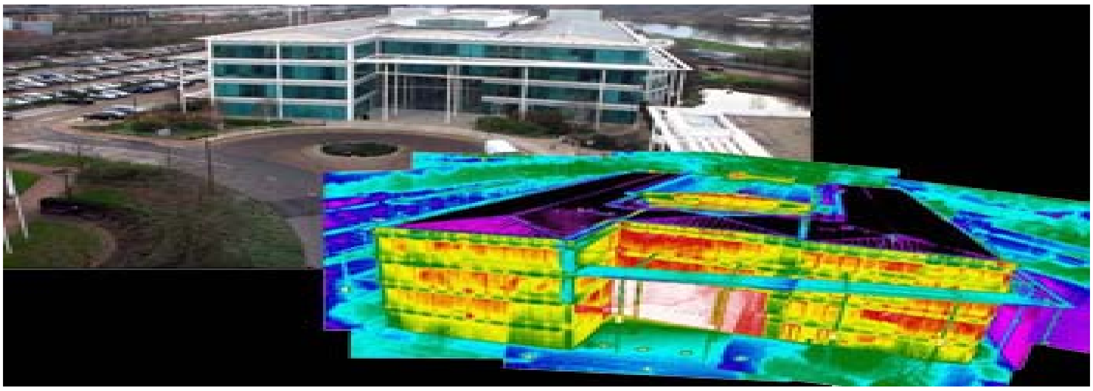
INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa



Evaluation of the Constructive and Environmental Impacts of the Thermal Regulation

Summary

Francisco Jorge Banha Roussado

Jury

President: Professor Jorge Manuel Caliço Lopes de Brito

Supervisor: Professor António Heleno Domingues Moret Rodrigues

Speaker: Professor Daniel Aelenei

October 2008

1. Introduction

The global energy situation leads to the rationalization of all types of energy consumption. Particularly in buildings, the main energy consumption is the one supplied for acclimatization. In Portugal, by adding the domestic sector to the services sector, the ERSE [1] data (*Entidade Reguladora dos Serviços Energéticos*) points one third of the final energy consumption to buildings.

In this context, conciliating lower values for energy consumption levels and a thermal comfort standards [2;3] improvement, comes out the new RCCTE [4] (*Regulamento das Características de Comportamento Térmico dos Edifícios*) in April 4th 2006. The thermal regulation impact in the type of constructive solutions applied was calculated by the regulation calculation method and a *software* called EnergyPlus [5], having as results the energy consumption and the respective carbon dioxide emissions according to the variation of four parameters: geographic localization, position of the fractions in height and solar orientation.

2. Calculation method

The energy needs results were obtained with two calculation methods. These two calculation methods correspond to two distinct behaviour natures: static and dynamic.

The calculation method of the new Regulation of the Characteristics of Thermal Behaviour of Buildings corresponds to the static method. Therefore the calculation is made on the hypothesis of the stationary heat transmission phenomena. With this method, in the heating period, the temperatures description is made by the heating degrees-day (GD) concept that consists on the sum of the positive differences between the interior reference temperature (20 ºC) and the exterior one. In the cooling period, the temperatures description is made by the exterior average summer temperature, being 25ºC the interior reference temperature. In practice this method consists in the new regulation calculation sheets fill up.

The dynamic method is the EnergyPlus [6] calculation method, which has an hourly description of the average temperatures. So, by iteration, the energy balance is calculated in all time intervals, showing in each hour the necessary energy for acclimatization.

Being the intention, to get two different perspectives on the energy needs having in account the same standard of thermal comfort, which is the same interior reference temperature, in the two methods, it was applied the same climatic data (heating degrees-day, exterior average summer temperature and solar radiation). In practice, what was done, besides the two different methods, was the EnergyPlus climatic data application in the new regulation calculation sheets.

In the carbon dioxide emissions calculation method, it resorts to the final energy, useful energy (heating and cooling needs of useful energy) and the acclimatization device income applied.

$$E_{final} = \frac{E_{useful}}{\eta} \quad (1)$$

In the winter period it was considered a boiler of natural gas as heating system, and in the summer period it was considered a heat bomb of electric energy as cooling system. The incomes and efficiencies[1] normalized values for these systems are respectively: η = 0,9 and ε = 3,0 (COP).

