Applied Energy 87 (2010) 661–672

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Thermal performance evaluation of a low-cost housing prototype made with plywood panels in Southern Brazil

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ARTICLE INFO

Article history:
Received 2 April 2009
Received in revised form 23 June 2009
Accepted 27 June 2009
Available online 17 September 2009

Keywords:
Low-cost houses
Building performance evaluation
Thermal comfort

ABSTRACT

Although the Brazilian Federal Government has been increasing investments in the housing sector since 2004, there has been a significant increase in the housing deficit as well. In 2007 this deficit had already reached 7.2 million dwellings. The majority (84%) consists of families with monthly income under three minimum wages. However, none of the traditional lines of credit considers families up to that monthly income level for building their own dwellings. In 2004, a program was created to subsidize low-cost housing (“Programa de Subsídio à Habitação de Interesse Social – PSH”) with a maximum subsidy of about US$ 2500 for the construction of ‘do-it-yourself’ units. The present research had the general purpose of conceiving, constructing and evaluating the performance of a low-cost prototype consisting of wood and plywood panels. The object of analysis in this case study was a building prototype located in Canoinhas, in the South of Brazil (26°10′38″S, altitude 765 m above sea level), which was built within the scope of a program for subsidized low-cost housing. The present paper is concerned with evaluating the thermal performance of the finished prototype by means of onsite measurements and performing computer simulations for testing improvements of the original building prototype. From obtained results, general guidelines were drawn for improving indoor comfort conditions.

1. Introduction

According to the *Ministério das Cidades* [1], in 2007 the Brazilian housing deficit encompassed 7.223 million units. The greatest part of this deficit is located in urban areas and in the northeastern and southeastern regions of the country. Over 10 million units of the existing low-cost dwellings require basic infrastructure and about 84% of the families earn up to three minimum wages (around US$ 750 monthly).

On the other hand, Brazil has a high agricultural and foresting potential. Exotic forests such as *Pinus* ssp. and *Eucalyptus* ssp. adapted well to tropical and subtropical climatic conditions, which characterize the Brazilian territory, mainly due to advanced foresting technologies. Productivity in this field may reach up to 10 times the output of temperate climates [2]. In Brazil, mainly pine and eucalyptus are grown (93% of the harvest). The southern region alone yields around 80% of the harvest.

There is a number of studies on the use of wood-based building systems for the Brazilian low-income population. Publications on the subject refer to: general construction requirements, in some cases through housing cooperatives [3,4]; supply chain analysis in wood production [5–8]; life-cycle-assessment of wood constructions [9]; energy consumption for the fabrication of wood panels in social housing [10], design and construction of wood houses for the low-income population [11–16], and, more specifically, to the wood-frame building system [17–19].

Traditionally, however, one verifies that most of the Brazilian wood constructions were built informally. Contemporary architects avoid building with wood and work rather with conventional masonry (ceramic bricks) in low-cost housing projects. This factor is related, among other factors, to the lack of skilled labor in building with wood.

1.1. Need of performance evaluations in Brazilian social housing

Delivering suitable dwellings to the low-income population in developing countries should include a whole range of issues starting with an adequate building siting, the definition of the building system itself and its construction steps and finally with the evaluation of the finished building (pre- and post-occupancy evaluations). In tropical and subtropical climates, the thermal performance evaluation of low-cost dwellings should be primarily related to the optimization of indoor comfort conditions, usually on free-running buildings. Nevertheless, from the financial point of view, the

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doi:10.1016/j.apenergy.2009.06.038

improvement of thermal comfort conditions in low-cost housing should not result in substantial increases in the final building costs.

There is a strong necessity to redefine new low-cost housing policies in Brazil and throughout the last decades several research projects were primarily concerned with the evaluation of building systems for the low-income sectors of the Brazilian population. Indeed, in several publications and congresses on this matter, the evaluation of low-cost housing projects, apart from technical and constructive considerations, has been taking into account the aspect of improving indoor thermal comfort conditions. Usually low-cost housing projects are implemented throughout Brazil irrespective of bioclimatic considerations. In this sense, a same building system is used in locations with very distinct climatic conditions. To correct such distortions, standards have been developed throughout the last decade within the framework of a Brazilian Thermal Performance Norm, with the aim of promoting more adequate low-cost dwellings, under the aspect of bioclimatic architecture.

One of the first contributions in Brazil with regard to thermal performance evaluations of wood-based building systems consisted of thermal simulations with the NBSLD program of wood shelters in Antarctica [20]. The authors pointed out the difficulties arising from the use of a building material with a good thermal resistance, but which presents a low heat capacity. Giglio [21] simulated wood panels used in wood-frame constructions with the French design tool COMFIE [22], compared results to the recommendations of the Brazilian Thermal Performance Norm [23] and concluded that wood-based building systems may not attend the recommendations of the Brazilian Norm in the Southern region of Brazil, although with improvements those systems may show a good thermal performance. In a comparison between different wood-based building systems in Santa Catarina State, in Southern Brazil, Bogo [24], also taking into consideration the recommendations of the Brazilian Thermal Performance Norm, showed that only 13 out of 24 building systems and partly other two would attend the proposed standards.

