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The missing energy
Improving the study of heat fluxes in buildings

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Abstract: *Efficient thermal insulation has so far focused on improving building's envelope, understanding a building as a unique thermal space. Although it could be the case for some kinds of constructions, because of the more independence of each person and the concentration of people in multistory buildings, there are more partitions between different heated spaces and it makes us wonder about the relevance of thermal energy loses through these interior partitions. Aiming to answer this question, we divided our research into two main steps: first basic calculations of different building typologies, and developing an accurate virtual model to represent this phenomenon. In our first approach we looked for some numbers of what this yet-non-studied energy flow could represent to the whole energy flux in two different building typologies by using a monitoring system named SIRENA from Universitat Politècnica de Catalunya (http://www.upc.edu/sirena). How relevant are interior losses compared with losses through the building's envelope? Are those losses hight enough to be studied and improved? The answer is rotundly "yes"! We concluded that this loses represents about a 20% of, what we named, a "Uni-Thermal-Zone Building (UZB) total loses and this value gets specially remarkable when rises to more than 70% in case of multistory and residential buildings, named as "Multi-Thermal-Zone Buildings" (MZB). Thus, according to our results, the significant percentage of heat lost through interior partitions indicate that they play a key role in a building's thermal fluxes. As a consequence, we developed a DesignBuilder thermal model with different utilization patterns to analyze how this energy flow affects the interior comfort in a MZB, which are the south of europe most extended type of building, during one day and how the energy is lost. The results suggests thinking about "thermal sectorization".*

Keywords: *Energy efficiency; Indoor heat transfer; Indoor heat flux; Internal partitions thermal insulation; occupancy patterns; Modeling of heat transfer in buildings.*

Summarized paper

1. Introduction

The following ressearch represents an improvement and a step forward into understanding what may happend in our thermal balances in were there are always some losses wich cannot be identified, regarding the one presented in SB13_München Congres by Roger Llorens Viader, in where it was pointed out that it is true that thermal efficiency can still be improved and focussed on inthernal heat fluxes and how is it transmited between different internal spaces through interior partitions, representing an inhabitant's confort improvement.

For some years now our country (spain) has been working towards a greater efficiency in the use of energy through passive measures such as the improvement of thermal insulation of building's enclosure walls that enable it to lower its cost. Although this field has experimented a huge rising, it is fairly clear that this progress was headed in one direction only: improving the external envelope.

It is true that the greatest amount of heat loss occurs through these enclosure walls. Nevertheless, and as it was proved in the full paper, which can be found in Catalan Polithecnical University digital archive through the following link: http://minilink.es/gp9, once exterior walls are improved, we realize we still have heat losses in our buildings probably through openings, ventilation systems, towards the interior of the building through internal partitions and so on. This is what we call “The missing energy case”.
This research will attempt to identify and quantify one of these possible thermal vanishing points using different thermal measurements and computational modelling. The phenomenon to be recognized in this project is the one on thermal losses through interior partitions that divide properties or spaces with different degrees of climate control.
The building tradition within the Spanish state displays a systematic lack of thermal insulation in these partitions, since the *Codigo Técnico de la Edificación* (CTE) has not included them explicitly until 2006. Currently, due to a much more dynamic and heterogeneous society where individuals are becoming more and more independent from their environment, we believe it to be necessary to review this lack of thermal insulation of interior partitions and contemplate the effectiveness of incorporating, or not, thermal insulation in its composition.

1.1. Goals

The main aim of this research is to continue the research presented on SB_13 München by Roger Llorens Viader representing LiTA Lab in where were presented the firsts studies of this "missing energy" that we can't idetify in our thermal balances because it is not lost through the external skin of buildings but interior partitions.

In this case we look forward to go dipper in muty-storey building's heat transfer focussing in what happens interiorly in order to open new devates to finally improve building's thermal efficiency theories and procedures.

1.2. Initial hypothesis

As thisis the second stadge following "Relevance of interior thermal fluxes through buildings' interio partitions" research by Roger Llorens from LiTA-UPC, whe already have some initial hypothesis verified such as:

:: Basic fluid mechanics theory. The temperature difference between two spaces will cause the energy flux through the partitions separating them.

:: The more insulated the building façade is the more the percentage of internal thermal loses will grow since, if untreated, the phenomenon will keep within constant values while we continue decreasing the energy transmission to the outside. This leads us to think that, in order to improve the energy efficiency of the buildings, it is necessary to consider both interior and exterior enclosure walls as “thermal frontiers” that must be treated simultaneously.

:: In buildings such as public facilities, managed by only one main air conditioning system, the interior thermal transmission will be less relevant due to the large volumes of air to move, the homogeneity of uses and the interior temperatures.

:: In residential buildings such as collective apartments or hotel complexes, the great fragmentation of spaces into little unities means a larger contact area between internal spaces with different levels of heating. Hence we suppose that there will be a higher percentage of internal losses. A priori, we assume that this sector is the most appropriate to apply our theories.

With these statements proved and accepted, more hypothesis can be developed regarding these residential buildings in where ara a lot of different people living lives together with different abits and a large number of thermal interactions between dwellings.

First of all, I would like to clarify that we have used Spain's most common heating sistem in where each inhabitant in the bloc can set the temperature of its dwelling independently so, we have a high range of different temperatures and utilization timings in the same building. Actually, this will be a key point in the ressearch as will be seen below.

:: In a residential bloc, there will be some different utilization patterns deppending on each individual heating habits wich will depend in some parameters wich will make the indoor heat in the building easily flow from one space to the other what may interior partitions become external walls (because of a great temperature difference) in some cases.

