UNIVERSITÀ DEGLI STUDI DI PADOVA

UNIVERSITÀ DEGLI STUDI DI PADOVA

Dipartimento di Ingegneria Industriale DII

Corso di Laurea Magistrale in Ingegneria Energetica

The evolution of the refurbishment of residential buildings in Hungarian regulation: a case study

Relator:

Chia.mo Prof. Michele de Carli

Correlators:

Dr. Ferenc Kalmár

Dott.ssa Samantha Graci

Laureando:

Nicola Furlan

1114638

Anno Accademico 2016/2017

Abstract

L’efficienza energetica degli edifici è uno dei principali obiettivi che l’Unione Europea impone per ridurre le emissioni di gas serra in atmosfera e fronteggiare il riscaldamento globale. A causa delle scarse prestazioni dell’involucro edilizio e di sistemi di generazione del calore datati e non sempre efficienti, il settore edilizio è tra quelli più energivori, con circa il 40% dei consumi totali [1]; è pertanto consigliabile intervenire sugli edifici per ottenere una significativa riduzione dei consumi energetici.

In quest’ottica l’Unione Europea ha fornito delle procedure standard per la valutazione della prestazione energetica degli edifici, le quali sono state recepite da ciascuno Stato membro attraverso decreti e normative tecniche.

Già a partire dalla Direttiva Europea 2002/91/CE [2] sul rendimento energetico nell’edilizia si pongono gli obiettivi di diminuire del 22% i consumi energetici comunitari entro il 2010, di ottenere un risparmio di energia primaria pari a 55 milioni di tep, e di ridurre le emissioni di CO_2 di un valore pari a 100 milioni di tonnellate.

Le direttive richiedono agli stati membri di provvedere affinché gli edifici di nuova costruzione e quelli esistenti sottoposti a ristrutturazioni importanti soddisfino requisiti minimi di rendimento energetico, monitorando “la quantità di energia effettivamente consumata o che si prevede possa essere necessaria per soddisfare i vari bisogni connessi a un uso standard dell'edificio, compresi, fra gli altri, il riscaldamento e il raffreddamento”. L'Attestato di Certificazione Energetica deve essere messo a disposizione in fase di costruzione, compravendita o locazione. In esso devono essere riportati “dati di riferimento che consentano ai consumatori di valutare e raffrontare il rendimento energetico dell'edificio” e “raccomandazioni per il miglioramento del rendimento energetico in termini di costi-benefici”.

La riduzione del consumo di energia negli edifici è una priorità indicata anche nella Direttiva europea 2010/31/UE [3], che adotta una comune metodologia di calcolo delle prestazioni che tiene conto di: condizioni climatiche interne, caratteristiche termiche (es. isolamento, capacità termica, ecc...), condizioni climatiche locali, esposizione al sole, illuminazione, impianti di condizionamento, impianti di illuminazione, sistemi di cogenerazione dell'elettricità.

Gli stati membri fissano dei requisiti minimi che devono essere aggiornati ogni 5 anni, conformi al metodo di calcolo. I minimi dovranno essere differenti se si considerano edifici nuovi o già esistenti, e differenti a seconda della tipologia edilizia. Per quanto riguarda gli edifici nuovi, questi dovranno rispettare determinati requisiti, come l'essere sottoposti a una valutazione preventiva sulla fattibilità di impianti di energia derivanti da fonti rinnovabili, inoltre la direttiva incoraggia l'introduzione di sistemi intelligenti per misurare il consumo energetico. Gli edifici che verranno ristrutturati dovranno migliorare la loro prestazione energetica per soddisfare i minimi richiesti.

Viene stabilito che gli elementi edilizi fanno parte dell'involucro e hanno un loro impatto significativo relativo alla prestazione dell'involucro (es. gli infissi). Devono anche questi rispettare dei minimi di requisito e devono essere rinnovati e sostituiti per raggiungere un livello ottimale relativo ai costi.