The Brazilian Thermal Performance Norm, i.e., the Brazilian standard for residential buildings up to five stories [23] presents an overall list of performance guidelines in order to meet occupant requirements. Within this project, performance guidelines were subdivided into three distinct groups: safety requirements, habitability requirements and sustainability requirements.

Furthermore, the Brazilian norm recommends general procedures for thermal monitoring and thermal simulations, which were followed during measurements and simulations. With regard to thermal performance evaluations, the Brazilian Thermal Performance Norm is divided in three documents:

- Terminology, symbols and units, based on definitions from several documents including the Brazilian norm NBR 12538, ASHRAE Fundamentals, ASHRAE Standard 55/1992 and ISO Standards 7726 and 7730.
- Calculation methods of thermal transmittance, thermal capacity, time-lag and solar gain factor of building elements and components, based on Calculation methods of ISO 6946.
- Brazilian bioclimatic zones and building guidelines for low-cost houses, which consists of guidelines for low-cost housing prototypes on the basis of a division of the Brazilian territory into eight bioclimatic zones, each zone with design guidelines specific of that particular region. For that purpose, Givonís Building Bioclimatic Chart was adapted [25].

This brief literature review on thermal performance evaluations in wood-based building systems in Brazil suggests the need of developing more adequate wood dwellings for the low-income population, which could guarantee comfortable levels. Wood constructions are still regarded as having low quality and as provisory dwellings. In many cases, the lack of interest with regard to wood houses are mostly related: to the unskilled construction of such dwellings; to a common prejudice of clients and civil engineers and architects, who are usually not familiar with wood constructions, in favor of conventional masonry buildings; and to legal restrictions (building codes and fire safety standards impose strict constraints with regard to wood houses). Despite this historical trend, examples of industrialized wood construction are an exception in Brazil, whereas informal wood constructions are the norm.

2. Description of the housing prototype

In 2006, the Southern Brazilian state of Santa Catarina received US$ 23 millions within the low-cost housing program PSH (*Programa de Subsídio à Habitação de Interesse Social)* for subsidizing low-cost dwellings for families with a monthly income up to US$ 420. The state of Santa Catarina then decided to subsidize do-it-yourself housing units. Municipalities would be in charge of providing the residential lots, supervising and assuming technical responsibilities for the construction of the housing units. The state has a long tradition in wood construction and is the second greatest Brazilian producer of pine forests. In association with the local housing cooperative (*Companhia Habitacional – COHAB*), the state determined the choice of pre-fabricated wood housing units for meeting the demand for low-cost dwellings. Thus, entrepreneurs linked to the Brazilian Association of Mechanically Processed Wood Industry (*Associação Brasileira da Indústria de Madeira Processada Mecanicamente – ABIMCI*) sponsored the construction of two housing prototypes, one built with massive wood boards, located in Lajes, Santa Catarina, and a second one built in Canoinhas, Santa Catarina, which resulted from the present research. The construction of such prototypes usually has commercial objectives (show house). In the case of the prototype in Canoinhas, one of the goals was to present a low-cost housing type of easy assembly for the low-income population, which could be built with unskilled labor within a self-help process.

The present paper presents the thermal performance analysis of the wood prototype, which was designed by one of the authors and built in Canoinhas, consisting of self-sustained wood panels in small dimensions, fabricated with plywood and reforestation wood. The research as a whole encompassed four stages: design and construction of the building prototype; monitoring of the quality of the building process; thermal and acoustic performance evaluation and simulations of the prototype's thermal performance for other climate types in the southern region of Brazil.

The prototype consists of small sized reforestation wood elements and double wall panels composed of plywood. A floor plan, commonly adopted in ceramic masonry units was used in the wood prototype. The basic plan was adapted to modules of 122 cm × 244 cm. Built area corresponds to 48.93 m^2. The roofing system consists of a pinewood structure covered by fiber cement tiles and a pinewood ceiling. The double walls also have a pinewood structure. Internal plywood panels have a wall thickness of 9 mm and external (façade) panels of 12 mm, which yields a wall thermal transmittance (U-value) of 2.17 $W\,m^{-2}\,K^{-1}$. Fig. 1 shows the prototype's floor plan.

The monitoring of the building process consisted of the management of building materials and the supervision of assembly steps. The purpose of the post-occupancy evaluation was to evaluate the thermal and acoustic performance of the building system as a whole. In this paper we focus on the thermal performance analysis.

3. Materials and methods

Subsequent to the construction of the prototype, habitability requirements have been evaluated. In the broader research, this