About the CO_2 emission factor, its definition consists in the carbon dioxide emitted mass ($kgCO_2$) by an energy source when supplying energy in one given activity (kWh). Finally, the amounts of carbon dioxide produced result from the final energy and the respective emission factor multiplication.

3. Case study

The analyses carried through took place in a residential building, having the choice relapsed on a six floor multi-familiar building (including the ground floor). The typical floor is composed by two autonomous fractions of T2 and T3 type and the respective common areas. In this article it will only be presented the results of the right fraction (T2) despite this having been experimented on the intermediate floor and floor under covering situation, this way representing the variation in height.

Figure 1 – (a) Front; (b) Back.

The reason for which it will only be presented results from the right fraction is because the difference between this and the left fraction (T3) it's a bigger area of the last one, for what, the conclusions concerning the parameters influence were the same in the two cases.

[1] The income of a thermal machine that extracts heat from a cold source and places it in the hot source, when work is supplied to it, it's called for efficiency or COP (*Coefficient of Performance*). In contrast to the income, efficiency can be superior to 1.

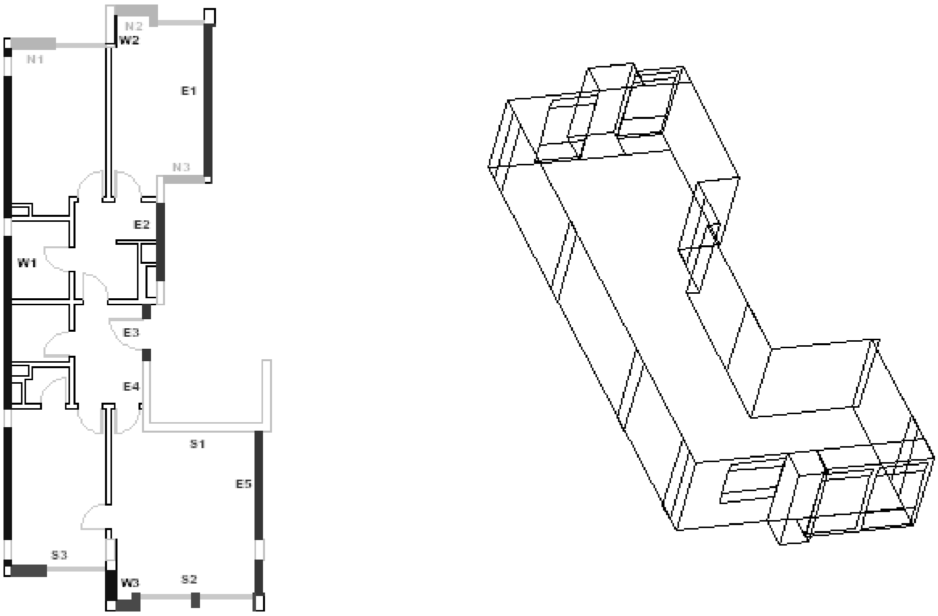


Figure 2 – (a) Right fraction (Plant); (b) Right fraction (Three-dimensional).

Besides the variation in height, a four different climatic zones study (*Porto*, *Bragança*, *Lisboa* and *Faro*) and three different solar orientations study (North-South, Northeast - Southwest and East - West) were also done. To add to the previous parameters, the application of five constructive solutions was also studied. Those solutions intend to represent constructions of different times. They are distinguished for the successive increase of thermal resistance along the chronological progression. The represented period starts on 70's decade and ends nowadays, having in account that, the fifth constructive solution intends to be a solution that, not being currently applied yet, reflects in a short-term, the future practices. The second and third sets of constructive solutions are associated with the old regulation [7] requirements, being the fourth and fifth, a more representative set of the new regulation requirements.

