ENERGY BALANCES OF FOUR OFFICE BUILDINGS IN DIFFERENT LOCATIONS IN SPAIN

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ABSTRACT

Southern European climates are characterised by a combination of heating and cooling needs. Under those conditions the building designer must combine and optimize the natural conditioning techniques for heating and cooling in order to reduce the global energy demand. Once the passive techniques have been implemented, active renewable energy systems must be included. In Southern Europe climates solar cooling is a good tool to achieve a high efficiency level.

This kind of combined solutions must be optimized to be able to reduce the greenhouse gases emissions to the atmosphere. To perform this operation, simulation techniques become an imprescindible tool. In this work, the complete process of the design and analysis of four different office buildings located all over Spain is presented.

INTRODUCTION

In order to lesser the greenhouse gases emissions to the atmosphere in Southern Europe, more efficient buildings must be designed. To achieve this goal the first aim is to design the building as the lowest demanding one as possible in a passive way. Then supply all the demand by active renewable systems, integrated in the building itself. That must be done with special attention in Typical Southern Europe climates, where the cooling demand is very significant. Solutions for heating must be combined and optimized with the cooling ones. Active technologies such as solar absorption cooling are a promising way of integrating solar thermal energy in the buildings sector.

In this context, the Spanish Ministry of Science and Innovation is promoting a Singular Strategic Project of Research and Development, PSE-ARFRISOL (Bioclimatic Architecture and Solar Cooling, in Spanish). This project plans to demonstrate that is possible to save up to 60% office building energy demand by means of solar passive techniques and reduce the conventional energy consumption with active solar devices: solar thermal collectors for heating and cooling and photovoltaic panels for electricity. For this purpose, five office buildings are to be built or restored in different climatic zones of Spain.

These buildings are being used as research prototypes to implement and analyze different bioclimatic strategies as well as the integration of renewable energies. With this aim, many theoretical and experimental evaluations of the buildings are being performed. This paper focuses on the methodology used for the theoretical analysis during the first stage of the project.

The knowledge of the weather conditions in the form of a Typical Meteorological Year for every location has been used to identify the most favourable passive techniques. Secondly, these strategies have been included in the design, optimizing the constructive parameters in order to reduce the cooling and heating demands. The simulation of the solar heating and cooling systems coupled with the building loads has allowed calculating the achievable solar fraction. Global energy balances by differentiating which percentage comes from passive techniques and what comes from solar installations are presented for each building.

All the theoretical analyses have been performed with the dynamic simulation tool TRNSYS 16. The simulations include the building with all their bioclimatic strategies, all the components of the solar heating and cooling systems, and the coupling between them. New models for special elements such as absorption pumps or solar chimneys have been created.

METHODOLOGY

In this project, the building and the systems design has been set an interaction between the energy analyst and the building designer, in an iterative process to get the best achievable solution for the four cases presented. First of all, a climate study is perfomed for every location. Typical Meteorological Years are obtained for every location, provided by the Spanish National Meteorological Agency. The closest station to every place is chosen and, since they are real data, no modification is done to take into account differences due to the distance to the station.

Once the data are collected, they are represented over a Givoni chart, which suggest some strategies to implement. This is a key step, since the Givoni chart gives a good idea of how a building should be in order to have the most positive reaction to the external conditions. At that stage, the building designer must full fill the rest of the buildings needs attending, for example, to the use specifications or aesthetical questions. The main actors at that stage are the building designer and the final owner of the building. The output of this phase is a basic design to be simulated and optimized by the energy analysts.

The previous basic design is introduced in the simulation software and batteries of simulations are run. Those simulations are used to evaluate the passive behaviour of the building and to calculate the effect of possible modifications. Also at this stage the coupling between the active solar systems and the passive behaviour is evaluated. Many of them, for example solar collectors, play a double role: as an active system (to collect the solar energy needed) and a passive one (acting as a shadowing of a part of the building).

