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THERMAL COMFORT AND MARKET NICHES FOR APARTMENT BUILDINGS: IMPACT OF THE CURRENT THERMAL REGULATION IN THE PRIVATE REAL ESTATE MARKET IN SANTIAGO DE CHILE

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Key words: thermal comfort, thermal regulation, market niches, real estate market

Abstract:

Almost a decade has passed since Chile begins to implement a Thermal Regulation for dwellings, which established a minimum requirement for each building component, according to different climatic zones. This article proposes a series of dynamic simulations, in order to assess the thermal comfort (during winter and summer) of apartments in Santiago de Chile for lower and upper middle class. Some building typologies were defined by means of the two-stage clustering methodology. These were built using the properties for sale database of Portalinmobiliario.com (2003-2009). The results of thermal simulations show that the Thermal Regulation has a positive impact in the thermal behaviour of these typologies during the heating season. However, at the same time, there is an important risk of overheating in summer.

1. Introduction

Since almost a decade, Chile has attempted to establish public policies in order to improve thermal comfort in dwellings. Actually, these regulations have been carrying out by means of two successive modifications to the National Building Code, implementing the first and second stages of the Thermal Regulation (2000 and 2006 respectively). These were defined based on a prescriptive approach, since they set a minimum requirement for each building component to satisfy the standard (for instance maximum thermal transmission coefficient of exterior walls or

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maximum glazing surface). Additionally, the Ministry of Housing and Urbanism have planned a third stage, related to energy certification and focused on a performance-based approach. This model should be implemented during the next year.

In the context of a preliminary study for the second stage of the Thermal Regulation, several building typologies were defined. Each typology was simulated in different climatic zones, in order to assess the impacts of the regulation. These results were expressed in terms of social cost savings regarding the new technical improvements (DECON, 2002). However, this study did not considerate any aspect of the real estate markets that were been impacted by this regulation. Additionally, thermal simulations were conducted under ideal conditions of location and orientation. Therefore, many of their results just were improvements over these initial assumptions.

The present study was developed during 2009 - three years after the second stage of the Thermal Regulation – with the aim of identify market niches for apartments in the private real estate market of Santiago de Chile. A first approach to define homogeneous market groups was considered, using the two-stage clustering method. After that, thermal behavior of each market niche was obtained, using a dynamic thermal simulation tool.

2. Bibliographical discussion

2.1 Envelope construction and Thermal Regulation

Santiago, capital city of Chile, is placed in the central valley of the country and presents a warm temperate climate with a prolonged dry season (between 7 and 8 months). The annual average temperature is 12.2°C and the thermal oscillation is considerable: the difference between maximum and minimum average temperatures for every month ranges between 10°C and 16°C. These characteristics define a typical Mediterranean climate, with a cold heating season and a prolonged summer, generally associated with high temperatures.

Santiago, with 6 million inhabitants concentrates 40% of the population of the country and 65.5% of the private real estate market. According to the National Statistics Institute, 37.4% and 36.0% of new housing during 2006 were built using mainly brick masonry and reinforced concrete in their walls, respectively (INE, 2007). In both cases, thermal insulation was not traditionally considered. Notwithstanding the required standards of the Thermal Regulation are weak in comparison to the international state-of-art (1.9 W/m2K as maximum admissible U-value for walls in Santiago), nowadays apartment buildings in Santiago are including at least 10 or 20 mm of thermal insulation in their walls to give compliance to the code. On the contrary, houses do not need to include thermal insulation in their walls, since just with brick masonry construction it is possible to reach the required standard. In that sense, the added layer of thermal insulation in the apartments, though thin, is able to modify the thermal behavior of them, both in winter and summer. This paper studies in which way this modification is produced and how can be understood from the point of view of the real estate market.

2.2 *Private real estate market to apartments in Santiago*

During the elaboration of the Thermal Regulation, several building topologies were defined from their general building characteristics (roof, walls and windows specification, surface, number of floors, etc), without consider the key aspects of the real estate market. Also, they were based on building permits statistics for the period 1994-1998 (DECON, 2000), which represent a very different scenario in comparison to the current situation (as can be observed in Table 1). In that sense, some assumptions considered during the elaboration of the second stage of Thermal Regulation – regarding participation of apartment buildings in the real estate market – nowadays are not completely valid, especially when the focus is Santiago.