Following this, the constructive solutions cross sections that constitute the surfaces of bigger area are presented, and therefore more relevant in terms of heat thermal transmission. Also the respective thermal transmission coefficients calculated in accordance with *Coeficientes de Transmissão Térmica de Elementos da Envolvente dos Edifícios* [8] are presented:

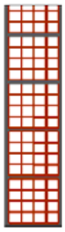
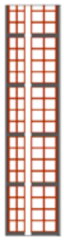
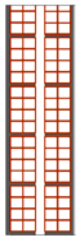
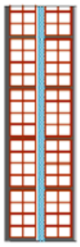
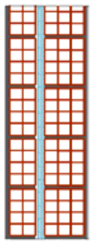
	Exterior wall 1	**Exterior wall 2**	**Exterior wall 3**	**Exterior wall 4**	**Exterior wall 5**
U (W/m^2°C)	1,396	1,172	1,072	0,499	0,403
Cross sections					

Table 1 – Thermal transmission coefficients and exterior walls cross sections.

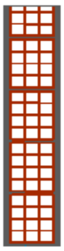
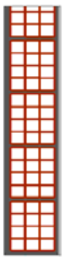
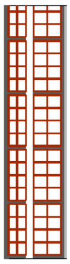
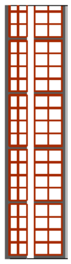
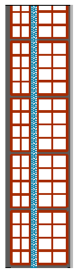
	Wall with not warmed places 1	**Wall with not warmed places 2**	**Wall with not warmed places 3**	**Wall with not warmed places 4**	**Wall with not warmed places 5**
U (W/m^2°C)	1,442	1,409	1,061	1,061	0,456
Cross sections					

Table 2 – Thermal transmission coefficients and walls with places not warmed cross sections.

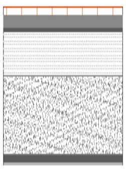
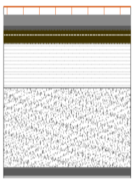
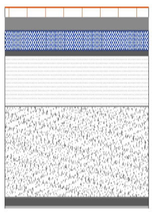
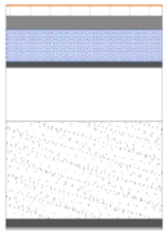
	Roof 1	**Roof 2**	**Roof 3**	**Roof 4**	**Roof 5**
U (W/m^2°C)	1,320	0,702	0,602	0,454	0,343
Cross sections					

Table 3 – Thermal transmission coefficients and roofs cross sections.

	Glass 1	**Glass 2**	**Glass 3**	**Glass 4**	**Glass 5**
U (W/m^2°C)	5,707	5,651	3,042	3,042	2,854
Description	Simple glass: 6 mm	Simple glass: 8 mm	Double glass: 4 + 10 + 6 mm	Double glass: 4 + 10 + 6 mm	Double glass: 6+ 12 + 6 mm

Table 4 – Thermal transmission coefficients and glasses description.

Remember that, besides the presented constructive elements in the previous tables it was also done a differentiation, throughout the five constructive solutions sets of the following elements: interior dividing walls, exterior columns, interior columns, floors and shadowing.

4. Results presentation

In skill of brief explanation of the following results presentation, one only note to refer that all the tables have three types of energy nominal needs, which correspond to the values obtained with: the new RCCTE calculation method, EnergyPlus climatic data applied in the new RCCTE calculation method and the EnergyPlus calculation method. In this article, due to dimension restrictions, it was chosen not to present an analysis that involves the confrontation of results gotten with different calculation methods. This way, all analyses have as basis the results obtained with the new regulation calculation method, being the values of the remaining methods a reinforcement of the results gotten with the new RCCTE calculation sheets.

The following table contains the energy nominal needs results gotten with the five constructive solutions in the 3rd right fraction (intermediate floor), in the *Porto* localization, with a North-South solar orientation, in the two periods.