This stage's work must be understood as a closed loop between the building designer and the energy analyst. This phase extents until the final solution is obtained, that is the one which full fills all the requirements of the project, at a reasonable cost and with the minimum greenhouse gases emissions. The output of this stage is the final version of the building, to be constructed.

Since this buildings form part of an R&D project, all the buildings will be fully monitorized, not only to certificate experimentally the energy savings, but to study aspects of the simulations which could be improved.

BUILDING DESCRIPTION

The four buildings selected for this study are located in different locations, spread all over Spain and covering the most representative climates of the nation: continental (Madrid), desertic (Almería), oceanic (Asturias) and extreme continental (Soria). Are office buildings comprised between 1000 and 2000 m^2 of surface. All of them implement office rooms and special ones such as conference rooms or laboratories. Two of them (Almería and Asturias ones) are new constructions, with few restrictions in orientation and design. The one located in Madrid is the ampliation of an existing building, so orientation and openings distribution in façade are fixed by law. Finally, the building located at Soria is a Refurbishment.

Each building implements different bioclimatic strategies according to the climate of the zone where it is located. All the building have flat plate solar thermal collector used for Domestic Hot Water production and for heating and cooling. During the summer, the heat collected by that system is used to feed absorption pumps to produce solar cooling. Among the benefits of solar cooling in Southern Europe climates are the uncoupling of the cooling load from the power grid, the use of a renewable and CO_2 emission-free energy source and the possibility of strengthen the surface of the solar thermal field avoiding the risk of overheating in summer (since the heat produced is employed in the production of solar cooling). Despite the priority of the renewable active systems is focused on the thermal field, all the buildings implement PV modules for electrical production, integrated also as passive systems. In the locations of Soria and Asturias, due to the principal characteristics of their climates (very low radiation in Asturias and extreme conditions at Soria) biomass burners have been installed in order to guarantee thermal comfort inside the building.

Figure 1. South façade view of the ED70 building, located at Madrid

All the buildings implement the same control system and are fully monitorized in order to evaluate experimentally the savings in energy produced by these systems. Tables 1, 2 and 3 resume general information of the buildings and Figures 1 to 4 show pictures taken from the south façade.

	ED70	PSA	BARREDO	CEDER
Location	Madrid	Almería	Asturias	Soria
Latitude	40º N	37º N	43º N	41º N
Climate	Continental	Desertic	Oceanic	Extreme continental
Total surface	2047 m^2	1114 m^2	1405 m^2	1088 m^2
Stories	3 + basement	1	3	2
Construction	Ampliation of an existing building	New	New	Refurbishment

Table 1. General characteristics of the buildings selected for the study

ED70	PSA	BARREDO	CEDER
Ventilated façade in all orientations	High inertial mass and insulation level in exterior walls	Roof fans and controlled-opening of windows for cross ventilation	Roof fans and controlled-opening of windows for cross ventilation
Improvement of insulation in exterior Walls	Big openings facing south and small openings facing north	Differential façade insulation according to orientation	Differential insulation treatment of façades according to orientation
Differential treatment of window glassing according to orientation	Shading porch at south façade	Strengthen solar gains by glass covered spaces and green houses (heat recovery to office rooms in winter time and ventilation in summer time)	Increase of inertia by new composite materials (grc)
Shading of south windows	Double glazing's and thermal bridge breaking	Narrow floor to promote natural cross ventilation	Strengthen solar gains by glass covered spaces (heat recovery to office rooms in winter time and ventilation in summer time)
Shading of roof	Natural ventilation induced by solar chimneys	Ventilated shadowed roofs	Cross ventilation coupled to evaporative systems
	100 m^2 north facing collectors without glass covers: radiant cooling at night time	Horizontal shadowing slats on south, west and east orientations	Horizontal shadowing slats south, west and east orientations
	Summer shading of roof		126 m^2 of radioconvective cooling system in the north cover of the building