Table 1: **Building permits statistics for the period 1994-1998, used during the elaboration of the second stage of Thermal Regulation (above) and current situation (year 2006) (below)**

TYPOLOGIES		BUILDING PERMITS, new dwellings, 1994-1998	
	number of typologies	units	%
Houses	10	389,540	79,9 %
Apartments	5	98,070	20,1 %
TOTAL*	15	487,610	100 %

Source: DECON, 2000
(*) Equivalent to 73.9% of total building permits

	BUILDING PERMITS, new dwellings, 2006					
	NATIONAL		SANTIAGO		REGIONS	
	units	%	units	%	units	%
Houses	106,054	65.0%	30,638	42.7%	75,416	82.5%
Apartments	57,182	35.0%	41,156	57.3%	16,026	17.5%
TOTAL	163,236	100%	71,794	100%	91,422	100%

Source: INE, 2007

There are several techniques to identify market niches and selection clustering method is one of these. This numerical taxonomy technique tries to identify homogeneous groups of individuals based on their characteristics (Hair 2005), which can be applied using a two-stage procedure (Perez, 2005). This method is appropriate when there are categorical and continuous variables at the same time. The own character of the apartment market in Santiago (Aguirre, 2008; Aguirre and Marchant 2007) requires this kind of approach, since it is possible to integrate

continuous variables (e.g. prices and surfaces) with other discrete variables, such as market attributes (e.g. quality finish or the existence of central heating).
In the following selection, some market niches for apartments in Santiago will be defined. Afterwards, a "robot apartment" will be proposed for each group, based on the most representative variables of each niche. These models were defined regarding the current real estate supply in Santiago, from the "Portal Inmobiliario.com" web site (http://www.portalinmobiliario.com). Finally, these robots will be simulated with and without the technical requirements of the Thermal Regulation using dynamic thermal simulation software.

3. Market niches definition by means of a model-based clustering

3.1 Description of the database

This study was possible thanks to the "Portalinmobiliario.com" database, which includes 25,711 apartments for sale and their most important real estate attributes, during the period 2003-2008. This database was firstly completed and standardized to afterwards carry out the clustering analysis.

Table 2 presents average values of apartment characteristics in Santiago for two periods:

- 2003-2006 (before Thermal Regulation)
- 2007-2009 (after Thermal Regulation)

The variance analysis (ANOVA), Table 3, suggest that statistically, category values in both periods are the same. This proves that there is not a significant change in the real estate values and products after the introduction of the regulation. Probably, the extra cost for incorporating the Thermal Regulation improvements was absorbed in the profit margin of the real estate developers.

Table 2: **Average values to apartments for sale in Santiago for the periods 2003-2006 and 2007-2009**

PERIOD 2003 – 2006 Cases number: 16,813				
Variables	**Min**	**Max**	**Mean**	**St. Deviation**
Useful surface [m^2]	17.81	279.00	63.03	27.90
Terrace surface [m^2]	0	155.26	7.72	7.70
Total surface [m^2]	17.81	321.50	70.75	33.11
Number of floors	1	29	8.85	5.02
Number of rooms	1	5	2.17	0.92
Number of bathrooms	1	5	1.78	0.69
Price [UF][1]	556	16,240	2,591	1,512
Price [UF/m^2][1]	16.64	114.21	40.33	10.59

PERIOD 2007 – 2009 Cases number: 8,898				
Variables	**Min**	**Max**	**Mean**	**St. Deviation**
Useful surface [m^2]	18.41	309.22	59.44	28.73
Terrace surface [m^2]	0	181.39	6.79	8.36
Total surface [m^2]	18.41	354.16	66.23	35.21
Number of floors	1	26	9.03	6.09
Number of rooms	1	5	2.25	0.85
Number of bathrooms	1	5	1.73	0.70
Price [UF][1]	567	22,500	2,464	1,773
Price [UF/m^2][1]	15.23	90.93	39.79	9.95

(1) 1 UF = EUR 27.3 according to Central Bank of Chile (http://www.bcentral.cl), 15-06-2009
Source: own elaboration.

