Housing design for temperate climates: the priority to energy sufficiency

Hugo R. R. Santos
Dr.
Research Group for Energy and Built Environment, INEGI
Portugal
hsantos@inegi.up.pt

Dr. Mariana Abrunhosa Pereira, Faculty of Architecture of the University of Porto, Portugal, mapereira@arq.up.pt
Professor Eduardo Oliveira Fernandes, Faculty of Engineering of the University of Porto, Portugal, eof@fe.up.pt

Abstract

Building physics is a well-established field of knowledge. Still, that is yet to be consistently translated into practice through state-of-the-art performance, exploring the potential of adaptive comfort and passive thermal behaviour to excel in terms of energy sufficiency in a dialogue with the local climate.

This is particularly relevant and well suited in temperate climates, where forefront knowledge for the past 40 years shows it is straightforward to build houses offering healthy and comfortable environments with no or very little need for additional heating and, even less, cooling, while also dismissing the need for active systems. This means exploring the building’s sufficiency even before caring about the efficiency of possibly unnecessary ‘add-on’ equipment.

A consistent approach to building design must be adopted in which constraints and parameters with highest impact on the building’s performance in its location and climate are set right from the start of the design process. Those can be, either, fairly location-agnostic (e.g. insulating from the outside while keeping thermal mass indoors), or, definitely, location- and climate-driven (e.g. window sizing and orientation), while others still more occupant- and activity-related (e.g. setting requirements for effective adaptive comfort and healthy building operation).

Only a holistic understanding and definition of those parameters in the pre-design stage can guarantee that the subsequent design explores the full potential for energy sufficiency and comfortable and healthy environments.

This paper will explore the above, proposing a rationale towards a better housing building stock, and demonstrating the enormous potential for low-energy housing for millions of citizens.

Keywords – Sufficiency; energy; residential buildings; conceptual design; constraints
1. Introduction

In addition to being solid and durable, buildings must also provide safe, healthy and comfortable environments to their occupants. From a structural perspective, long-held knowledge of construction technologies and materials have allowed buildings to stand easily for several decades, or even centuries, with barely any maintenance or concern. On the other hand, the design of healthy and comfortable interior spaces still faces the challenge of wisely adapting buildings to their local climate while also keeping in mind the cultural factors inherent to all architectural expressions. And this has become ever more important with the advent of pernicious influences on architectural and construction solutions between very different parts of the world.

In locations with severer climates, i.e. cold or hot/humid, it is difficult for a building to achieve comfort conditions on its own; therefore, designing formulas tend to follow a set of well-known strategies. For instance, in Northern European countries, good building design calls for high insulation, tight envelopes and mechanical ventilation with heat recovery (among other aspects). Conversely, in hot and humid climates, air conditioning and closed windows are an almost certainty. In these cases, indoor/outdoor difference is generally too large to be feasibly tackled by passive solutions alone, and, consequently, the use of ‘add-on’ equipment for heating and/or cooling becomes imperative. The conditions offered by temperate climates, however, call for a different approach.

Proper attention to the local climate should result in architectural options and constructive solutions that promote a significant reduction of heating and cooling needs through the careful use of building physics. When properly explored in temperate climates, this should result in smaller or even no thermal equipment/systems being required to fulfill the specified comfort needs. This approach has been called ‘energy sufficiency’ and should be prioritized to the ‘energy efficiency’ associated to the energy equipment or systems (Fernandes, 2016).

The sufficiency approach has been briefly discussed by both the 5th Intergovernmental Panel on Climate Change Report (Lucon, 2014) and the International Energy Agency’s report on ‘Modernizing Building Energy Codes’ (IEA, 2013). In the former, it is pointed out that current indicators refer too much to ‘efficiency’ instead of ‘sufficiency’ and, in the latter, that energy sufficiency must be the first design consideration in the path towards low-energy and low-carbon buildings. When applied to building design, the sufficiency approach prioritizes solutions that reduce and fine-tune the building’s energy needs, towards a minimization of CO₂ emissions, therefore, contributing to the global sustainability.