Table 2 Passive systems implemented in the buildings selected for the study

ED70	PSA	BARREDO	CEDER
Solar cooling. 4 climatewell 20 kW machines connected to cooling tower	Solar cooling. 4 climatewell 20 kW machines connected to cooling tower	Solar cooling. 5 climatewell 20 kW machines connected to geothermal horizontal dissipation	Solar cooling. 5 climatewell 20 kW machines connected to geothermal vertical dissipation
180 m^2 of tim flat plate solar collectors (also as a shading roof) with 4 m3 water storage	180 m^2 of tim flat plate solar collectors	88 m^2 of flat plate solar collectors with 2 m^3 water storage	126 m^2 of flat plate solar collectors with 3 m^3 water storage
Semitransparent PV panels (5'7 kWp) used also as shadowing for south façade openings	Semitransparent PV panels (8'1 kWp) used also as shadowing for south façade openings	PV modules (4'1 kWp) integrated in south gallery	PV modules (7'5 kWp) integrated in parking shadowing
Air-air climatization. Four-pipe installation connected to ATU's and inductors for distribution	Buried pipes for air treatment	120 kw biomass burner	148 kW biomass burner
Intelligent indoors illumination system	Air-air and radiant floor climatization. Two-pipe installation connected to ATU's and inductors only for cooling	Air-air and radiant floor (for heating and cooling) climatization. Two-pipe installation connected to individual systems	Air-air and radiant floor Conditioning. Four-pipe installation connected to individual systems. Radiant floor used for heating and cooling.
	Intelligent indoors illumination system		

Table 3. Active renewable systems and climatization of the buildings selected for the study

Figure 2. Aerial view of the PSA Building, located at Almería

SIMULATION DESCRIPTION

The simulations of the four buildings have been performed with the dynamic simulation tool TRNSYS 16, following the same scheme. The meteorological data available for every localization is read in a generic form (Type 9) and completed, when is needed, with radiation processors (Type 16), sky temperature (Type 69) or psychometric calculations (Type 33) to feed the building and the systems (passive and active) implemented in each case.

Each building has been implemented by means of Type 56. The first step in this methodology comes from the very first design of the architect to be optimized under the following general assumptions:

- Each room is considered as a thermal zone in the model.
- The ground is considered at a constant temperature equal to the average of the annual ambient air temperature.
- The internal occupancy and the power equipment have been set equal to the nominal occupancy and equipment considerations of the project, modulated by a schedule. This schedule supposes 100% occupancy from 8am to 5pm from Monday to Friday and 0% otherwise.

Figure 3. View of Barredo building, located at Asturias

- Lighting systems values are given by the project and are modulated with two schedules: one for winter and one for summer. Summer is considered from the 1st of April until 30th of September, and the lighting power is only 20% of the nominal to take into account natural lighting. Winter is considered from the 1st of October to the 30th of March. Since in winter there are less sun hours, it is considered 80% of the lighting power during the first two hours and the last one of the occupancy time.
- For the external convection coefficient of the building walls, instead of a constant value the following correlation has been used: hc = 2'8 + 3'2v, where v is the external wind speed [Incropera, 1985].
- The infiltration rate is set to 1 ren/h. It is a value acceptable but slightly high for a new construction (0'6 from ASHRAE, 1997). This parameter is chosen in this way to take into account the worst situation.
- Set temperatures for conditioning system are 20ºC for heating and 26ºC for cooling.
- The heating system is considered only during the occupancy time for winter (1st October - 30th April). The cooling system is considered also only during the occupancy time for summer (1st May - 30th September).

For the different bioclimatic systems the following approach has been used:

- Shadowings are modelled by means of Type 34.
- Shadows produced by external obstacles (other buildings) and other parts of the building itself are implemented by means of Type 68.
- Solar Chimneys for night ventilation in summer are modelled by a ventilation rate of 1'4 ren/h from 0 to 7 am with external air temperature. This value is chosen from studies performed at a scale model at CIEMAT installations [Marti et al, 2006].
- Direct Evaporative systems are implemented in a new Type taking into account the energy and mass balances produces in the process [Liao et al, 2002].
- Air-earth exchangers are evaluated through Type 556 from the Tess libraries.
- Radiative cooling systems have been implemented in a new Type [Errell el al, 2000].