Table 3: **Variance Analysis (ANOVA)**

Variable		Sum of Squares	df	Mean Square	F	Sig.
Price [UF]	Between Groups	9.419 E7	1	9.419 E7	36.479	0.000
	Within Groups	6.638 E10	25709	2581974.103		
	TOTAL	6.647 E10	25710			
Price [UF/m^2]	Between Groups	1685.829	1	1685.829	15.670	0.000
	Within Groups	2765791.318	25709	107.581		
	TOTAL	2767477.147	25710			

Source: own elaboration.

In this two-stage clustering analysis, it is not necessary to reduce the variables by means of the principal component analysis (factorial method). In that sense, this procedure reduces discrete and continuous variables in the same form, which cannot be an accurate way to estimate clusters regarding the real estate database considered for this study.

In order to obtain the information for the "robot" apartments, mean values of continues variables for each cluster were calculated (see Table 4). These values correspond to the robust averages for these variables in each cluster whereas discrete variables are selected in terms of frequency (mode). In consequence, each cluster was represented by a "robot apartment", which were selected from the "Portal Inmobiliario.com" real estate supply database (for the period 2003-2009), considering the obtained values and other indicators. This database contains architectural layouts and a complete description of real estate attributes for each case.

Figure 1 presents the layout and the most representative orientation for each cluster, which will constitute the based-models for thermal simulations. Additionally, cluster IV presents two orientations, due to both eastern and western facades are the most representatives (each one with 22% participation).

Table 4: **Number of apartments and percentage of the total for each cluster**

Cluster	Number	Percentage (%)
I	4,975	19,3%
II	4,255	16,5%
III	7,563	29,4%
IV	8,918	34,7%
Total	25,711	100%

Source: own elaboration.

Table 5: **Mean and standard deviation of clusters**

Cluster	Useful surface		Price	
	Mean	St. Dev	Mean	St. Dev
	[m^2]	[m^2]	[UF]	[UF]
I	55.07	19.36	2,272.2	1,040.1
II	104.09	32.03	4,958.7	2,112.4
III	49.22	16.16	1,961.7	812.7
IV	56.01	18.23	2,045.6	896.1
Total	61.78	28.23	2,546.9	1,608.0

Source: own elaboration.

Figure 1: **Layout and orientation for each cluster used for thermal simulations. Ground floor plan taking from TAS models**



Source: own elaboration.

4. Thermal behaviour of clusters

4.1. Definition of models for thermal simulation

With the aim of studying the impact of the Thermal Regulation in terms of thermal comfort, certain simulations were made using TAS software (http://www.edsl.net), a dynamic state modelling tool.

Figure 1 presents the 5 models, which were assessed by means of this software. TAS estimates the thermal behaviour through a multizone approach, in order to represent correctly significant temperature differences between the different spaces, which can occur especially during summer period (Alvarez, 2009). The results were expressed in terms of thermal comfort (heating and overheating degree hours below 20°C and over 26°C, respectively). Internal gains considered for all simulations reached a value of 90 Wh/m^2/day, which are mainly associated to occupancy, lighting, and equipment.

Three scenarios were considered for establishing the impact of the Thermal Regulation in the performance of the clusters. These were defined by means of a before-and-after approach. Table V presents these three scenarios (S1, S2 and S3).

Table 5: **Building elements for different scenarios regarding Thermal Regulation**

SCENARIOS		WINDOWS		EXTERNAL WALLS				
		Material	U-Value	Material	Thickness	Density	Thermal conductivity	U-Value
			[W/m^{2}K]		[mm]	[kg/m^3]	[W/mK]	[W/m^{2}K]
S1	Before 2nd stage of Thermal Regulation	Single glazing	5.8	Concrete	200	2400	1.63	3.41
S2	After 2nd stage of Thermal Regulation	Single glazing	5.8	Gypsum board	10	700	0.26	1.25
				EPS	20	10	0.043	
				Concrete	200	2400	1.63	
S3	After 2nd stage of Thermal Regulation and double glazing	Double glazing	2.8	Gypsum board	10	700	0.26	1.25
				EPS	20	10	0.043	
				Concrete	200	2400	1.63	

Source: own elaboration.