		Porto - 3rd right - N-S								
		N_{ic}	N_i	CO_2	CO_2	N_{vc}	N_v	CO_2	CO_2	
Constructive solution 1	RCCTE	90.16	68.10	1938.77	1464.25	0.92	16.00	6.77	118.16	REP
	RCCTE - EnergyPlus	102.33	75.96	2200.31	1633.27	0.72	16.00	5.32	118.16	REP
	EnergyPlus	83.68	-	1799.37	-	0.04	-	0.30	-	-
Constructive solution 2	RCCTE	84.98	68.10	1827.33	1464.25	0.91	16.00	6.70	118.16	REP
	RCCTE - EnergyPlus	96.49	75.96	2074.77	1633.27	0.72	16.00	5.32	118.16	REP
	EnergyPlus	78.81	-	1694.65	-	0.05	-	0.37	-	-
Constructive solution 3	RCCTE	65.14	68.10	1400.62	1464.25	1.25	16.00	9.21	118.16	APR
	RCCTE - EnergyPlus	74.16	75.96	1594.75	1633.27	1.00	16.00	7.39	118.16	APR
	EnergyPlus	66.95	-	1439.63	-	0.20	-	1.48	-	-
Constructive solution 4	RCCTE	45.49	68.10	978.14	1464.25	1.57	16.00	11.61	118.16	APR
	RCCTE - EnergyPlus	52.05	75.96	1119.19	1633.27	1.28	16.00	9.45	118.16	APR
	EnergyPlus	46.55	-	1000.96	-	0.41	-	3.03	-	-
Constructive solution 5	RCCTE	40.68	68.10	874.67	1464.25	1.65	16.00	12.18	118.16	APR
	RCCTE - EnergyPlus	46.61	75.96	1002.36	1633.27	1.35	16.00	9.97	118.16	APR
	EnergyPlus	40.35	-	867.65	-	0.63	-	4.65	-	-
		$kWh/m^2.year$		kg/year		$kWh/m^2.year$		kg/year		

Table 5 - Nominal needs and CO_2 emissions of the five constructive solutions (3rd right, Porto, N-S).

The heating nominal needs decrease throughout the constructive solutions progression remains in the other localizations in each level of height, even though, the absolute values are different. Predictably, these nominal needs diminish with the successive thermal resistance increase of the elements that constitute the constructive solutions, even so, they don't decrease linearly.

About the course of the cooling nominal needs, this depends on the localization. Therefore, taking *Porto* as an example, what was verified isn't valid for the remaining localizations. Without deepening the explanation too much the main reason is related with the fact that thermal isolation, by itself, influences thermal losses and thermal gains making the trend of the values depend on each localization climatic conditions (summer exterior average temperature and incident solar radiation).

The following table contains the nominal needs results in the two periods, in the four localizations, in the 3rd right fraction (intermediate floor), applying the fourth constructive solution and with a solar orientation North-South.

		Constructive solution 4 – 3rd right - N-S								
		N_{ic}	N_i	CO_2	CO_2	N_{vc}	N_v	CO_2	CO_2	
Porto	RCCTE	45.49	68.10	978.14	1464.25	1.57	16.00	11.61	118.16	APR
	RCCTE - EnergyPlus	52.05	75.96	1119.19	1633.27	1.28	16.00	9.45	118.16	APR
	EnergyPlus	46.55	-	1000.96	-	0.41	-	3.03	-	-
Bragança	RCCTE	99.84	117.08	2146.86	2517.46	1.62	18.00	11.94	132.94	APR
	RCCTE - EnergyPlus	87.75	103.61	1886.93	2227.83	2.05	18.00	15.14	132.94	APR
	EnergyPlus	73.94	-	1589.93	-	3.06	-	22.60	-	-
Lisboa	RCCTE	30.32	51.51	652.02	1107.51	11.21	32.00	82.81	236.33	APR
	RCCTE - EnergyPlus	32.65	49.06	702.11	1054.85	5.85	32.00	43.20	236.33	APR
	EnergyPlus	27.74	-	596.49	-	6.09	-	44.98	-	-
Faro	RCCTE	29.07	46.37	625.01	997.09	11.21	32.00	82.81	236.33	APR
	RCCTE - EnergyPlus	20.41	35.11	438.82	755.02	9.73	32.00	71.86	236.33	APR
	EnergyPlus	16.55	-	355.87	-	9.23	-	68.17	-	-
		$kWh/m^2.year$		kg/year		$kWh/m^2.year$		kg/year		

Table 6 – Nominal needs and CO_2 emissions in the four localizations (3rd right, constructive solution 4, N-S).

The difference of N_{ic} values gotten with different localizations has to do almost exclusively with the heating degrees-day (GD) and in the cooling period with the summer exterior average temperature. Although it has been taken as an example the constructive solution 4, the same applies to the remaining constructive solutions.

