INSULATION AND SOLAR CONTROL IN ISLAND SERVICE BUILDINGS

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Abstract. *The study of a hotel to be built under the mild climate of Madeira Island, Portugal, is presented. The program DOE-2.1E was used for the thermal load simulation, using as climatic input a Typical Year file constructed for this case. The simulation for the base building showed low heating loads and high cooling loads, of which a very important fraction derives from solar gains. Changes in the building envelope were then considered, and it was found that controlling solar gains by means of shading and adequate glazing can strongly reduce the cooling loads although slightly increasing the heating loads. On the other hand, the increase of the thermal insulation of walls is not advisable as it increases the cooling loads while the reduction on heating loads is of little importance. In fact, the exterior walls help release the heat stored in the mass inertia construction during the day, especially from solar gains, and this effect is reduced when greater insulation is applied. As a result, care should be taken during the building conception or when making thermal regulations for buildings since using high thermal insulation of exterior surfaces is not a good practice for all types of climates.*

Keywords: *thermal insulation, solar gains, thermal loads, glazing, DOE-2.1E*

1. INTRODUCTION

High thermal insulation of exterior surfaces is usually considered a good practice in buildings. This idea is highly supported by northern countries experience as well as Mediterranean climates, where applying strong thermal insulation helps both increase thermal comfort at a lower energy demand and reduce the risk of building pathologies derived from condensation. Care should be taken, however, not to wrongly generalise such assumptions, as the local climate plays an important role in determining the more suited strategy to reduce HVAC energy consumption.

The thermal analysis performed during the conception of a Hotel to be built in Madeira Island shows that the large use of insulation is not advisable in this case. As a result, limitations of the Portuguese thermal regulation for buildings are also discussed.

2. DESCRIPTION OF THE CASE STUDIED

The Hotel will be built in eastern end of Madeira Island. This Island is located in the Atlantic Ocean, latitude 30 ºN, about 800 km from the closest continental land. The climate at construction site is mild: typically oceanic with reduced thermal range between warmer and cooler month (about 8ºC), average temperature around 18ºC, average relative humidity around 73% and low precipitation amount (under 800 mm/year) and can be classified as coastal Mediterranean.

The hotel is a 7 storey building, located at sea level and very close to the shore, in a south facing bay. It includes the hotel area (rooms and services) and a Marine area (services). The building has very large fenestration (approximately all of the south surfaces and most of the east surfaces are windows, some of them partially shaded by balconies from the floors above) and important underground surfaces at north, as it is partially buried into a hill.

2.1 Simulation Model

The original model constructed for the simulations considers the geometry and construction characteristics supplied by the architect's team. It also considers the space conditions (desirable temperatures and the expected occupation, lighting and equipment loads, air changes, etc.) for the various zones. Total area of construction is 19032 m^2 and total area of conditioned spaces is 11662 m^2. Figure 1 shows an image representing the model.