La Commissione europea promuove l'attuazione di una certificazione energetica degli edifici. Questo documento dovrà comprendere informazioni sul consumo energetico e su

come migliorare questo consumo in relazione ai costi. Viene fatto obbligo di far figurare l'attestato di prestazione energetica in tutti gli annunci commerciali dell'immobile. In caso di vendita o locazione dovrà sempre essere allegato alla documentazione e mostrato al potenziale acquirente. Deve essere redatto in caso di nuova costruzione o di ristrutturazione edilizia.

Questa normativa ha di fatto abrogato la direttiva 2002/91/CE [4].

Nel seguito si vuole presentare un'analisi termo-energetica svolta con TRNSYS, per mettere in evidenza alcuni aspetti importanti nel processo di diagnosi energetica e nella valutazione degli interventi di riduzione dei consumi, tenendo presente le diverse esigenze di utilizzo e le possibilità di intervento di fronte al progredire delle normative in merito.

Il caso di studio è un edificio residenziale costruito nel 2003, ubicato a Budapest, in Suzglò utca n° 99. Esso consiste in 4 piani fuori terra, di cui l'ultimo atticato, e di un garage sotterraneo. In ogni piano vi sono 8 unità immobiliari che spaziano tra gli 80 e i 120 m^2 ciascuna.

I dati a disposizione per il caso di studio sono:
- planimetria dell'edificio,
- stratigrafia delle murature e del tetto,
- trasmittanza termica degli infissi,
- valore di portata d'aria aspirata da cucine e bagni.

Figure 0.1 - View of the building from the street

Acknowledgements

I would like to thank first and foremost my Professor and Italian relator, Michele De Carli, who introduced me to the field of buildings, namely with the course “Impianti termotecnici” and “Energy and Buildings”;

My Hungarian supervisor from Debreceni Egyetem Professor Ferenc Kelmar, for his great availability at every hour of the day, and for this project he provided me;

But above all I would like to thanks PHD Samantha Graci for introducing me the software TRNSYS, and patiently answering all my questions, giving me a chance to improve my skills with that versatile software.

Table of Contents

List of figures

List of tables

1 Introduction

1.1 Background and scope

The European Union aims at a drastic reduction in greenhouse gases (GHG) emission, being bound by the Kyoto Protocol to the reduction of such gases by at least 5 per cent below 1990 levels in the period 2008 to 2012 [5] and targeting to really ambitious commitment for 2020, with “the EU climate and energy package” [6], and for 2050, with “Roadmap for moving to a competitive low carbon economy in 2050” [7].

The EU climate and energy policy sets the following targets for 2020:

- Cutting greenhouse gases by at least 20% of 1990 levels;
- Cutting energy consumption by 20% of projected 2020 levels - by improving energy efficiency;
- Increasing use of renewables energies (wind, solar, biomass, etc.) to 20% of total energy production (currently ± 8.5%).

EU bound itself to even higher commitment to reduce GHG emission to 80-95% below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group.

Since buildings account for around 40% of total energy consumption and 36% of CO_2 emission in Europe [1], the reduction of energy consumption and the use of energy from renewable sources in the building sector constitute therefore important measures needed to reduce energy dependency and GHG emission. Without consequently exploiting the great potential saving of buildings the EU will miss its reduction targets.

By improving the energy efficiency of buildings, is possible to reduce total EU energy consumption by 5-6% and lower CO_2 emissions by about 5%. [8]

To reduce building energy consumption, regulations are enhancing the appeal of sustainable constructions. Nevertheless, the rate of construction is low in most of developed countries. Efforts have to be made in existing buildings, which are statistically more energy-consuming than new residential buildings. To conduct an adapted energy retrofitting, an energy audit can be realized as a pre-study.

Aware of this huge saving potential, in order to comply with the emission commitments, EU parliament published the Directive 2010/31/EU (EPBD recast) [9] on the energy performance of buildings.

This legislation aims to improve the energy performance of buildings in the EU, taking into account various climatic and local conditions. It sets out minimum requirements and a common methodology. It covers energy used for heating, hot water, cooling, ventilation and lighting.