	Porto	***Bragança***	***Lisboa***	***Faro***
Number of heating degree-day (GD) (ºC.days)	1610	2850	1190	1060

Table 7 - RCCTE number of degrees-day of heating, in the four localizations.

	Porto	***Bragança***	***Lisboa***	***Faro***
Summer exterior average temperature (ºC)	19	19	23	23

Table 8 - Summer exterior average temperature (ºC) of the RCCTE in the four localizations.

About the comparison between results gotten in the same conditions but varying the floor position in height, the heating nominal needs are predictable. When joining an additional surface where heat losses occur like in the situation of the under the roof fraction, when in the intermediate floor situation this surface was adiabatic, this turns into an increase of the heating nominal needs. The following table analyzes, for the five constructive solutions in *Lisboa*, the difference between nominal needs of the two floors fractions.

		Lisboa						
		5th right			**3rd right**			
		Nic	Nvc	Totals	Nic	Nvc	Totals	
Constructive solution 1	RCCTE	100.47	20.43	120.90	62.90	11.64	74.54	38%
Constructive solution 2	RCCTE	79.12	16.12	95.23	59.17	11.00	70.17	26%
Constructive solution 3	RCCTE	61.65	16.13	77.78	44.66	11.89	56.55	27%
Constructive solution 4	RCCTE	42.90	14.46	57.36	30.32	11.21	41.54	28%
Constructive solution 5	RCCTE	36.32	13.51	49.83	26.92	11.04	37.96	24%
		$kWh/m^2.year$			$kWh/m^2.year$			

Table 9 – Nominal needs (RCCTE) in Lisbon of the fractions 3rd and 5th right (constructive solutions 1,2,3,4 and 5).

Table 9 shows that in the constructive solution of weak thermal resistance, (constructive solution 1), the total nominal needs can be reduced in about 38 %.

About the cooling nominal needs, as it’s revealed in the previous table, they are always bigger in the under the roof fraction that in the intermediate fraction. The reason as to do with the fact that solar radiations on horizontal surfaces are bigger that on vertical surfaces, making a thermal gain increase by the opaque surface in the 5th floor fraction.

The variation of the solar orientation parameter can be observed in the following table:

		Constructive solution 4 – 5th right - *Lisboa*								
		N_{ic}	N_i	CO_2	CO_2	N_{vc}	N_v	CO_2	CO_2	
N - S	RCCTE	42.90	61.97	1349.07	1768.81	14.46	32.00	14.20	118.16	APR
	RCCTE - EnergyPlus	44.77	58.98	1536.76	1975.48	7.64	32.00	11.52	118.16	APR
	EnergyPlus	39.68	-	1386.51	-	5.19	-	0.59	-	-
NE - SW	RCCTE	43.82	61.97	942.18	1332.63	17.45	32.00	128.87	236.33	APR
	RCCTE - EnergyPlus	45.48	58.98	978.03	1268.24	10.08	32.00	74.44	236.33	APR
	EnergyPlus	43.23	-	929.57	-	6.93	-	51.18	-	-
E - W	RCCTE	45.03	61.97	968.21	1332.63	18.44	32.00	136.22	236.33	APR
	RCCTE - EnergyPlus	46.43	58.98	998.36	1268.24	10.93	32.00	80.72	236.33	APR
	EnergyPlus	46.69	-	1003.97	-	8.22	-	60.71	-	-
		kWh/m2.year		kg/year		kWh/m2.year		kg/year		

Table 10 - Nominal needs and CO_2 emissions of the three orientations (5th right, constructive solution 4, *Lisboa*).

In both periods the table results show that there is a small increase of the energy consumed when rotating from the N-S direction to the E-W direction. In the cooling period, this happens because with this orientation the windows are submitted to a bigger solar radiation. In the heating period, due to the window equivalent area loss at South when the orientation is East – West there is an increase of the energy consumption.

The environmental impacts represented by the carbon dioxide emissions are proportional to the nominal needs values. Therefore, the CO_2 emissions course throughout the previous parameters variation has the same justification of the nominal needs, varying only the absolute values.

5. Conclusions

The following tables present the actual energy savings and CO_2 emissions reductions by comparing the extreme elements in each parameter. These results were calculated with the RCCTE method because of its official nature. The third column results of each element (totals) are the sum of the two previous columns.