:: More exterior dwellyngs may not be the ones that looses the greater amount of energy in the building. Because of the previously mentioned utilization patterns will appear some units/dwellings that can steal heat from adjoining units wile others just give energy so, there may be a thermal inefficiency for the user who will be heating others spaces.

1.3. Previous ressearch

In order to summarize the previous steps developed in the first stadge of this investigation, it was divided into two main first stages: Study of one Uni-thermal-Zone Building (UZB) and Study of one Multi-thermal-Zone Building (MZB). We were able thus to do a progressive approximation to the phenomenon as increasing the complexity of each step.

:: Typology 01. Uni-thermal-Zone Buildings [UZB]

First, we focussed on doing the preliminary verification of the phenomenon in the “Escola Tècnica Superior d’Arquitectura del Vallès’ building”, which is linked to the Catalan Polithecnical University [UPC - ETSAV]. We carried out a measurement protocol in where it whas checked that heat flows through interior partitions from one interior space to another to finally develop a basic calculation model in where we were able to compare internal loses with exterior loses.

:: Typology 02. Multi-thermal-Zone Buildings [MZB]

After this first aproach, we went through multystorey buildings. In the previous research it was developed a basic calculation model in order to be compared with the one developed in UZB an consequently it was basic in a synchronic situation and a theoric model. However, results where so significant that we have developed the present research as a final step to prove the phenomenon's relevance with advanced simulation.