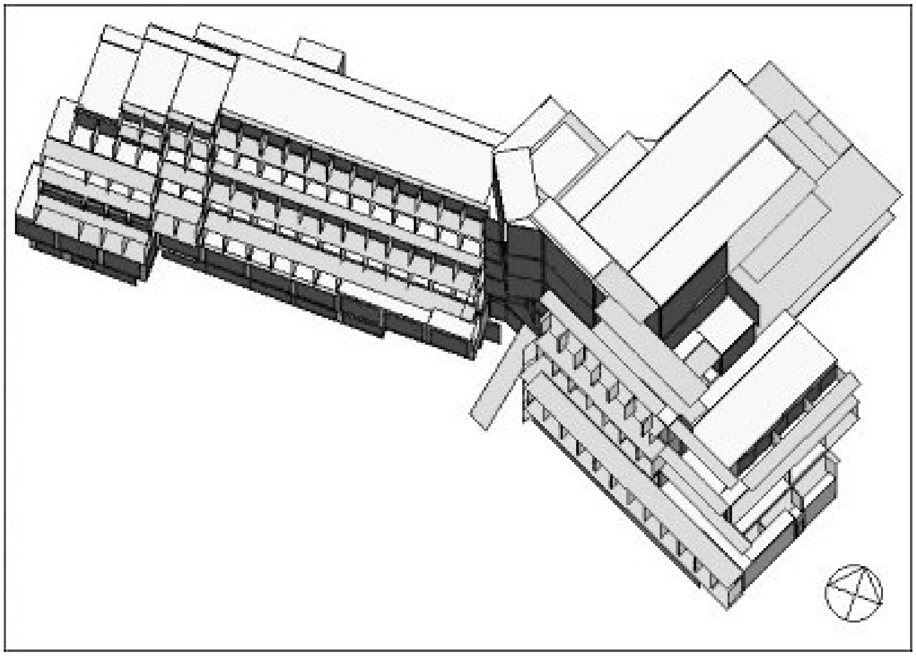

Figure 1- South-East view of the Hotel building - model

2.1.1 Building materials

The materials' definition in the architectural project is listed below. The description of the building element starts with the outside layer, unless otherwise stated. :
. Exterior Wall: double wall with expanded polystyrene insulation: 2 cm plaster, 7 cm hollow brick, 2.5 cm insulation, 11 cm hollow brick, 1 cm plaster. K = 0.71 W/m2ºC
. Interior Wall: 17 cm hollow brick with 1.5 cm plaster on both faces; K = 1.3 W/m2ºC
. Interior boundary Wall: 19 cm perforated brick with 1.5 cm plaster on both faces; K = 1.1 W/m2ºC
. Internal wall: identical to the interior wall, with 200 kg/m2 weight (used to simulate zone's thermal inertia).
. Interior floors: 25 cm current concrete plus 10 cm light concrete, with plaster on the lower face, K = 1.5 W/m2ºC.
. Roofs: 2.5 cm limestone, 2.5 cm bond, 4 cm expanded polystyrene insulation, 25 cm concrete and plaster or stucco on the lower face, K = 0.572 W/m2ºC.
. Underground walls and floors are described by a linear thermal conductance of k = 1 W/mºC and the dimension used on the definition of such surfaces is the perimeter exposed to unconditioned environments as proposed by ASHRAE.

The glazed surfaces considered were double, clear, 3+3 mm width with a 12.7 mm air gap, k = 2.79 W/m2ºC, SC = 0.89, visible transmission of 0.81, total solar transmission of 0.7 .

2.1.2 Space conditions

The space conditions were imposed for conditioned areas such as rooms, social areas (restaurant, lobby, etc.) and for unconditioned areas (kitchen, laundry, parking, etc.). Lighting, equipment and occupancy rates and schedules were taken from regulation and literature. For the conditioned spaces, temperature was fixed at 22 ºC. 1 air change per hour was allowed except in high occupation areas like auditorium, restaurant, gymnasium and cloak-room.

2.2 Results for the initial proposal

The estimate thermal loads for the building (Hotel and Marina), summed up for all the conditioned spaces, are given in Table1.

Table 1. Thermal loads for building, initial proposal

	Heating	**Cooling**		
		total	Sensible	Latent
load (MWh/year)	150.8	2200.6	1359.3	841.3
peak load (kW)	527.1	736.2	559.1	177.1
peak load: W/m2 of conditioned area	45.2	63.1	47.9	15. 2

The values show the importance of cooling, with a significant part (38%) of latent cooling. The cooling peak load is also greater than the heating peak load, but the difference is not as large as in the annual loads. Cooling loads (e.g. heat gains) are important, even during the colder months, as seen in Figure 2 where the monthly load distribution is presented.