		3rd right - N-S						
		Bragança			***Faro***			
		N_{ic}	N_{vc}	Totals	N_{ic}	N_{vc}	Totals	
Constructive solution 1	RCCTE	180.22	0.99	181.21	58.33	11.64	69.97	61%
Constructive solution 2	RCCTE	170.68	0.97	171.66	54.97	11.26	66.23	61%
Constructive solution 3	RCCTE	135.10	1.33	136.43	41.96	11.89	53.85	61%
Constructive solution 4	RCCTE	99.84	1.62	101.46	29.07	11.21	40.28	60%
Constructive solution 5	RCCTE	90.81	1.69	92.50	25.96	11.04	37.00	60%
		kWh/m^2.year			kWh/m^2.year			

Table 11 – Nominal needs (RCCTE) of the five constructive solutions (*Bragança* and *Faro*).

		3º right - N-S						
		Bragança			***Faro***			
		N_{ic} - CO_2	N_{vc} - CO_2	Totals	N_{ic} - CO_2	N_{vc} - CO_2	Totals	
Constructive solution 1	RCCTE	3875.26	7.30	3882.56	1254.31	85.97	1340.28	65%
Constructive solution 2	RCCTE	3670.21	7.19	3677.40	1182.01	83.15	1265.15	66%
Constructive solution 3	RCCTE	2904.97	9.85	2914.82	902.26	87.83	990.09	66%
Constructive solution 4	RCCTE	2146.86	11.94	2158.80	625.01	82.81	707.82	67%
Constructive solution 5	RCCTE	1952.72	12.46	1965.18	558.16	81.55	639.71	67%
		kg/year			kg/year			

Table 12 – CO_2 emissions (RCCTE) of the five constructive solutions (*Bragança* and *Faro*).

		3rd right - N-S						
		Constructive solution 1			Constructive solution 5			
		N_{ic}	N_{vc}	Totals	N_{ic}	N_{vc}	Totals	
Porto	RCCTE	90.16	0.92	91.08	40.68	1.65	42.33	54%
Bragança	RCCTE	180.22	0.99	181.21	90.81	1.69	92.50	49%
Lisboa	RCCTE	62.90	11.64	74.54	26.92	11.04	37.96	49%
Faro	RCCTE	58.33	11.64	69.97	25.96	11.04	37.00	47%
		kWh/m^2.year			kWh/m^2.year			

Table 13 – Nominal needs (RCCTE) in the four localizations (constructive solution 1 e 5).

		3º right - N-S						
		Constructive solution 1			Constructive solution 5			
		N_{ic} - CO_2	N_{vc} - CO_2	Totals	N_{ic} - CO_2	N_{vc} - CO_2	Totals	
Porto	RCCTE	1938.77	6.77	1945.54	874.67	12.18	886.86	54%
Bragança	RCCTE	3875.26	7.30	3882.56	1952.72	12.46	1965.18	49%
Lisboa	RCCTE	1352.46	85.97	1438.43	578.89	81.55	660.44	54%
Faro	RCCTE	1254.31	85.97	1340.28	558.16	81.55	639.71	52%
		kg/year			kg/year			

Table 14 –CO_2 emissions (RCCTE) in the four localizations (constructive solution 1 e 5).

		Lisboa						
		5th right			3rd right			
		Nic	Nvc	Totais	Nic	Nvc	Totais	
Solução construtiva 1	RCCTE	100.47	20.43	120.90	62.90	11.64	74.54	38%
Solução construtiva 2	RCCTE	79.12	16.12	95.23	59.17	11.00	70.17	26%
Solução construtiva 3	RCCTE	61.65	16.13	77.78	44.66	11.89	56.55	27%
Solução construtiva 4	RCCTE	42.90	14.46	57.36	30.32	11.21	41.54	28%
Solução construtiva 5	RCCTE	36.32	13.51	49.83	26.92	11.04	37.96	24%
		kWh/m2.ano			kWh/m2.ano			

Table 15 – Nominal needs (RCCTE) in Lisbon of the fractions 3rd and 5th right (constructive solutions 1,2,3,4 and 5).