1.4. Previous ressearch :: Results

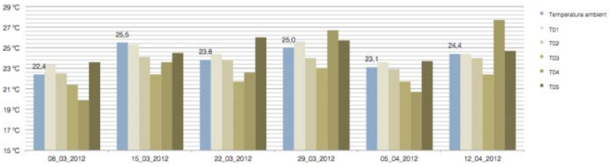


Fig.1: ETSAV's Auditorium thermal monitoring

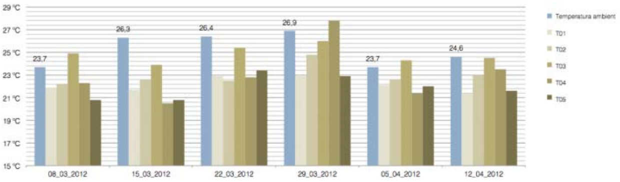


Fig. 2: ETSAV's Library thermal monitoring

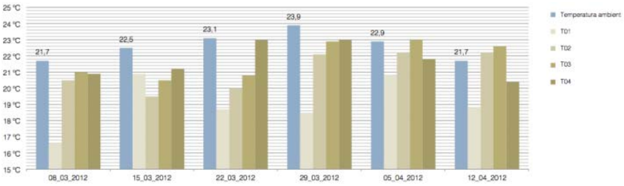


Fig. 3: ETSAV's Computer room thermal monitoring

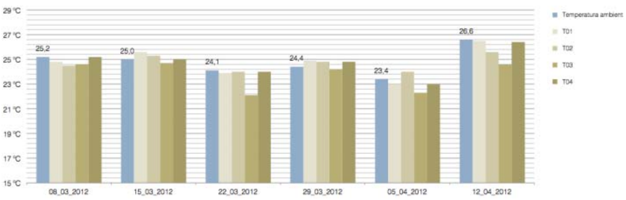


Fig. 4: ETSAV's 24h-work-room thermal monitoring

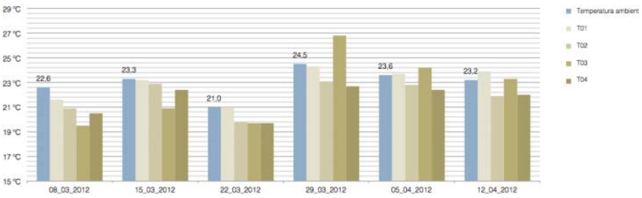


Fig. 5: ETSAV's shop thermal monitoring

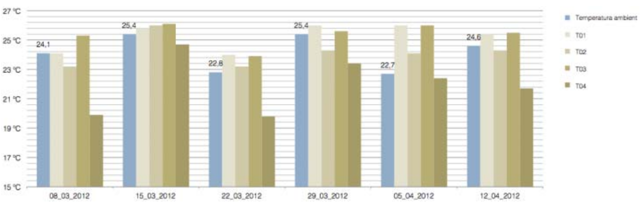


Fig. 6: ETSAV's bathroom thermal monitoring

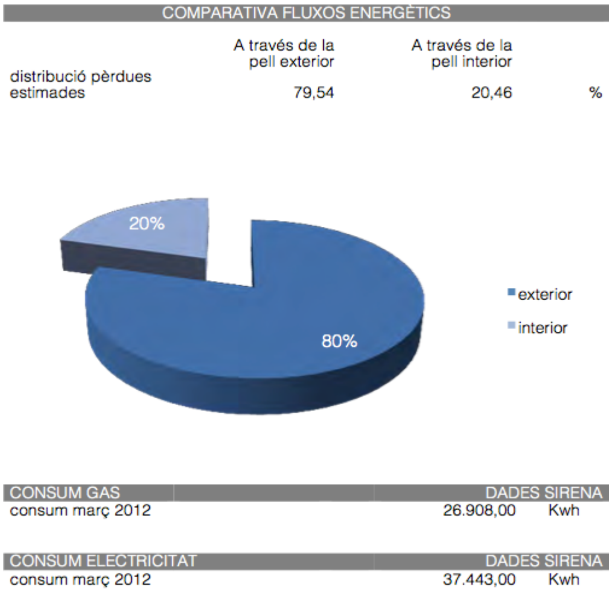


Fig. 7: Thermal loss through interior/exterior partitions

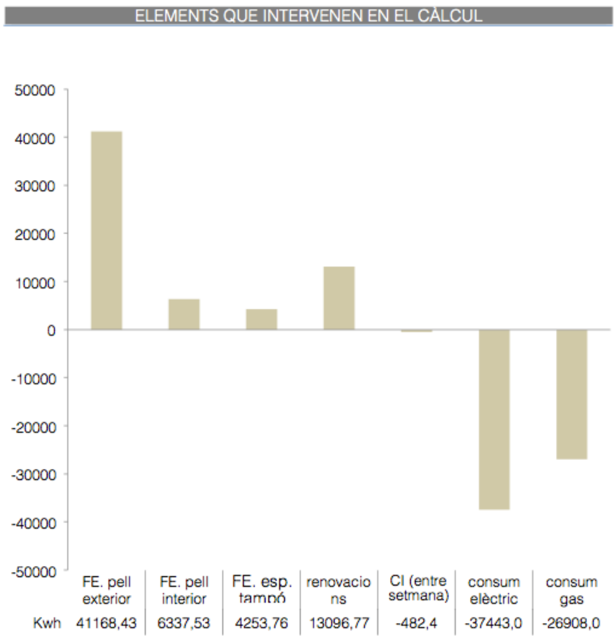


Fig. 8: parameters involved in UZB calculation

With the first campaigns carried out in UZB, we can begin to draw reliable conclusions that will benchmark our first hypothesis thanks to the data extracted from the previous exercises. If we keep the development process in perspective we can corroborate most of our initial hypothesis:

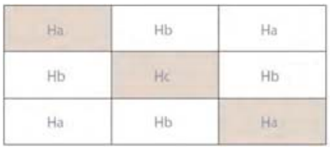
:: Once we have done our small scale measurements, we have expanded this scale of work throughout the evaluation of the building, while not limiting ourselves to observation only, we have done a more detailed analytical approximation of the factors involved in the heat balance fluxes. At the same time, we have confirmed that these transmissions constitute 20% of thermal losses in a building such as the ETSAV.

:: We have confirmed that the ETSAV building as chosen prototype to carry out the evaluation, contributed several circumstantial variables that hinder the contrast of the expected results- 80% of energy loss through the façade is due to the large number of thermal bridges, the poor efficiency of its exterior walls, especially in the use of simple glass, and a large contact surface. In this sense, the number of unheated interior spaces is also reduced and could it thus be considered that the results obtained from the 20% correspond to a cautious scenario. Therefore, we can state that in a building with these characteristics, the usual minimum value of the thermal loss through interior walls rounds up to about 20% of the total flux of heat contributed.