As part of the strategy to achieving energy sufficiency, the adaptive concept for comfort (ASHRAE, 2004) has shown that, in many cases, buildings may provide adequate comfort conditions to occupants without the need for heating or cooling systems (Matias et al., 2009; Roulet, 2005; Clausen, 2003). This outcome, which is particularly relevant to buildings in temperate climates, results from the linear correlation observed between the indoor comfort temperature in naturally acclimatized buildings and the outdoor temperature (Nicol, 2002).

While building designers should properly address the building’s thermal aspects, evidence shows that this is yet to be done correctly and consistently. One of the main culprits is the fact that building thermal assessment is generally performed only after the architectural choices have been essentially established, i.e. at an advanced point of the building design process. At this late stage, the most important decisions have already been made and it is generally too late to change the design significantly.

This paper revisits results published elsewhere (Pereira, 2016) and goes beyond the analysis there presented in questioning the strategies and tools that can help address the above issues, particularly by exploring the ways building design for energy sufficiency should consider the site’s and the building physics’ constraints and potentialities, all while using a simple and accessible language and methodology that can be applied right from the initial design stages.
2. Methodology

The methodology used in this work has been previously described in detail (Pereira, 2016). In summary, a standard assessment procedure, namely the one formerly used in Portugal in the Building Energy Certification System (RCCTE, 1990), was used as a basis of calculus to estimating the heating and cooling needs in a number of representative reference architectural spaces, and conducting a sensitive analysis over particularly relevant design parameters.

All the reference spaces have the same internal volume (300 m³) but differ in their façade’s thermal conductance ranging from 1.12 to 0.18 W/°C.m². This is modelled through different conditions of thermal insulation in walls and/or roof, or by assuming a different number of walls in contact with the exterior, for instance, the reference space can be modelled as if it was above or below or right next to one or more heated spaces). Windows are assumed as standard double-glazing and air infiltration is assumed at an average 0.6 ACH⁻¹ (or about 200 m³/h), both fairly typical for recent construction solutions in Portugal without particularly airtight envelopes.

From a large number of possible design parameters, an early analysis and mapping of their impacts in the building’s thermal performance picked up five as being of particular relevance and, hence, were the ones explored in this work, namely:

- **thermal insulation** – here explored through the façade’s thermal conductance, as discussed above;
- **thermal inertia** – defined by the amount of exposed internal thermal mass and categorized as either “heavy” or “weak” according to the standard assessment ranges;
- **window orientation** – particularly relevant in terms of north and south;
- **window size** – defined as a percentage relative to the floor area and ranging from 5% up to 40%;
- **window shading** – two conditions analysed, either very little shading through internal curtains or high shading through opaque external shading devices.

Portugal has a temperate/moderate climate all-around, serving as a good basis to model the buildings’ performance in this type of climate. Figure 1 shows Portugal’s location within the world map coloured according to the Köppen climate classification (Peel, 2007). Despite being almost fully covered by Mediterranean type climate (Csa and Csb in the Köppen classification), there are variations in local climates that are relevant to explore. Thus, architectural spaces in four distinct...
cities were modelled within the sensitivity analysis (also shown on the right-hand side in figure 1), namely:
- Bragança: coldest winters, mild summers (continental influences);
- Évora: cold winters, hottest summers (continental influences);
- Porto: mild climate all year-round (oceanic influences);
- Lisboa: warm winters, hot summers (oceanic influences).

Only the most relevant aspects and observations for a limited number of combinations of these parameters are presented and discussed here.

