to complicate and sensitive high-tech equipment, as poor people normally lack the resources for expensive maintenance and repair. Systems and equipment have be simple and resilient, without the necessity of permanent and expensive specialized maintenance. Even more than during construction, it is important for economic and organizational reasons that the necessary maintenance of houses and equipment can be realized by local (skilled) workers and enterprises or the users themselves, eventually after some additional training. Moreover, the design and passive concept should be sufficiently resilient and flexible, that minor changes during construction or use, realized by local workers or the occupants themselves, don't impede the proper functioning of the concept for thermal comfort. It is an important advantage of the passive solutions proposed here that they are simpler and easier to understand and maintain than energy consuming active equipment.
As before, cooperative and partizipative administration of houses can facilitate these activities.

**Operation** and use of houses and their components for thermal comfort have to be realized by the occupants themselves. In general these lack a professional training in the area and are not accustomed to read and apply manuals written in technical language. Therefore operation has to be simple and intuitive. Basic training, for example in the proper ventilation and shading strategies, should form an integral part of implementation, at least until these technologies get more common.
Participation of users and basic training on the principles of passive heating and cooling like shading, cross and night ventilation or solar heating can help to realize the technical potential of passive houses and maintain their effectiveness even after future renovation or modification of houses.

From the analysis above it can be observed and resumed that from scientific research passing through construction to final use, the appropriate level, complexity and cost of technology gradually decrease whereas the need of participation and training increases. During the process of realization and implementation of new technologies the cooperation with local stakeholders, workers and users is essential, combining the efforts of universities with government agencies, enterprises, solidarity economy / cooperatives and social organizations like Non Governmental Organizations in the most adequate way for every task, region and target group. On a professional level, interdisciplinary / transdisciplinary cooperation is essential.

## 4. Conclusions

The design recommendations showed that with an optimized simple design it's possible to improve significantly the thermal comfort conditions in economically accessible dwellings of the region. The methodology and approach developed here are extendable to other regions and climate zones of Latin America and emerging countries.

The design and dissemination of sustainable housing have to respect the three main dimensions of social, ecological and economic sustainability. The careful selection of appropriate technologies for every region and target group is important for the success of proposed solutions. Participation and interdisciplinary cooperation are central elements in the process of design and implementation. This way, investigation can contribute to the improvement of thermal comfort and the application of solar energy in the housing sector as essential elements of a sustainable development process.

## 5. Acknowledgements

This investigation was possible thanks to the participation in an international project on "Earthquake Resistant Housing with Passive Climatization, Built with Local Materials in Rural Zones of the Andes Region" of the Building Research Institute. The original hourly climate data for Santiago were obtained thanks to the cooperation of the National Centre for the Environment CENMA from measurements of the National Environmental Commission CONAMA, both in Santiago de Chile. The program DEROB-LTH could be used thanks to the cooperation with Lund University (Sweden).

## 6. References

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

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

Kollektiv der Innovationswerkstatt der Universität São Paulo ITCP-USP, 2005. Die Inkubation von Gruppen für Solidarische Ökonomie, in: Clarita Müller-Plantenberg et. al., Solidarische Ökonomie in Brasilien und Deutschland - Wege zur konkreten Utopie (Entwicklungsperspektiven Nr. 83/84), pp. 129-133, Kassel.

Ministério da Agricultura e Reforma Agrária, Secretaria Nacional de Irrigação, Departamento Nacional de Meteorologia, 1992. Normais Climatológicas (1961-1990), Brasília - Brasil.

Ministerio de Vivienda y Urbanismo MINVU, 2000. Manual de Aplicación, Reglamentación Térmica, Ordenanza General de Urbanismo y Construcciones, Santiago.

Minke, G., 2001. Manual de construcción para viviendas antisísmicas de tierra, Segunda edición revisada y ampliada, Forschungslabor für Experimentelles Bauen, Universidad de Kassel, Alemania.

Müller, E., 2001. 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.

Müller, E., 2002. Manual de diseño para viviendas con climatización pasiva, Building Research Institute, University of Kassel - Germany. (Manual for the design of passive houses; in Spanish)

Müller, E., 2006. Crucial Building Parameters as a Novel Approach for the Design of Passive Solar Houses in a Mediterranean Climate. PLEA - The 23rd International Conference on Passive and Low Energy Architecture, Geneva - Switzerland.

Müller, E., 2007. Estratégias para o Desenho de Casas Passivas e Sustentáveis numa Zona de Clima Mediterrâneo. IV Encontro Nacional e II Encontro Latino-americano sobre Edificações e Comunidades Sustentáveis, Campo Grande / MS - Brasil. (Strategies for the design of sustainable passive houses in a mediterranean climate zone; in Portuguese)

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

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

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

The World Bank Group, 2011. http://data.worldbank.org. (data from "http://api.worldbank.org/datafiles/3_Topic_MetaData_en_EXCEL.xls")

United Nations Development Programme UNDP, 2010. Human Development Report 2010, New York. ("http://hdr.undp.org/en/media/HDR_2010_EN_Complete_reprint.pdf" and "http://hdr.undp.org/en/media/HDR10%20EN%20summary_without%20table.pdf"; data from "http://hdr.undp.org/en/media/HDR_2010_EN_Tables_rev.xls")