:: Finally, we wonder that this phenomenon takes up a main role in well-insulated buildings, or those in which thermal efficiency in façades has been taken into account during ithe designing stage. We consequently expect the problem of thermal loss through interior partitions to be more relevant in thermal efficiency oriented buildings.

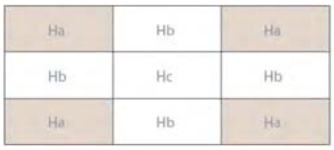
1.5. Previous ressearch :: Results

1.5.1. simple combination results



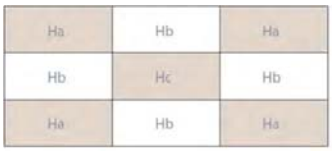
Ha :: coberta	on	x1 / 2	1.211,04	kWh
Ha :: solera	on	x1 / 2	1192,24	kWh
Hb :: coberta	off	x0 / 1	0	kWh
Hb :: solera	off	x0 / 1	0	kWh
Hb :: façana	off	x0 / 2	0	kWh
Hc :: central	on	x1 / 1	1582,69	kWh
FLUX TOTAL			3985,97	kWh
FLUX PONDERAT / UT ACTIVADA			1328,66	kWh

Fig. 9: simple MZB combination 01



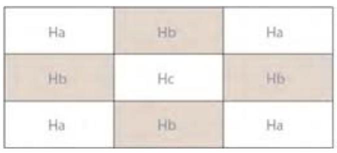
Ha :: coberta	on	x2 / 2	2.422,09	kWh
Ha :: solera	on	x2 / 2	2384,47	kWh
Hb :: coberta	off	x0 / 1	0	kWh
Hb :: solera	off	x0 / 1	0	kWh
Hb :: façana	off	x0 / 2	0	kWh
Hc :: central	off	x0 / 1	0	kWh
FLUX TOTAL			4806,56	kWh
FLUX PONDERAT / UT ACTIVADA			1201,64	kWh

Fig. 10: simple MZB combination 02



Ha :: coberta	on	x2 / 2	2.422,09	kWh
Ha :: solera	on	x2 / 2	2384,47	kWh
Hb :: coberta	off	x0 / 1	0	kWh
Hb :: solera	off	x0 / 1	0	kWh
Hb :: façana	off	x0 / 2	0	kWh
Hc :: central	on	x1 / 1	1582,69	kWh
FLUX TOTAL			6389,25	kWh
FLUX PONDERAT / UT ACTIVADA			1277,85	kWh

Fig. 11: simple MZB combination 03



Ha :: coberta	off	x0 / 2	0	kWh
Ha :: solera	off	x0 / 2	0	kWh
Hb :: coberta	on	x1 / 1	1252,59	kWh
Hb :: solera	on	x1 / 1	1233,78	kWh
Hb :: façana	on	x1 / 2	2164,08	kWh
Hc :: central	off	x0 / 1	0	kWh
FLUX TOTAL			4650,45	kWh
FLUX PONDERAT / UT ACTIVADA			1162,61	kWh