1.2 Objective of the thesis

The objective of the present work is the thermal analysis and the following energetically refurbishment of an existing residential building in Hungary, shown in Figure 0.1.

The thermal properties of the envelope, and the energy use for heating and cooling are analysed. In addition to this, also energy needs for ventilation and for DHW is calculate.

The project develops different proposals for the refurbishment of the envelope on an energy point of view, according to different Hungarians regulations, more restrictive over time. Several regulation have been considered: the regulations of 2006 [10], the cost optimum of 2014 [11], and finally the nZEB requirements [12], supposed in 2016.

The purpose of the thesis is therefore to discuss which could be the technical and economic implications and challenges of energetical refurbishment applied at residential scale. More advanced and complex calculations and measurements can obviously improve the result accuracy.

Nevertheless, the introduced approach gives a first understanding of a building, by analysing its strengths and its weaknesses. This renovation plan can then be used as a first-decision making tool for the retrofitting project.

1.3 Structure of the thesis

Chapter 1: an introduction to the motivations of the thesis and its purposes are provided.

Chapter 2: the chapter gives an overview about the case study, describing the building that will be analysed in detail, paying particular attention to the subdivision of the various floors of the building.
Secondly, thermal properties and stratigraphy of the walls will be presented, deepening finally with an analysis of the building's thermal bridges.

Chapter 3: the chapter will describe the dynamic simulation software TRNSYS; afterwards the TRNSYS model of the building will be described.

Chapter 4: in the chapter the pre-retrofit analysis is presented, reporting the calculated results of peak heating power of the building, the rating heating demand, the primary energy need and the CO_2 emissions.

Chapter 5: Energy retrofitting plans are created and analysed. Are reported retrofitting plans according to normative in 2006, 2014 and nZEB in 2016.

Chapter 6: Each retrofitting solution is analysed and evaluated in terms of investment cost and energy savings.

Chapter 7: Conclusions are presented.

2 Description of the case study

2.1 Description of the building

The case study is an apartment building built in 2003. It is located in Budapest, Suzglò utca n° 99; GPS coordinates are 47.519328, 19.118576. [13]

The apartment block is composed by 32 apartments distributed in 4 floors, with an underground garage. The last floor has a mansard roof. Each apartment is facing the outside, and to an internal corridor that links all the apartments to the stairwell and to an elevator, as the floor plans (Figure 2.6 - Figure 2.10) shows.