Figure 4. View of CEDER building, located at Almería

Once all the passive systems have been implemented (when proceed), two simulations are performed to calculate the buildings energy demand: one for heating and one for cooling. Those simulations are run forcing the indoors temperature to be equal to the set point (20º C for heating and 26º C for cooling) in order to calculate the energy needed to maintain that situation every hour of the year.

To analyse the energy performance of the solar heating and cooling systems a new simulation project has been created. This incorporates the building loads, the solar thermal collector field and the absorption system.

- The integration of the precalculated building loads into the model has been done using a model of a fluid pipe that allows to injecting or extracting heat into the fluid flow when cooling or heating the building.
- Types of the standard and TESS library have been used to model all the components of the system including: solar collector field, heat exchangers, the storage tank, hydronics and controllers.
- The absorption systems are based on the heat pump CW10 (Climatewell). A new simulation model in TRNSYS to characterise each unit has been created. The model contains an internal variable that represents the energy level (accumulated in crystallized salts).
- Additionally, to optimize the performance of a system composed by any number of CW units, a model that rules the charging and discharging sequences has been developed.

Once each of the solar absorption systems have been fully defined for each building, two simulations have been done: one for heating and one for cooling. The results allow to obtaining the solar contribution of the system to the building demands.

RESULTS

The summarized results for the energy demand of the five buildings and the performance of the solar system can be seen in Table 4. The following data are provided for each building: heating and cooling demand per year and meter square, occupancy, total conditioned surface, total surface of the solar thermal field, collector efficiency curves, storage capacity and number of absorption pumps (CW). Finally, the installation seasonal performance and the solar fraction achieved are given.

	ED70		PSA		BARREDO		CEDER	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Buildings demand (kWh/m2 año)	8.33	35.23	13.40	23.04	17.34	14.60	42.21	13.07
Occupancy (people)	58		49		98		19	
Buildings Surface (m2)	404		494		549		619	
Solar Thermal field surface (m2)	189		180		88		126	
Collector efficiency	0.82/3.97	0.82/3.97	0.7/3.1	0.7/3.1	0.82/3.97	0.82/3.97	0.82/3.7	0.82/3.97
Storage (L)	4000		N/A		2000		3000	
Number of absorption pumps	4		4		5		5	
Installation Seasonal performance	0.10	0.23	0.37	0.61	0.13	0.15	0.65	0.18
Solar fraction	0.99	0.85	0.88	0.89	0.32	0.62	0.44	0.97

Table 4. Summary of the results of the simulations for the selected buildings.

The Spanish Government through its Industry Ministry offers official data of energy consumption in several locations and different types of buildings (single house, residential blocks and office buildings). That document (*E4 Document*) contains the Spanish Strategy for Energy Saving and Efficiency (2004-2012). It provides real data of final energy consumption for heating and cooling, for the locations of Sevilla, Madrid and Burgos.

These data have been used as reference values to evaluate the energy savings achieved in each building of this study due to bioclimatic strategies, called in this work bioclimatic fraction.

In order to make a reasonable comparison, only the office rooms of each building are selected to evaluate the energy demand. Since only three locations are provided in E4 Document, the ED70 building is compared to the Madrid data, the PSA building to the Sevilla data, the Soria building to the Burgos data and the Asturias building is compared to Madrid for heating and Burgos for cooling.

Savings due to bioclimatic strategies (bioclimatic fraction) have been calculated comparing the final building demands resulting of the simulations, to the reference values of energy demands in office buildings of the E4 document.

Once the bioclimatic fraction has been calculated, the solar fraction is applied to know which percentage of energy is still to be covered with other sources. It is convenient to remember at this point that the Asturias and Soria buildings employ biomass to supply the rest of the energy, so they are 100% renewable.