3. Results and discussion

Figure 2 shows the results for estimated annual heating and cooling needs for each location while varying the façade’s conductance and window size. Thermal inertia is set to “heavy”, windows face south and are lightly shaded internally. This is a fairly common occurrence in typical Portuguese buildings. Some observations are immediately evident:
- As expected, the coldest climate (Bragança) presents the highest heating needs while the warmest climate (Évora) presents the highest cooling needs;
- Buildings with lower façade conductance (darker curves in figure 1) always present lower heating and cooling needs but the impact is significantly higher for heating (e.g. heating needs are cut by about 2/3 when the façade’s conductance is reduced from 1.12 to 0.18 W/m².°C, regardless of climate); however the impact on cooling needs is fairly small;
- Larger windows facing south always result in a reduction of heating needs but, conversely, lead to higher cooling loads in the absence of adequate external shading thus resulting in excessive solar gains in the summer;
- The lowest total thermal energy needs are found in Lisboa for spaces with very low glazed areas (lowest heating needs due to warm winters and low cooling needs due to small windows); however, the situation is inverted when bigger windows are used, in which case Porto becomes the best case (it gains significantly from having larger windows in terms of heating needs reduction and the impact of solar gains in the summer is lower than in Lisboa).
One of the biggest benefits of a temperate climate comes from the large potential for useful solar gains which frequently are enough to reduce heating needs to essentially zero in well-designed spaces. That much is illustrated in figure 2 where the heating needs curve for the best insulated space reaches zero (or comes close) in all the tested locations.

However, those same solar gains can very quickly become detrimental if solar shading is not adequately considered. Figure 3 illustrates this for two of the locations (Porto and Lisboa), for simplicity. In the exact same conditions as before but now considering external and opaque solar shading during periods of excessive solar radiation, the cooling needs are drastically reduced, potentially reaching a point where comfort can be guaranteed by simple actions by occupants (e.g. cross-ventilating spaces or using a simple indoor fan). In fact, this result shows how simple construction (e.g. brick or concrete) with good external insulation, standard heavy thermal inertia (i.e. no light materials such as plasterboard or wood covering the internal walls) and without any mechanical ventilation, heat recovery, air-tightness or other extraneous solutions can easily result in a building whose total thermal needs stay below 10 kWh/m².year in a temperate climate.
The proper consideration to window size and orientation in temperate climates becomes even better illustrated by a scenario where openings are oriented towards north (i.e. no direct solar radiation can get inside during winter and only very little can during the summer in the Northern hemisphere), as shown in figure 4. In this case, as expected, bigger window openings directly correlate with significantly increased heating needs. On the other hand, while cooling needs are reduced when compared to the scenario with the windows facing south, the gains do not quite reach the same values as using proper external shading.

Lastly, thermal inertia is another of the parameters that has significant importance in achieving thermal comfort in temperate climates, particularly in places with large daily thermal amplitudes, as the case of the locations with continental influences, farther from the thermal levelling effects of the sea, here represented by Bragança and Évora. When comparing a scenario with weak thermal inertia, shown in figure 5, with the one with heavy inertia in figure 2, the effect becomes clear when the windows are bigger. In particular, the heat storage capacity of the space becomes saturated past a certain point and extra solar gains through bigger windows no longer result in decreasing heating needs. While not as visually obvious, there is a similar impact in the cooling needs, which are slightly raised at the largest window sizes.
Figure 5 Similar to figure 1 except internal construction provides weak thermal inertia.

While not particularly innovative, these results intend to illustrate in a very simple and straightforward way how a very simple methodology can be used to assess particularly relevant design parameters. They show how even within a small country like Portugal, the buildings’ thermal performance is still quite sensitive to some of the broad options made during its design. When the thermal performance assessment is performed only after the design has been mostly set, the opportunity to make significant changes is rarely there and, when that happens, the usual outcome is to compensate for the design’s weaknesses by installing HVAC equipment. In temperate climates, as here shown, this is frequently not required if only the buildings are designed properly. Thus, it should become standard practice to perform this sort of assessment, based on applying the existing tools for building energy certification (or similar) on simplified reference spaces, to assess local potential for passive design, even before any design comes to mind.

