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Potential of attached sunspaces in winter season comparing different technological choices in Central and Southern Europe

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ABSTRACT

The present study focuses on the potential applicability of attached sunspaces in Southern and Central Europe (winter season). Sunspace is a diffuse passive solution which reduces winter thermal losses and increases solar gains. This article analyses the geo-climatic applicability of this technology following a two-step study: 1) a climate based pre-evaluation of sunspace potential for 50 selected locations representing different climatic situations; 2) a calculation of sunspace potential in reducing energy consumption for heating using energy dynamic simulations on a sample building by comparing different technological choices.

Step 1 examines heating demand (Heating Degree Days - HDD) and total solar radiation on a horizontal plane for each location. HDD was assumed as an indicator of the heating demand at different base temperatures ($20 \pm 2\,^{\circ}$C), while total winter solar radiation is considered as a general indicator of the "virtual" heating potential of attached sunspaces. Both calculations are based on a typical meteorological year (TMY). Step 2 is based on energy dynamic simulations of a sample building in order to analyse heating energy reduction caused by an attached sunspace on a monthly basis. Different technological choices were taken into account for both sunspaces and building envelopes in order to identify the best local solutions for passive heating as regards energy consumption in a set of 50 selected locations. Considerations and potential maps are reported to help designers optimise the applicability of sunspaces according to local climatic conditions and building technologies. Finally, the summer performances and the potential cooling demand reduction by shading and natural ventilation of sunspaces are analysed.

1. Introduction

The use of sunspaces in building design to reduce winter energy consumption is a strategy that has been widely employed since the 70 s and is included in standards, building codes and incentivizing policies. Several national and local energy codes report methodologies for estimating the functioning of such systems in new and existing buildings [1,2], while research on new and more suitable models is continuing [3–6]. Nevertheless, the greenhouse effect to heat an environment –especially for plant/tree cultivation- has been commonly used since Roman times, for example by covering specific spaces with mica sheets [7,8]. Several pioneering examples and applications of sunspaces for the specific aim of reducing heating demand in buildings have been and monitored in Europe and around the world in conjunction with the spread of an environmentally-friendly culture in design since the 1st oil crises [e.g. 9]. In Italy, for example, there was the great European demonstration project U.P.S.E. (1979–1983) co-funded by the CER, the Ministry of public works and the Piedmont Union of Building Developers (UPSE), which dealt with the construction and a long-term survey of 17 solar-heated buildings in the Piedmont Region (for a total of 500 solar-heated dwellings) [10–13].

Recent research on sunspace analyses have been developed for several different countries and building typologies. For example, Owrak et al. [4] analysed, through both experiment and simulation, the performance of a room, built in Karaj (Iran), which was heated by an attached sunspace with heat storage by using EnergyPlus software. Chen and Shi [14] analysed the indoor thermal environment when attached sunspaces are used in rural residential buildings in China. Furthermore, thermal analyses and cost optimization for a sunspace located in Northern Greece were conducted by Bakos and Tsagas [15]. Aelenei et al. [16] studied different sun-

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Nomenclature

SHP	Sunspace heating potential
TMY	Typical meteorological year
HDD	Heating degree day
CDH	Cooling degree hours

spaces for residential building retrofitting in six cities in Portugal. Bataineh and Fayez [17] presented a study on the thermal performance of an attached sunspace in Amman (Jordan) by considering six different configurations, orientations and overheating prevention methods. Ignjatović et al. [18] analysed the application of sunspaces in reducing energy demand in residential buildings in Serbia and also studied some economic aspects.

A sensitivity analysis of sunspace potential in energy conservation, linked with overheating phenomena and buried pipes, was developed by Mihalakakou and Ferrante [19] by using TRNSYS in four European cities. The study continued with the Mihalakakou's paper [20], in which the same four cities were analysed to study the relationship between climate and sunspace during both winter and summer by comparing different technologies that prevent overheating.

The present paper compares, by using EnergyPlus energy dynamic simulations on a sample building, the potential effectiveness of a sunspace in reducing an apartment's sensible heat demand when different technological definitions of the building and of the sunspace envelope are considered.