		Lisboa						
		5th right			3rd right			
		Nic	Nvc	Totals	Nic	Nvc	Totals	
Constructive solution 1	RCCTE	2160.45	150.90	2311.35	1352.46	85.97	1438.43	38%
Constructive solution 2	RCCTE	1701.26	119.03	1820.29	1272.39	81.25	1353.64	26%
Constructive solution 3	RCCTE	1325.61	119.12	1444.73	960.33	87.83	1048.16	27%
Constructive solution 4	RCCTE	922.55	106.77	1029.32	652.02	82.81	734.84	29%
Constructive solution 5	RCCTE	781.06	99.78	880.84	578.89	81.55	660.44	25%
		kWh/m2.year			kWh/m2.year			

Table 16 –CO_2 emissions (RCCTE) in Lisbon of the fractions 3rd and 5th right (constructive solutions 1,2,3,4 and 5).

		5th right - Constructive solution 4						
		E-W			N-S			
		N_{ic}	N_{vc}	Totals	N_{ic}	N_{vc}	Totals	
Porto	RCCTE	65.10	2.89	67.99	62.74	1.92	64.66	5%
Bragança	RCCTE	133.62	3.36	136.98	130.82	2.09	132.91	3%
Lisboa	RCCTE	45.03	18.44	63.47	42.90	14.46	57.36	10%
Faro	RCCTE	42.13	18.44	60.58	40.38	14.46	54.84	9%
		$kWh/m^2.year$			$kWh/m^2.year$			

Table 17 – Nominal needs (RCCTE) of the N-S e E-W orientation in the four localizations (constructive solution 4).

		5th right - Constructive solution 4						
		E-W			N-S			
		N_{ic} - CO_2	N_{vc} - CO_2	Totals	N_{ic} - CO_2	N_{vc} - CO_2	Totals	
Porto	RCCTE	1399.81	21.32	1421.13	1349.07	14.20	1363.27	4%
Bragança	RCCTE	2873.16	24.80	2897.96	2812.94	15.45	2828.39	2%
Lisboa	RCCTE	968.21	136.22	1104.42	922.55	106.77	1029.32	7%
Faro	RCCTE	906.01	136.22	1042.23	868.39	106.77	975.16	6%
		kg/year			kg/year			

Table 18 –CO_2 emissions (RCCTE) of the N-S e E-W orientation in the four localizations (constructive solution 4).

Summarizing, it can be said that, the difference between geographic localizations is the most important parameter. Therefore it's where a bigger decrease of energy consumption and carbon dioxide emissions occur when comparing localizations of extreme climatic conditions. As second more important parameter appears the type of constructive solution applied, in which can be verified that the thermal isolation increase in solutions already thermally resistant is less efficient due to the losses that don't depend on isolation (air renewal). In third comes the position of the fraction in height, and finally, in last, the solar orientation.

About the comparison of results gotten with different methods, the difference of values must essentially do to the different climatic data, although, comparing values gotten with equal data it's verified that the new RCCTE method tends to be aggravating.

6. Bibliography

[1] www.erse.pt.

[2] www.asrae.org, ASHRAE STANDARD 55-2004, *Thermal Environmental Conditions for Human Occupancy*, 1 de Agosto de 2004.

[3] CSOPT, CEGENE/GTEGENE, *Regras de Qualidade Térmica de Edifícios*, 17 de Junho de 1984.

[4] PORTO EDITORA, *Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE)*, Decreto-Lei Nº 80/2006, de 4 de Abril, Lisboa.

[5] www.eere.energy.gov/buildings/energyplus.

[6] THE BOARD OF TRUSTEES OF THE UNIVERSITY OF THE ILLINOIS AND THE REGENTS OF THE UNIVERSITY OF CALIFORNIA THROUGH THE ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY, *Input Output Reference – The Encyclopaedia Reference to EnergyPlus Input and Output*, USA, September 2006.

[7] PORTO EDITORA, *Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE)*, Decreto-Lei Nº 40/1990, de 6 de Fevereiro, Lisboa.

[8] A. PINA DOS SANTOS, C.; MATIAS, L.; *Coeficientes de Transmissão Térmica de Elementos da Envolvente dos Edifícios*, Edições LNEC, Lisboa, 2007.