Fig. 12: simple MZB combination 04

QUADRE RESUM DE PERDUES TERMIQUES SEGONS POSICIO D'HABITATGE

	Pèrdues a través dels tancaments exterior	Pèrdues a través dels tancaments interior	TOTAL
Ha :: coberta	2,33 kWh	3,18 kWh	5,51 kWh
	42,3%	57,7%	100%
Ha :: solera	2,24 kWh	3,18 kWh	5,42 kWh
	41,4%	58,6%	100%
Hb :: coberta	1,43 kWh	4,27 kWh	5,70 kWh
	25,1%	74,9%	100%
Hb :: solera	1,34 kWh	4,27 kWh	5,61 kWh
	23,9%	76,1%	100%
Hb :: façana	1,74 kWh	3,18 kWh	4,92 kWh
	35,4%	64,6%	100%
Hc :: central	0,84 kWh	6,35 kWh	7,19 kWh
	11,7%	88,3%	100%

Fig. 13: Thermal loss through linterior/exterior partitions in MZB simple

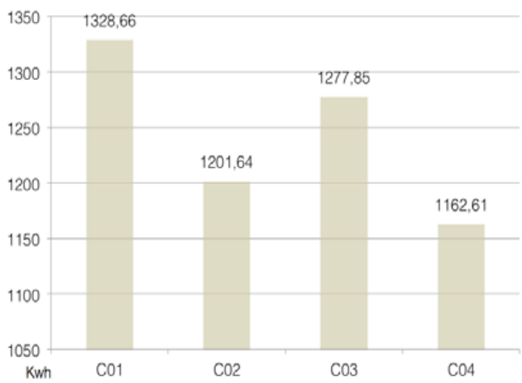


Fig. 14: Total energy loss in C01 to C04 combinations

1.5.2. complex combination results

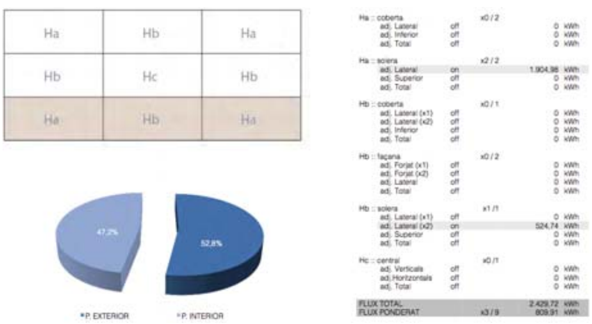


Fig. 15: complex MZB combination 05

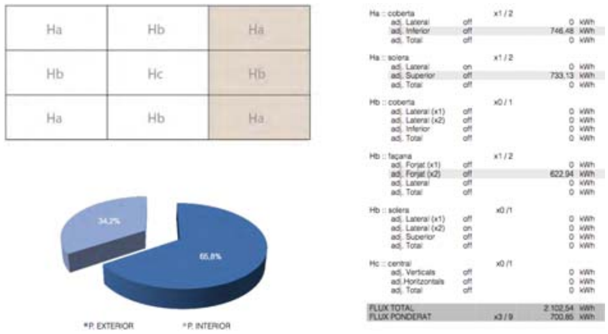


Fig. 18: complex MZB combination 08

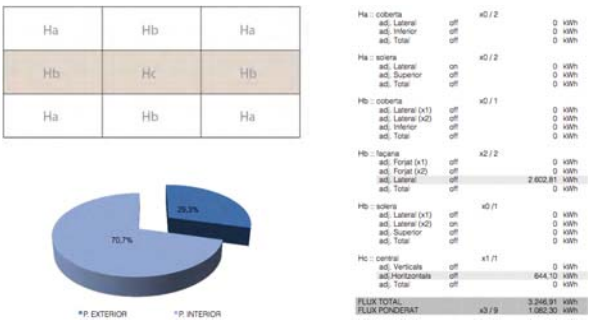


Fig. 16: complex MZB combination 06

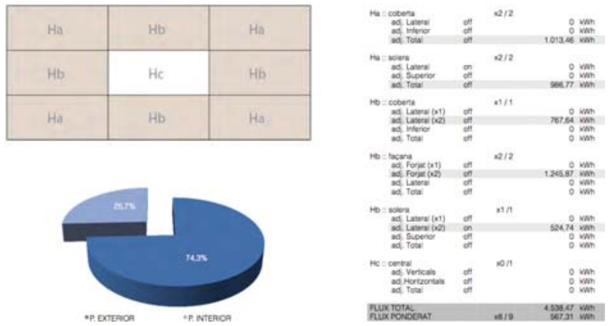


Fig. 19: complex MZB combination 09

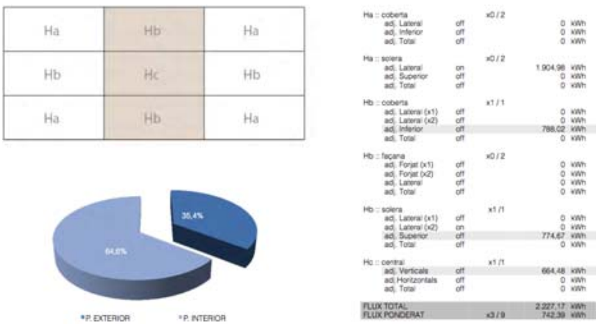


Fig. 17: complex MZB combination 07

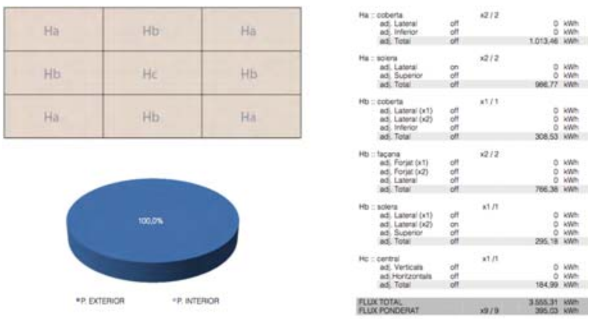


Fig. 20: complex MZB combination 10

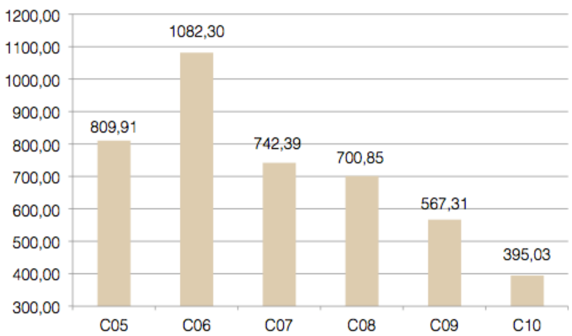


Fig. 21: Total energy loss in C05 to C10 combinations

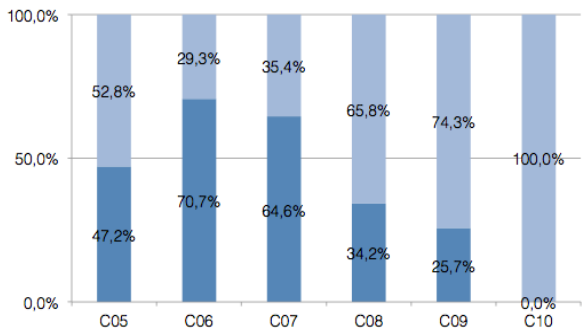


Fig. 22: Thermal loss through interior/exterior partitions

According to the MZB, which could represent all the residential buildings managed by individual thermal generators, we can confirm that this building type is more affected by this phenomenon. The typical features of this type of constructions, with very small units, as could be seen in the different houses in a block of flats or rooms in a hotel complex, naturally lead to this result. There are lots of clearly defined spaces with different utilization patterns and heating protocols. According to our models, we found out that depending on the situation of the studied unit within the building as a whole and above all of the occupation and at the same time air conditioning units around it, the values relating to the thermal loss through the interior partitions is ranged between 25.7 % and more than 70 %. This proves that these enclosure walls are truly relevant to the flux of thermal energy and we therefore believe that they are the next huge topic to consider in the improving of the thermal efficiency of residential buildings, as they represent the most extensive building type in all developed world.

Finally, we can confirm that the strategy that would give us the best efficiency regarding the thermal efficiency of the entire building in a synchronous model, for instance, in a single instant of time, is to activate all units at the same time, avoiding the largest number of thermal breaks and therefore reducing the surface thermal transmission in the façade, which is supposed to be correctly insulated. This strategy reduces thermal losses up to 63.5% but is not very widespread in our country so, and to make it more realiable, we will develop a *DesignBuilding* advanced modalization to try to simulate some user/heating patterns algong one day.

2. Methodology

In order to organize this new research step, it was precised to use realistic data and anadvanced software. First of all, and in colaboration with Maruixa Toucedo and Javier Neila from Technology department at Escuela Técnica de Arquitectura de Madrid (ETSAV) part of Universidad Politécnica de Madrid (UPM), a virtualized building was designed by using *DesignBuilder* simulation software.

In order to make the following results comparable to the ones obtained from the first research, we have simulated the new building in the same climate as the first exaple: Barcelona, Catalunya in a North-East orientation. In order to simulate it is an operative building during the whole year, although we have made the simulation from February 20th to April 1st hour by hour, mesurements for future calculations has been taken from May 15th expecting it to be fully heated and stabilized.