The research focuses on a methodology for assessing sunspace feasibility in different Southern and Central European locations according to local climates and different technological choices. Even if, as mentioned above, other researches have analysed the potentiality of sunspaces in specific locations, this paper introduces a potentiality map based on a large set of locations (50) which takes into consideration, after a pre-evaluation step, based on climatic variables, the results from energy dynamic simulations on a sample case study while varying the technological definition of the sunspace and of the building envelope. These analyses were used to represent the territorial distribution of the expected Sunspace Heating Potential (SHP) according to different technological choices. Furthermore, the summer potential over-cooling demand due to sunspace is analysed by comparing different technological passive solutions as shading systems and natural ventilation. The aim is to help designers and administrators to analyse, from the early design phases, if sunspaces can represent a good solution to reduce energy consumption, by also comparing them with different insulation levels of the envelope of the related building. Other studies on climatic potential are reported in [21–23].

2. Territorial climate analysis

Before introducing simulations on a reference building, a climatic analysis was carried out. This first step focused on the elaboration of climatic data to analyse the geographical distribution of variables related to the "virtual" applicability and potential of an attached sunspace in southern and central Europe. For this reason, 50 locations were selected as being a representative sample of different climatic conditions in Southern Europe. Each location was characterized by its specific Typical hourly Meteorological Year (TMY) taken from the EnergyPlus database, which is the same database used in further simulations. Hence, this step is also useful to define the climatic boundary conditions of simulation results.

Firstly, a climatic subdivision of each location was carried out by using the well-known Köppen-Geiger classification [24]; secondly, two parameters were assumed as indicators to assess the applicability of sunspaces in each location, before any building definition was carried out: local heating demand and average solar radiation on a horizontal plane. The first helps to define the amount and the intensity of "virtual" heating demand, while the second is an indicator of potential solar gain intensity.

Table 1
Köppen-Geiger classes identified in Section 2.

Climate class	Climate name	Notes
BSk	*Cold Steppe*	*Semi-arid dry climate – annual precipitation in the range 50–100% of the threshold. At least one month average temperature is below 0 °C*
Cfa	*Temperate climate*	*Hot summer and cool quite temperate winter*
Cfb	*Maritime temperate*	*Warm summer and quite temperate winter*
Csa	*Mediterranean Climate*	*Mediterranean climate with dry hot summer*
Csb	*Mediterranean Climate*	*Mediterranean climate with dry warm summer*
Dfa	*Hot summer continental*	*Continental climate with humid hot summer*
Dfb	*Warm summer continental*	*Continental climate with humid warm summer and cold winter*

A list of the chosen locations is reported in Appendix A in Table A1 together with their related Köppen-Geiger climate classification (see definitions in Table 1). Köppen-Geiger classes here reported refer to the TMYs used (Design Builder weather indications) and can differ from other sources [25]. Izmir, Turkey, for example is here classified as Cfa (Temperate climate), while in Ref. [25] its climate is Csa (Mediterranean climate). However the heating degree days (HDD) of these two climate classes are comparable as underlined in Fig. 1(a). Seven different climates are covered by this analysis, even if most of the locations refer to only three classes (Cfa, Cfb and Dfb) which are most representative of Central and Southern Europe according to the climatic database taken into account. In the pie chart of Fig. 1(b), the entire set of locations is subdivided according to relative climate classes.

Local heating demand is calculated by using the Heating Degree Days (HDD) index and varying the base temperature in the following domain {18; 20; 22}. This analysis is presented in § 2.1. Total hourly solar radiation is calculated over an extended winter period (1st October – 30th April) and on a yearly basis while considering both the entire period and only those hours when heating is required. The results are presented in § 2.2.

2.1. Heating degree day calculation

For each selected location, HDD was calculated according to the standard UNI EN ISO 15927-6:2008 [26] by using different base temperatures (ϑ_b) and varying the "virtual" indoor comfort temperature set to 20 °C around a ±2 °C range. This choice was justified in order to further compare the heating degrees with the simulation results, even if for other purposes different base temperatures can be assumed by considering the real or hypothetic support given by internal and solar gains, e.g. 18.3 °C – 65 °F [27], 15.5 [28], or 12 °C [26]. Therefore, three HDDs (HDD_{20}; HDD_{18}; HDD_{22}) were calculated using the following equation:

$$HDD_{set.temp} = \left[\Sigma_{h=1}^{n} \Delta\vartheta_h \left(set_{temp.}\right)\right]/24 \quad (1)$$

Where:

if $\vartheta_h < set_{temp.}$ then $\Delta\vartheta_h(set_{temp.}) = (set_{temp.} - \vartheta_h)$ else $\Delta\vartheta_h(set_{temp.}) = 0$

$set_{temp.}$ = chosen base temperature {18 °C; 20 °C; 22 °C}

n = period of the heating season.