4.2. Results

Table 6 presents the results in terms of heating and overheating degree hours. For all clusters, reduction of degree hours below 20°C - associated to the extra insulation of the scenario after Thermal Regulation (S2) - varies between 4 and 17%. Evidently, this could represent a very limited improvement. However, when double glazing is applied over the Thermal Regulation requirements (S3), the situation notoriously improves, reaches around 30% reductions.

At the same time, the thermally insulated cases (S2 & S3) show a considerable increase in terms of overheating degree hours when they are compared to the scenario before Thermal Regulation (S1). This increment even duplicates the amount of overheating degree hours in some clusters, specifically when double glazing is considered (S3). In order reduce this overheating level without modifying the thermal insulation; some alternatives regarding passive cooling were studied. Table 7 present three ventilation strategies (V1, V2 & V3) that were considered for simulations. V1 corresponds to a steady ventilation (the same regimen used for the previous simulations of Table V), whereas V2 & V3 represent a manually controlled natural ventilation and night ventilation (with a fixed air change rate during night time), respectively.

Table 8 presents overheating degree hours above 26°C for Cluster I and the three scenarios with different ventilation strategies. In view of these results, some observations could be enunciated:

- The percentage of reduction for V2 and V3 in comparison to V1 is slightly more effective when the envelope is more insulated, such as in the S2 and S3 scenarios (especially in the last one, since it incorporates double glazing).

- V3 is much more effective in absolute terms than the other two ventilation strategies, but probably could be difficult to reach exclusively with a manually controlled system (for reasons of security, privacy, external noise, etc). In that sense, V3 could be considered much less applicable than V2 - at least in the Chilean context - since also air management systems are not common in dwellings. In that sense, although V2 could represent a more real approach than V3, in practice corresponds to an "ideal user" (because windows are operable under very precise and specific conditions). Therefore, this alternative just represents the optimum performance that can be reached through a manually controlled strategy, but not necessarily the behaviour of a common user.

Table 6: **Heating degree hours below 20°C for each cluster in different scenarios**

Cluster	Scenario	HEATING DEGREE HOURS (Winter Comfort)		OVERHEATING DEGREE HOURS (Summer Comfort)	
		Degree hours below 20°C	% reduction compared to S1	Degree hours over 26°C	% reduction compared to S1
I	S1	63,972		23,346	
	S2	52,853	17%	31,694	- 36%
	S3	41,191	36%	47,474	- 103%
II	S1	73,008		17,948	
	S2	63,677	13%	24,402	- 36%
	S3	48,925	33%	35,419	- 97%
III	S1	90,513		20,569	
	S2	86,860	4%	22,744	- 11%
	S3	69,431	23%	37,171	- 81%
IVa	S1	80,431		30,459	
	S2	73,769	8%	37,418	- 23%
	S3	58,809	27%	57,351	- 88%
IVb	S1	69,515		52,188	
	S2	62,972	9%	61,233	- 17%
	S3	48,263	31%	87,009	- 67%

Source: own elaboration.

Table 7: **Building elements for different scenarios regarding Thermal Regulation**

VENTILATION STRATEGIES		WINTER		SUMMER	
		ACH	OPERATION	ACH	OPERATION
V1	Steady ventilation	1	24 hours	1	24 hours
V2	Operable windows (managed by users)	1	*Windows are closed*	Free	*Windows are open*: when T° interior > T° exterior; T° interior ≥ 26°C and T° exterior ≥ 16°C
				1	*Windows are closed* (rest of the time)
V3	Night ventilation*	1	24 hours, from May to October	1	Daytime (between 07:00 and 24:00), from November to April
				4	Night (between 24:00 and 07:00), from November to April

(*) Ventilation regimen used by the CCTEv2.0 software, to give compliance to the procedures of the new official energy certification rating system for buildings
Source: own elaboration.