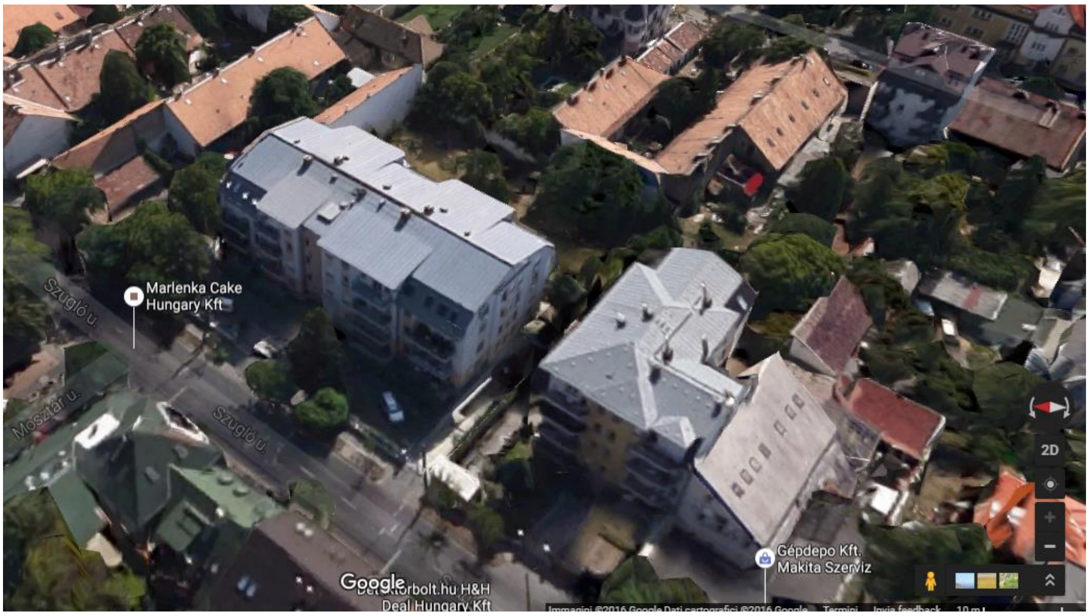
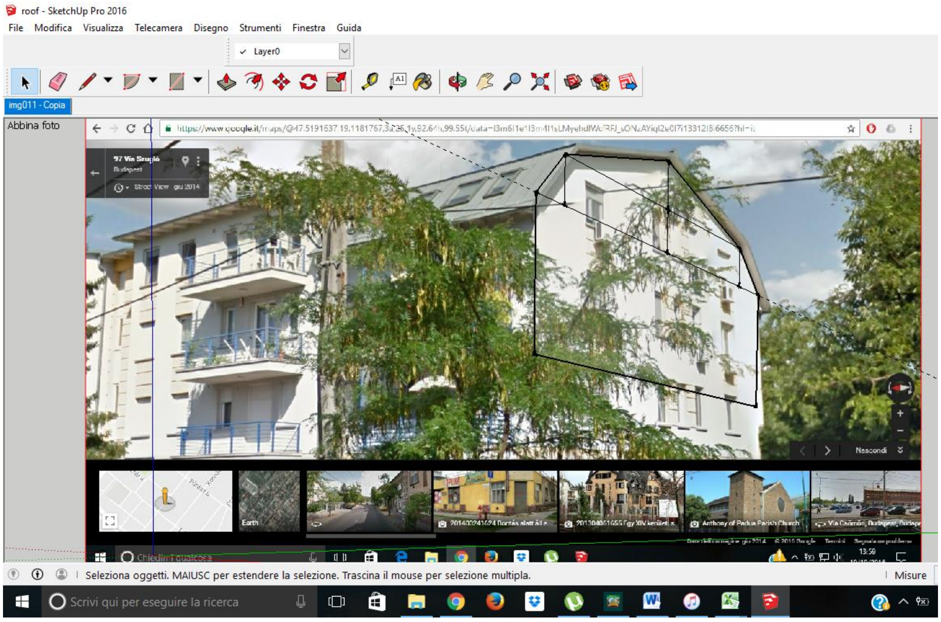


Figure 2.1 - Aerial view of the building

Unfortunately the original plans and sections were not available, so it was not easy to establish the right inclination angles of the roof. To obtain a result as precise as possible, it was decided to proceed as follow:

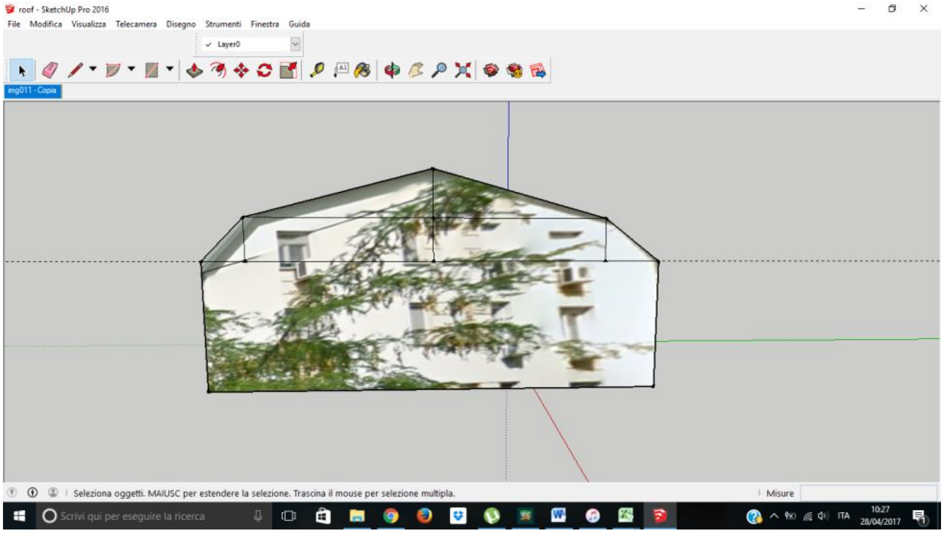
- Pictures of the building were searched in google Maps, and was taken a screenshot of the building. (Figure 0.1, Figure 2.1)
- The photo of the facade of the building was uploaded on google SketchUp, and prospective lines were drawn. (Figure 2.2)