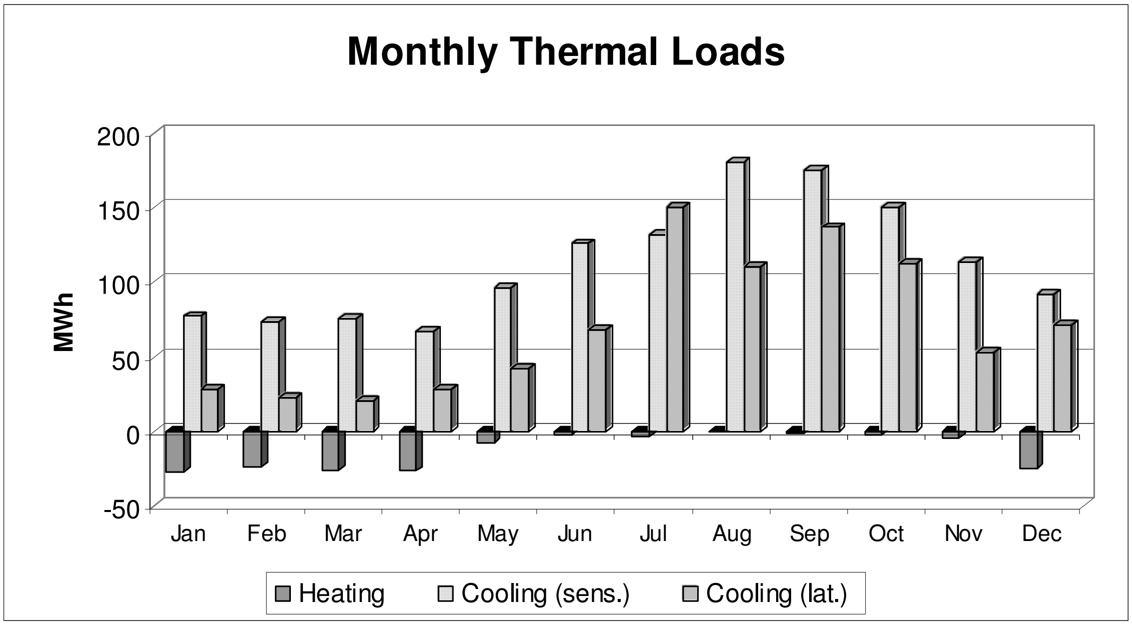

Figure 2- Monthly distribution of heating and cooling loads

Heating condition takes place when the overall load is negative, meaning that the space is loosing heat, while cooling condition refers to the opposite situation. Figure 3 represents the annual sum of heating and cooling for each type of load, the sums being calculated separately for the overall cooling situation and heating situation. The internal loads, imposed by the space conditions, increase the cooling needs, but decrease the heating ones, since they are always positive. The exterior surfaces conduction loads are not very important, both because the insulation of the walls and roofs is good but especially because the difference between the internal and external temperatures is reduced. Comparatively, the interior partitions conduction cooling load is much higher, because it relates to conduction gains from the ventilated technical areas, where the temperatures are higher. The latent cooling loads due to infiltration are large, since the high atmospheric humidity characteristic of the local climate. The overall negative value of sensible cooling due to infiltration shows that the mild climate contributes to cool down the spaces, heated by internal loads and solar gains. The solar gains are responsible for much of the cooling sensible load. This is the only important source that refers directly to the characteristics of the building’s construction, as the internal loads (occupation, lighting, and equipment) refer to the use of the building.

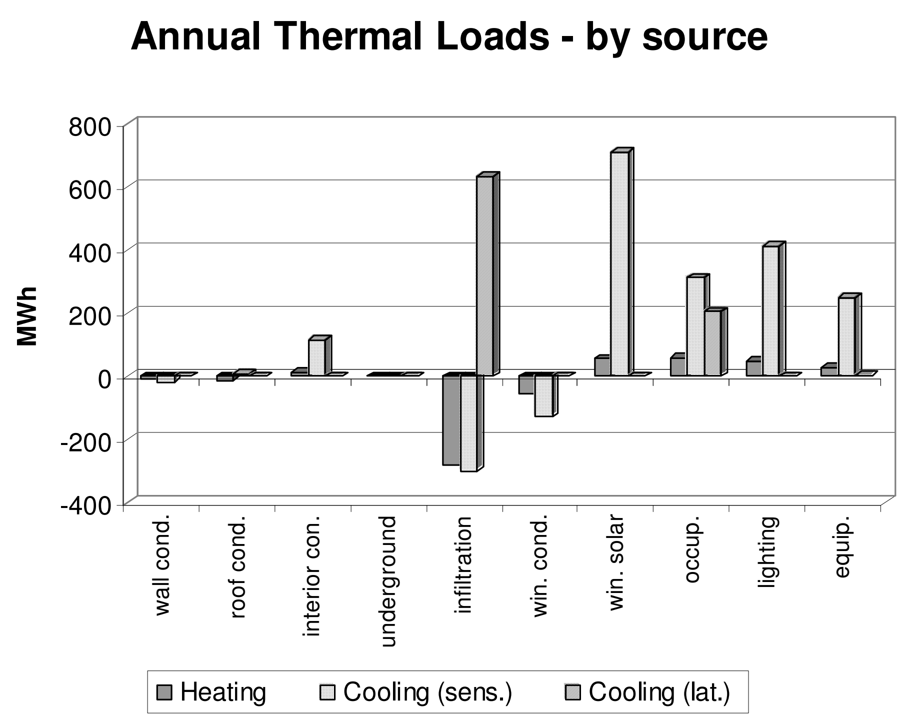

Figure 3- Annual thermal loads, by source

3. CHANGES TO ANALYSE

Changes to the initial building envelope were considered. They correspond to the following cases:

Case 1: insulation increased to 5.5 cm of the roof (total area 6443 m^2), resulting in a global heat transfer coefficient of 0.445 W/m^{2}ºC;