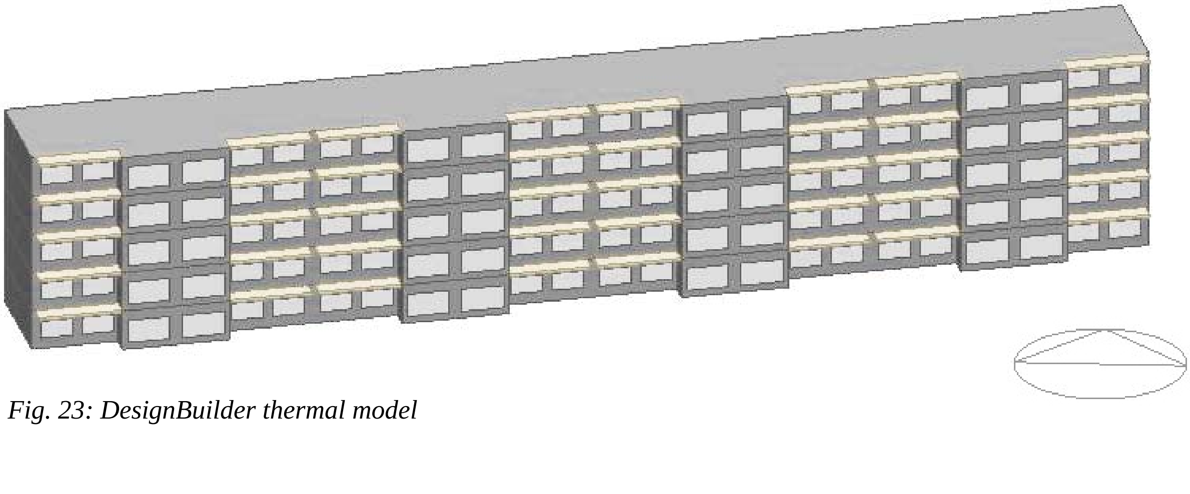


Fig. 23: DesignBuilder thermal model

Turning to small units, it has been determined that all of them are heated with most common climatization system in Spain: individualized heaters and HVAC systems. Actually, this system is the key point of the whole research because it is what gives building's large number of different heated spaces, what then creates the indoor heat flux and makes some users to loose energy while others gain it.

Acordingly, some user patterns has been determined from 2012 INE data (Instituto Nacional de Estadistica, from Spain) which were used to determine which inhabitants agrupations are the most common in this country and how much are they in percentage. This will allow us to simulate different kinds of utilizations patterns with different timetables and so, different heating levels.

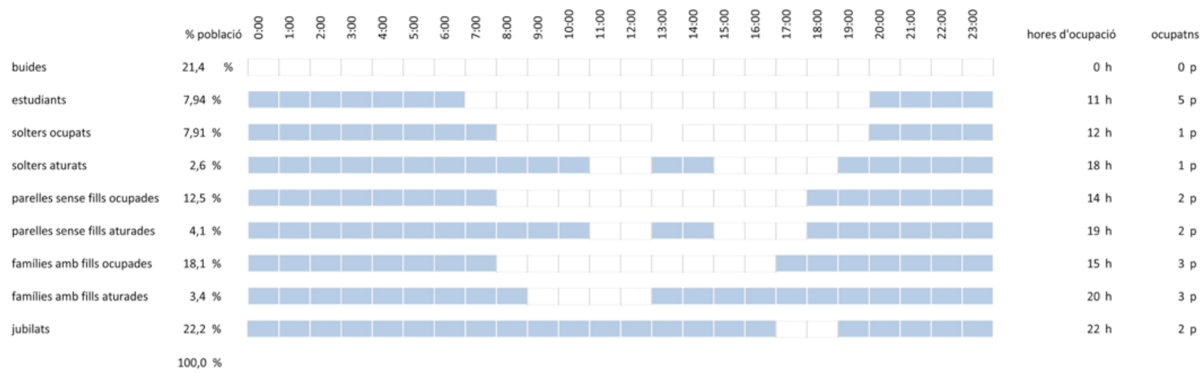


Fig. 24: Utilization Patterns features

Finally, the procedure will be to put them into the building strategycaly but mainly randomly in order to simulate a real building in where no one is able to control other's heating protocols and at the same time could represent a significant portion of Spanish society.

4 2.6% 100%	1 24.4% 11.1%	9 22.2% 11.1%	6 4.1% 50.0%	1 24.4% 11.1%	7 18.1% 14.3%	8 3.4% 100%	5 12.5% 20.0%
2 7.9% 33.3%	9 22.2% 11.1%	1 24.4% 11.1%	7 18.1% 14.3%	5 12.5% 20.0%	1 24.4% 11.1%	9 22.2% 11.1%	7 18.1% 14.3%
9 22.2% 11.1%	5 12.5% 20.0%	3 7.9% 33.3%	2 7.9% 33.3%	1 24.4% 11.1%	9 22.2% 11.1%	7 18.1% 14.3%	1 24.4% 11.1%
3 7.9% 33.3%	1 24.4% 11.1%	7 18.1% 14.3%	9 22.2% 11.1%	7 18.1% 14.3%	1 24.4% 11.1%	5 12.5% 20.0%	9 22.2% 11.1%
7 18.1% 14.3%	9 22.2% 11.1%	2 7.9% 33.3%	1 24.4% 11.1%	5 12.5% 20.0%	9 22.2% 11.1%	6 4.1% 50.0%	3 7.9% 33.3%

Fig. 25: UtilisationPatterns situation and quantities

With this first data summarized in this dwellings block, we managed to simulate its heat indoor flux in order to finally see if it could be a future improvement in Thermal Efficiency therories or if in the other hand it doesn't look important enough. As results will show, we are facing a very important phenomenon wich will bring us the key for users thermal efficiency, confort and money saving improvement.

4. Simulation: Nation Representative Block.

Tha last step in this research, is to put together all the basic data and hypothesis results to build up a complex simulation with *DesignBuilder* in order to introduce the time parameter variations in a building that could represent the average population of a whole country.

See in *Fig. 30*, software results that concerns to our research, which represent the energy lost from each space through every surfice in order to start developing some easy-understanding graphics showing thermal energy flux and where the energy is lost through.