Furthermore, by knowing which constructive solutions offer the best chances to explore the site’s potential, the architect can eliminate, right from the start, conceptual designs that will likely not meet the requirements for good thermal performance. Still, within this framework there will be a large number of designs and innovative solutions to explore but always with a higher probability of the final design having a good thermal performance.

Going further, the potential for this sort of analysis can be seen even more broadly, not only from a building design perspective but also from an urban planning perspective or even from a regional regulation (or best practices recommendations) point of view. The analysis is agnostic enough to be generally applicable to a number of locations within a region, where climate and orography are similar, notwithstanding the fact that each building design will still have its specific constraints and that its relationship with its particular site should be carefully analysed within this framework. It can also help better inform urban planners in terms of valuing the buildings’ energy sufficiency potential in a certain area, particularly by keeping in mind the possible orientations of façades, distances and solar obstructions between buildings, etc.

It is too common for regulations and recommendations to be set nationwide (or even at international level as frequently seen within the EU), and this almost always ends up being inadequate in most locations. In fact, either the regulations are too broad to really direct the local practice in any particular direction or, conversely, are too prescriptive or detailed and thus only really appropriate to a minority of the locations. If within a small country such as Portugal, large differences can be found between different design constraints, then these will be even more pronounced between very different climates. While the most recent recast of the European Performance of Buildings Directive (EPBD, 2010) tries to take into consideration the local realities of each country, it does not go far enough and, instead, should aim at promoting clear standard practices within regions that can guarantee that the regulations and construction practices are the best at, first, guaranteeing energy efficiency of the building stock, and then, second, promoting high energy efficiency of the equipment (where needed). This is not expected to be corrected in this year’s second recast. Furthermore, the current designation of nearly zero energy buildings (nZEB), used in the regulation, is not clear enough and does not convey the best message. While it correctly aims at promot-
ing a priority to the reduction of energy needs, followed by high energy efficiency of equipment and, lastly, promoting the use of local renewable energy sources (which seems close enough to the message this paper tries to convey above), the fact is that it is not clearly stated in this way, leaving the definitions of the concept to each of the member states and failing to create a methodological infrastructure that can guarantee a high quality building stock. The work here presented demonstrates that this purpose is easily achievable with the already existing tools and knowledge.

4. Conclusion

Standard building assessment tools are now common in many parts of the world and consist of simple tools and calculation methods with which one can easily estimate the thermal performance of buildings. By using this framework over a simple reference space within a particular location, one can easily run a sensitivity analysis in regards to particularly relevant design parameters and thus constrain them into the best ranges. In the same way a design is constrained by local orography, urban planning and construction rules, it should also be informed by these in order to maximise the local potential for the building’s energy sufficiency and, consequently, act locally towards a better building stock and globally for a lower environmental impact.

While this strategy helps optimising the building design process towards achieving better thermal performance, it can also be used in a broader way in informing local and national authorities and professionals about the local potentials for a better building stock, and helping them think and assess some of the construction and design solutions that are most appropriate to a particular location and climate. Hopefully, this will work on top of the globalization of knowledge, materials and construction technologies, helping adapt alien construction and architectural practices into the local reality and thus avoiding some of the gross mistakes that have been seen far too often all throughout the world.

5. Acknowledgments

Authors gratefully acknowledge the funding of Project NORTE-01-0145-FEDER-000010 – Health, Comfort and Energy in the Built Environment (HEBE), cofinanced by Programa Operacional Regional do Norte (NORTE2020), through Fundo Europeu de Desenvolvimento Regional (FEDER). The second author is grateful for the financial support provided by FCT (Fundação para a Ciência e a Tecnologia), through the doctoral grant SFRH/BD/69487/2010 in the scope of the PhD Program of Sustainable Energy Systems, FEUP – MIT Portugal. Thanks are also due to Architect Francisco Almeida for his inspiring inputs.

6. References


Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.


Santos, H

Housing design for temperate climates: the priority to energy sufficiency

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.