Case 2: insulation increase to 4 cm of the exterior walls (total area, excluding windows, 2579 m^2) resulting in a global heat transfer coefficient of 0.525 W/m^{2}ºC

Case 3: insertion of 50cm deep overhang or increasing depth of roof overhangs for shading of south and east windows that are not shaded by the building geometry;

Case 4: change in the type of glazing of windows already identified as not being shaded (total area is 1609 m^2), using double glazing: bronze, reflective, 6+6 mm with 12.7 mm air gap, K=2.35 W/m^{2}ºC, SC=0.18, visible transmission of 0.08, total solar transmission 0.04;

Case 5: actions 1 to 4 combined

Case 6: actions 3 and 4 combined

3.1 Results of changes

The analysis of the different actions is made in terms of difference from the original solution's results and the results are presented in Tables 2 and 3:

Table 2. Change of Peak Loads

CHANGE OF PEAK LOADS	Cooling load (kW)	%	Heating load (kW)	%
Case 1 (roofs insul.)	-3.9	-0.5	-2.8	-0.5
Case 2 (walls insul.)	0.0	0.0	-1.6	-0.3
Case 3 (shading)	-20.7	-2.8	2.8	0.5
Case 4 (glazing)	-118.0	-16.3	17.6	3.3
Case 5 (1 to 4 comb.)	-128.8	-17.7	13.8	2.6
Case 6 (3 and 4 comb.)	-124.3	-17.1	18.0	3.4

Table 3. Change of Annual Loads

CHANGE OF ANNUAL LOADS	Cooling load (MWh/year)	%	Heating load (MWh/year)	%
Case 1 (roofs insul.)	4.9	0.2	-3.6	-2.4
Case 2 (walls insul.)	5.7	0.3	-1.2	-0.8
Case 3 (shading)	-53.9	-2.4	3.4	2.3
Case 4 (glazing)	-344.6	-15.7	41.8	27.7
Case 5 (1 to 4 comb.)	-351.1	-16.0	37.4	24.8
Case 6 (3 and 4 comb.)	-358.4	-16.3	43.3	28.7

The results show that the most relevant actions are those aiming at the reduction of solar gains, particularly cases 4, 5 and 6, which include glazing improvement. For these actions, the effect is a reduction of the cooling loads and an increase of the heating loads, both peak and annual. Regarding the peak loads, the unwanted increase of heating loads is less significant than the reduction of cooling loads (11 to 12%).

As expected, the increase of insulation is not relevant, though it tends to decrease the annual heating loads and increase the annual cooling loads. This happens because, as we increase the insulation of the exterior surfaces, the building is not able to release at night the heat gains, mainly solar, accumulated during the day in its massive interior structure.

4. ECONOMIC ANALYSIS

To better compare the results of the proposed changes, a simple economic analysis is performed. A 4-piped system for ambient heating and cooling is considered, with refrigeration and heating provided by vapor compression chillers and hot water boiler, respectively. Air diffusers are used in common areas and fan-coils are used in room areas. Fresh air handling units are also used to provide the necessary fresh air to the different local areas. This is a common conception if no energy recovery and storage energy systems are included.

Building construction will have extra costs, according to the envelope change, but the peak load reduction will result in a lower installed capacity of the HVAC system. It is considered that the differences in the thermal loads will not have a large influence on secondary system design (cooling and hot water distribution system as well as air handling systems). Thus, they will result in changes of the plant and primary system. Furthermore, the decrease of the installed electrical power associated with lower cooling peak load is not considered.

The changes in the investment for the system must be divided in investment due to heating differences and to cooling differences. The changes in the investment are considered proportional to the variations suffered by the peak loads of heating and cooling, for each proposed case. In this study, the assumed average costs of installation are 249.4 € for kW of cooling load and 74.8 € for kW of heating load. It is also considered that the annual energy consumption is proportional to the annual thermal loads, and for cooling the average COP is 3.2 and transport losses are 3% while for heating the average boiler efficiency is 0.94 and transport losses are 6%.

The average cost of electricity is 0.086 €/kWh, obtained from energetic audits performed by AREAM relating to hotels in Madeira. This value includes energy and installed power and is the global mean value considering consumption in peak and off-peak hours. The average cost of propane is 0.0374 euros/kWh, obtained from DGE (Directorate of Energy of Portugal).