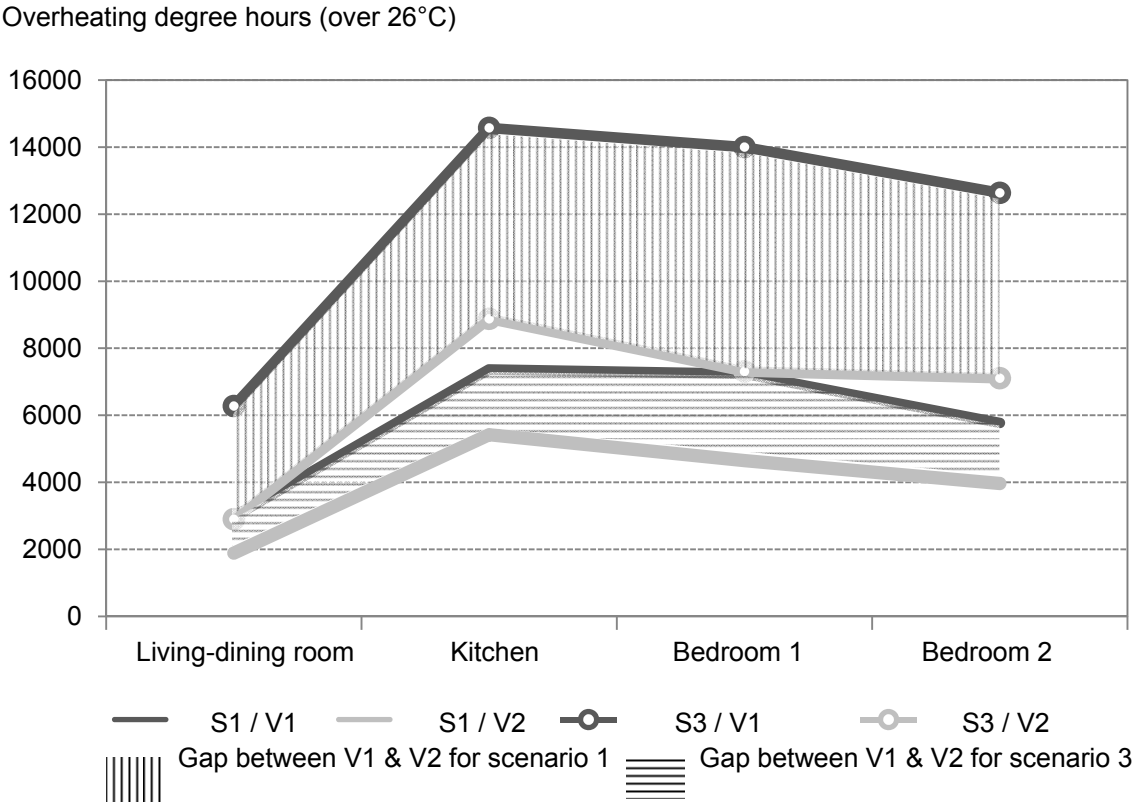
Table 8: **Overheating degree hours for Cluster I with ventilation strategies**

CLUSTER	SCENARIO	VENTILATION STRATEGIES	OVERHEATING DEGREE HOURS (Summer Comfort)	
			Degree hours over 26°C	% reduction compared to S1
I	S1	V1	23,347	- - -
		V2	15,922	32%
		V3	10,673	54%
	S2	V1	31,694	- - -
		V2	22,713	28%
		V3	13,307	58%
	S3	V1	47,475	- - -
		V2	26,179	45%
		V3	17,657	63%

Source: own elaboration.

Figure 2 presents overheating degree hours in different rooms of Cluster I under different ventilation strategies for both S1 and S3 scenarios (the most favourable and unfavourable in terms of overheating, respectively). The gap between V1 and V2 (represented for S1 and S3 through areas filled with horizontal and vertical lines, respectively) is considerable higher in the thermally insulated case (S3), since here the range of overheating varies significantly. Therefore, in this critical case is very important to determine the most probable ventilation regimen (related to a common user), as way to can more accurately predict the thermal performance of these models. For this reason, a field survey of occupant's habits and preferences with regard to ventilation and other behavioural aspects is proposed as further research for this study.