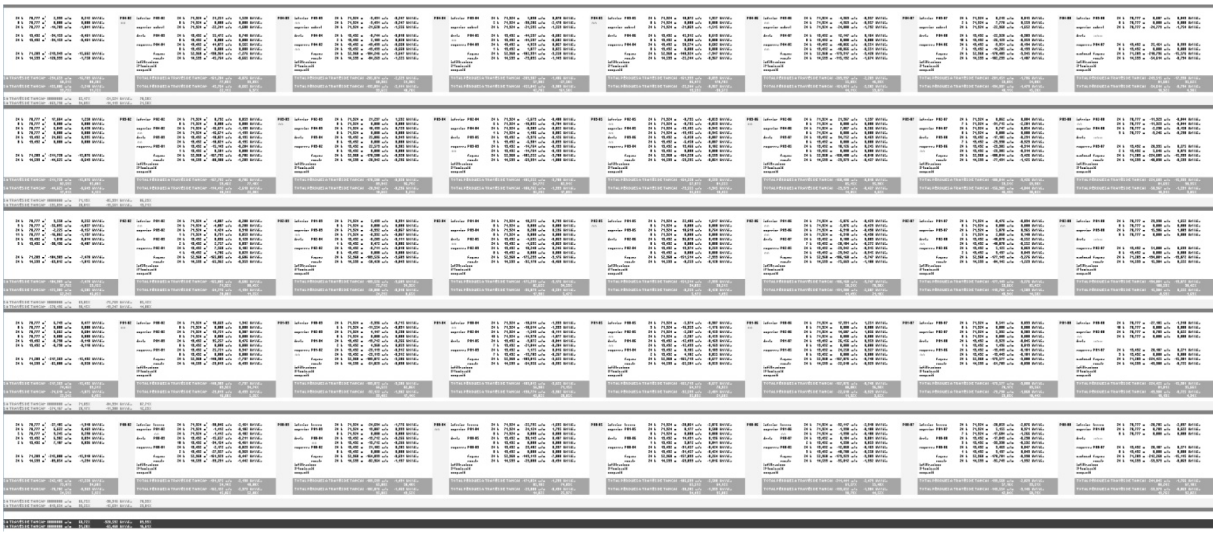


Fig. 26: DesignBuilding graphically-arranged numeric results

More closely, each dwelling modelized looked like the following table where it is shown the quantity of heat lost through all partitions during both, the most expected transmision periods and the whole day.

P00-02	inferior	terreny	24 h	71,924 m²	-30,046 w/m²	-2,161 kW/dia
	superior	P01-02	24 h	71,924 m²	-1,412 w/m²	-0,102 kW/dia
		buida	24 h	71,924 m²	-1,412 w/m²	-0,102 kW/dia
	dreta	P00-03	24 h	13,492 m²	-15,657 w/m²	-0,211 kW/dia
			10 h	13,492 m²	-34,154 w/m²	-0,461 kW/dia
	esquerra	P00-01	24 h	13,492 m²	-2,172 w/m²	-0,029 kW/dia
			2 h	13,492 m²	-27,327 w/m²	-0,369 kW/dia
		façana	24 h	52,360 m²	-161,329 w/m²	-8,447 kW/dia
		escales	24 h	14,533 m²	-99,231 w/m²	-1,442 kW/dia
	infiltracions					
	il·luminació					
	ocupació					
	TOTAL PÈRDUES A TRAVÉS DE TANCAMENTS EXTERIORS				-191,375 w/m²	-2,190 kW/dia
					54,14%	48,00%
	TOTAL PÈRDUES A TRAVÉS DE TANCAMENTS INTERIORS				-162,122 w/m²	-2,373 kW/dia
					45,86%	52,00%

Fig. 27: DesignBuilder graphically-arranged numeric results

As we know it is a very complicated simulation, we have just taken into acount engergy from heating systems, climate and situation. As it can be seen in Fig. 31, we expect in the future to be able to involve ventilation, lighting and people heat too.

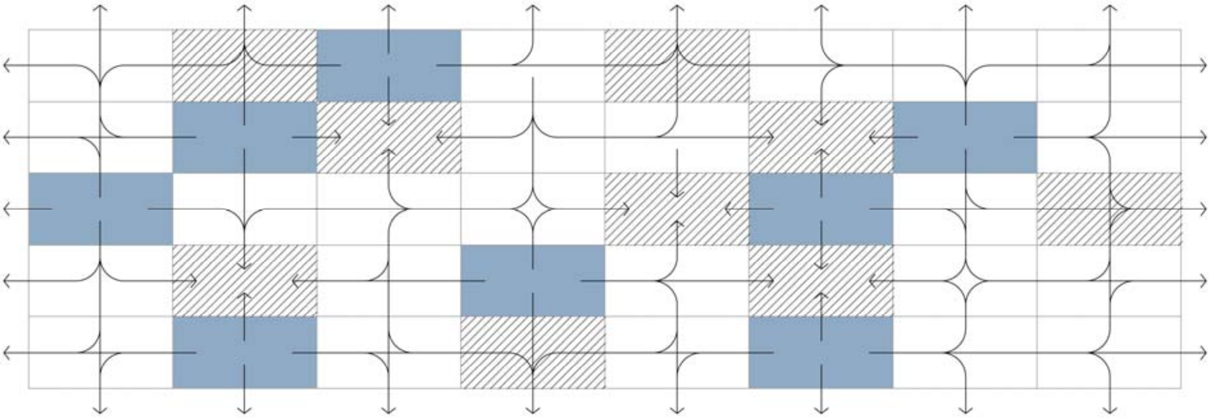


Fig. 28: DesignBuilding flow simulation chart. *Most heat looser units* *Empty units*

11,72%	6,97%	48,70%	72,42%	30,57%	52,07%	45,20%	4,38%
4,12%	22,90%	3,21%	17,09%	18,45%	4,62%	30,02%	9,65%
46,85%	11,55%	8,65%	5,47%	1,49%	21,10%	14,58%	1,63%
6,49%	5,26%	17,14%	28,85%	21,68%	3,62%	10,44%	4,34%
5,32%	52,0%	49,52%	25,97%	35,88%	41,52%	60,79%	32,32%