Considering both the performance of the systems and the costs of both types of usable energy, the average costs of each MWh of thermal load, for cooling and heating, are given by:

1 MWh cooling load → 0.322 MWh electricity → 27.706 €
1 MWh heating load → 1.132 MWh propane → 42.327 €

Assuming that the operation costs remains constant in time, the payback time **n** (years) associated to an increase of investment ΔCinvest can be roughly estimated as the smaller **n** that verifies:

$$\Delta C_{\text{invest}} - \sum_{i=1}^{n} \frac{\Delta C_{\text{exp lor}}}{(1+\text{dr})^{i}} \leq 0 \tag{1}$$

where the difference of investment (ΔCinvest) is positive and the difference of operation cost (ΔCexplor) is negative. The discount rate dr considered was 11%. The investment and operation costs and the payback time for the various cases are shown in table 4.

Table 4. Economic Analysis of the proposed changes

	Δ investment costs (10^3 euro)				**Δ exploration costs (10^3 euro)**			**payback time**
	building	cooling	heating	**total**	cooling	heating	**total**	
Case 1 (roofs insul.)	27.254	-0.975	-0.206	26.073	0.134	-0.153	-0.019	unprofitable
Case 2 (walls insul.)	9.259	0.010	-0.121	9.148	0.158	-0.052	0.106	unprofitable
Case 3 (shading)	13.050	-5.153	0.213	8.110	-1.493	0.144	-1.349	11 years
Case 4 (glazing)	64.240	-29.436	1.314	36.118	-9.547	1.767	-7.779	7 years
Case 5 (1 to 4 comb.)	113.802	-32.106	1.147	82.843	-9.869	1.639	-8.230	over 60 years
Case 6 (3 and 4 comb.)	77.290	-31.012	1.344	47.622	-9.929	1.835	-8.094	10 years

The results show that any proposals relating to the increase of insulation (cases 1, 2 and 5) are economically inadequate in this case. Only cases 3, 4 and 6 are of interest. Case 5 is energetically viable (because it includes solar control studied in case 4) but it is of no economical interest. For the present project is recommend to use action 6 (windows shading and glazing improvement), because although it looks less favorable economically than case 4 (greater payback time), it is energetically more favorable.

5. THERMAL REGULATIONS ANALYSIS

The present results are of importance to review the regulatory values for building insulation that are presented in the present Portuguese regulation (RCCTE, RSECE) and in the future regulation since both regulations have been revised, and important changes in the methodology and limiting values will take place.

In the current version of RCCTE (at present, this regulation applies to all type of service buildings and housing) no difference in the methodology used takes place, either the building is sited in the mainland or in the Autonomous Regions of Madeira or Azores. The differences are only in the climatic conditions to be considered. Hence the approach to insulation of roofs and walls as well as window shading is identical and follows the generalized concept that an increase in insulation is always thermally correct. In other words, the present regulation is not well suited to the Autonomous Regions.

Future regulations will make only compulsory the use of RSECE for buildings using a centralized system as previously described for the hotel. Limiting values to the overall heat transfer coefficient of walls still exist, since the future RSECE will depend on some limiting values imposed by the future RCCTE. But these values roughly correspond to twice the limiting values for the Continental region of Portugal. Hence the importance of insulation in walls and roofs is only considered for the Continental region, and correctly considered of little importance in islands. Furthermore, in the future RSECE, the limiting value of consumption and power capacity of the primary units is determined by using a simulation method and different software's can be used, like DOE2. As a result the problem of inadequacy of the methodology does not take place. Using different approaches to the building envelope, using a simulation methodology as presented above, the project team can determine the best solution in terms of energy use.

However it must be stressed that a simulation involves approximations of the real building when building the model to be studied using the chosen software. The major softwares for system analysis do not have in-built routines for all the same occurrences in a building (shading, non-controlled spaces, HVAC systems, equipment and accessories) and do not provide the same approach in all cases solved by these programs. Different software and different approaches (using the same software) will lead to different calculated heat loads that can result in the choice of equipment with different heating or cooling power as clearly demonstrated in a paper published by one of the authors. Since the future regulation imposes that a verification by a different team is carried out to confirm that the heat and cooling power of the equipment (installed) is correct, and no guidelines to the approaches that can be made are stated in the regulation, care and good sense have to be present during the project and the verification phases, in order to avoid the need for going into court decision.

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Acknowledgements

The authors would like to thank the European Commission for supporting the project in which this paper was based: “Integrating Self Supply into End Use for Sustainable Tourism - GREENHOTEL” RTD and Demonstration Project on the European Commission’s Framework 5 ‘Energy, Environment and Sustainable Development’ Program. Contract No. NNE5/2001/707