Table 5 and Figure 5 show the global energy balances by differentiating which percentage comes from passive techniques and what comes from solar installations. It can be seen that the combination of passive and active solar energy strategies allow to achieving savings near 80% of energy. If combined with biomass, the buildings become totally renewable.

These buildings are fully monitorized in order to check experimentally the validity of the approach.

	ED70	PSA	BARREDO	CEDER
Bioclimatic fraction (%)	51.13	62.00	52.75	49.22
Solar Active fraction (%)	42.85	33.68	33.22	29.98
Other sources/biomass (%)	6.02	4.32	14.03	20.81
TOTAL SOLAR SAVINGS (%)	93.98	95.68	85.97	79.19

Table 5. Energy savings of each building referred to the Official measurements

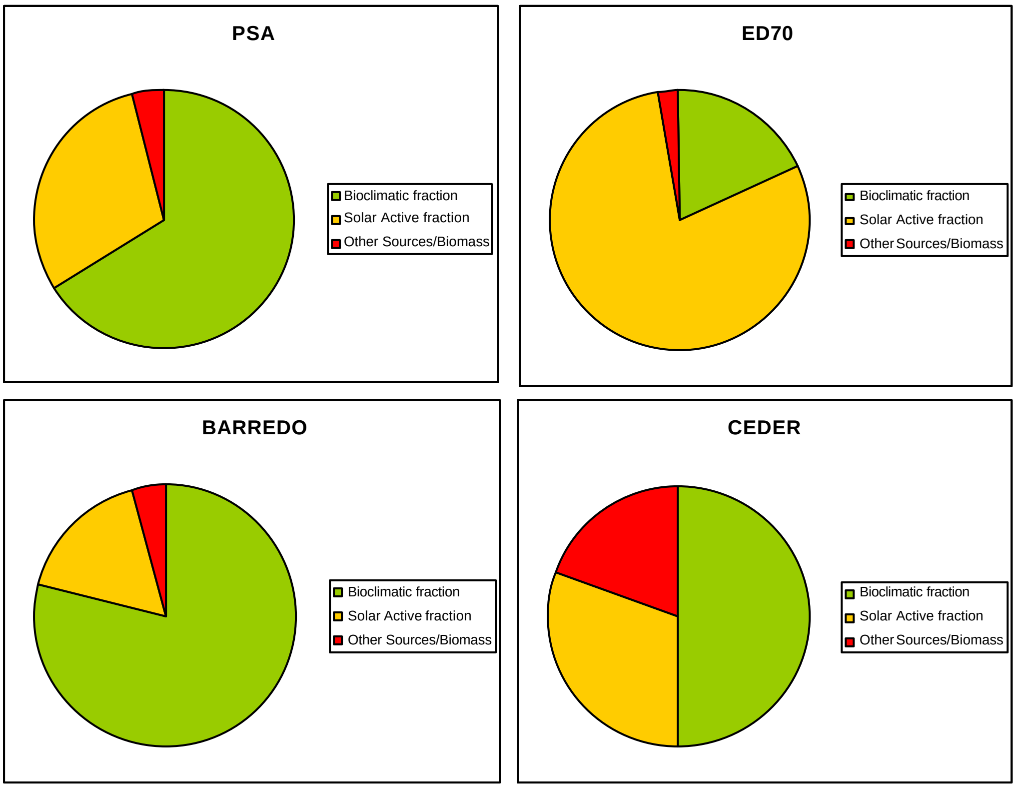

Figure 5. Energy savings of each building of the study

CONCLUSIONS

It is shown that, in principle, is possible to construct very energy efficient buildings in typical Southern Europe climates, where cooling is a big issue.

The coupled simulation of the active and passive solar systems is a necessary tool to optimize the design of an efficient building. It is also a good tool to develop control algorithms to couple active and passive systems.

The combination of active and passive solar systems in Southern European climates can produce savings in the energy demand of at least an 80% of the actual energy consumptions.

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