Fig. 29: Losses though interio partitions *>10%* *>20%* *>40%*

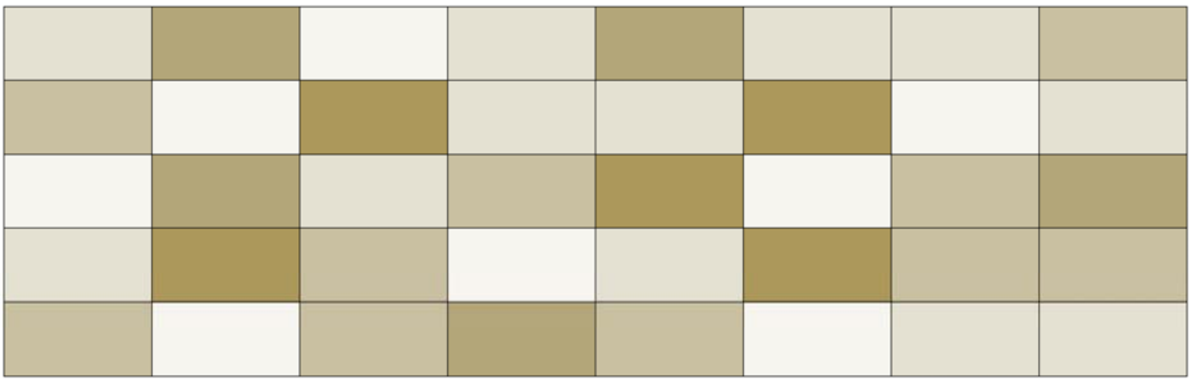


Fig. 30: Most energy-givers units *Most energy-thieves units*

With DesignBuilder results, we are able to develop the firsts charts and get conclusions:

Fig. 28: Energy flow balance after a whole day testing once the building has been fully heated. It can be appreciated how energy moves inside the building through interior partitions.

Fig. 29: It has been calculated how much energy is lost through exterior walls and interior partitions. As it can be seen, 62,5% of total units has at least a 10% of its energy lost through interior partitions. Then a 42,5% loses more than 20% through them, and finally there is a 22,5% of units that loses even more than 40% if its total heat through interior partitons.

Fig. 30: Finally, it has been deduced that within the same block, there are some units giving heat to other units and some others who steal it.

3. Conclusions

To summarize both researchs into some general conclusions, once having seen all the results together, we can say that we have come up with most of the answers of the hypothesis initially raised. Following a complexity-rising procedure, it has been proved through different methods and in different types of buildings that indoor heat losses through interior partitions is something that exists and can reach very important values that should be minimized in order to acheave a full energy efficiency in some typs of buildings.

According to the UZB managed by a single thermal generator, we find out that the value of these losses can reach up to 20.46%, which is a significant amount, bearing in mind that we are talking about buildings with a lot of volume and therefore a high thermal homogeneity. In addition, it must be remembered that the building chosen for this study, the ETSAV building, has a very little thermally efficient façade since, for example, all the overtures, which represent a 35, 4% of the façade's surface, are resolved with simple glass and aluminium frames without breaking of thermal bridge. Therefore, if we would decide to improve the thermal efficiency of the façade, we would see the losses value through the interior edge would droping enormously and in consequence the 20.46% value that we obtained with our first simulation would increase extremely in comparison with the results that we could achieve with a thermal efficiency façade improvement. Consequently, we believe that for this type of buildings, it is necessary to do a strategic thermal sectionalisation in order to minimize the internal losses.

According to the MZB, which could represent all the residential buildings managed by individual thermal generators, we can confirm that this building type is more affected by this phenomenon. The typical features of this type of constructions, with very small units, as could be seen in the different houses in a block of flats or rooms in a hotel complex, naturally lead to this result. There are lots of clearly defined spaces with different utilization patterns and heating protocols. According to our models, we found out that depending on the situation of the studied unit within the building as a whole and above all of the occupation and at the same time air conditioning units around it, the values relating to the thermal loss through the interior partitions is ranged between 25.7% and more than 70%. This proves that these enclosure walls are truly relevant to the flux of thermal energy and we therefore believe that they are the next huge topic to consider in the improving of the thermal efficiency of residential buildings, as they represent the most extensive building type in all developed world.

In this line and after completing our research with the most sophisticated simulation software, we realize that we have two main possibilities to improve interior thermal efficiency as suggested by proffessor Ray Galvin from Aachen University. The first one, is through education and management. As we have seen, utilization patterns are a key point in interior thermal building's efficiency. Consequently, it can be teached some utilization abits and combine these abits with a correct recources management in order to, for instance, keep some strategically units always heated to reduce big interior temperature differences or, in a more advanced scen, create a heated ring all around the building to reduce the need of heating of interior units giving this way a homogenious temperature in all units with a low variation pattern and consequently a low energy consumption.

The second and, may be, more direct way to avoid these looses could be by start thinking about buildings of an agglomeration of little individual and auto-regulated spaces in where each person is able to determine his dwelling temperature. To acheave this freedom for the user we should invest more resources in a correct isolation of interior partitions because with this model, what we finally get are little isolated units with no interior partitions.

Both theoryes has to bee deeply analyzed but the most probable conclusion is that each solution will be chosed depending on the country in which it is applied regarding climate, heating abits, most extended climatization system and some other parameters that would have to be taken into account. In any case, this first approach to the phenomenon represents an open gate to further investigations leading to a complet thermal efficiency in buildings.

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6. Further research

- In-deep analisy of DesignBuilder simulation Results.
- Technical solutions for Energy Retrofiting Interventions. Thermal sectorization.