Figure 2: **Overheating degree hours for different rooms of Cluster I under different conditions**

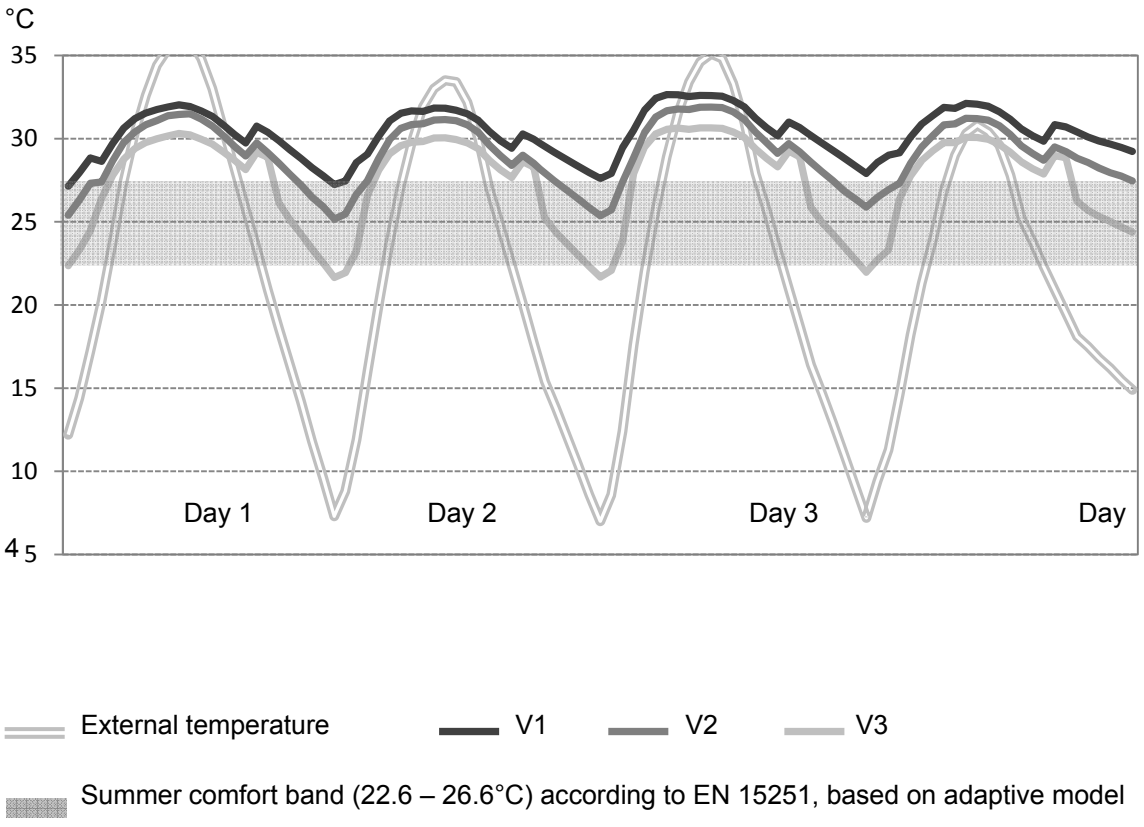


Source: own elaboration.

Finally, Figure 3 presents temperature variation for cluster I in different ventilation strategies in the scenario S3. The variation of temperature shows a notorious difference between the three ventilation strategies, especially during the night. However, neither of these strategies is able to reduce completely the overheating during daytime, without reaching the comfort band. From the point of view of the real estate market could be interesting to identify which clusters can reach

the summer comfort using just passive cooling techniques. For that, it is clear that it is necessary to integrate other measures, such as solar protection and thermal inertia in the study.

Figure 3: **Temperature variation [°C] for Cluster I in different ventilation strategies and scenario S3 in three summer days (January)**



Source: own elaboration.

5. Conclusions

First of all, the decision of the current Thermal Regulation to incorporate thermal insulation in the external envelope of apartments in Santiago appears as appropriate to improve winter comfort conditions. Also, the results shows that thermal insulation could be convenient even for summer comfort, when is combined with ventilation strategies. At the same time, there is an important future challenge to introduce most restrictive requirements in the regulation and encouraging the use of double glazing.

At the same time, it is necessary incorporate other passive cooling techniques, such as solar protection and thermal inertia (combined to the studied ventilation strategies) in the study, to define how it is possible reach summer comfort without the incorporation of air conditioning.

Finally, in view of the obtained results, a field survey of ventilation habits and other behavioural aspects related to occupants in Santiago is proposed as further research. The ventilation strategies used in this article represent at this moment just boundary models (which define the optimum and minimum performance related to ventilation), which should be compared to most realistic patterns in order to can more accurately predict the thermal behaviour of these apartments.

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