Seleziona oggetti. MAIUSC per estendere la selezione. Trascina il mouse per selezione multipla.

Figure 2.2 - Drawing of guidelines in Google Sketchup

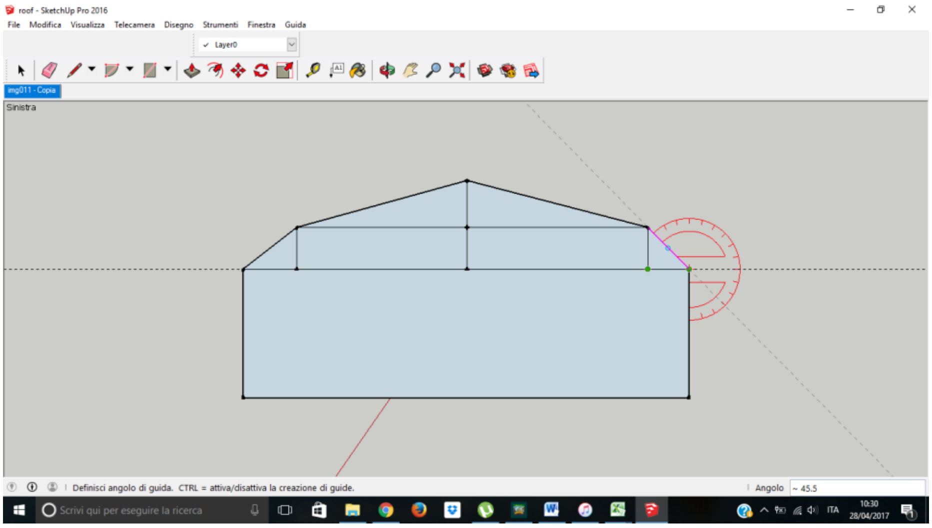
- The third step is to rotate the image of the façade of the building and the construction lines in a plane parallel to the screen (Figure 2.3)



Seleziona oggetti. MAIUSC per estendere la selezione. Trascina il mouse per selezione multipla.

Figure 2.3 - Rotating the image to make it parallel

- Finally was possible to remove the watermark of the façade, and measure the angles of inclinations for the pitch of the roof. (Figure 2.4)



Definisci angolo di guida. CTRL = attiva/disattiva la creazione di guide.

Angolo ~ 45.5

Figure 2.4 - Lateral view of the building

Because of the distortion of the picture in google maps, it was not found a symmetrical angle, but an inclination between 14.5 ÷ 17.5° for the upper pitch of the roof, and a value between 46 and 56° for the lower one.

It has been decided to use an angle of 48° for the lower pitch. For the upper one, was taken the value of 15°.

Following in Figure 2.5, a 3D rendering of the whole building.

Figure 2.5 - Rendering of the building

2.2 Distribution of apartments

The case study is a four-storey building, composed by a ground floor, a first and second identical floors and an attic. The geometrical characterization of each floor is following presented.

2.2.1 Cellar

Garage has a global area of 620 m^2 and a volume of 1543 m^3. In Figure 2.6 a map of the floor is presented; in Figure 2.7 a 3D representation.

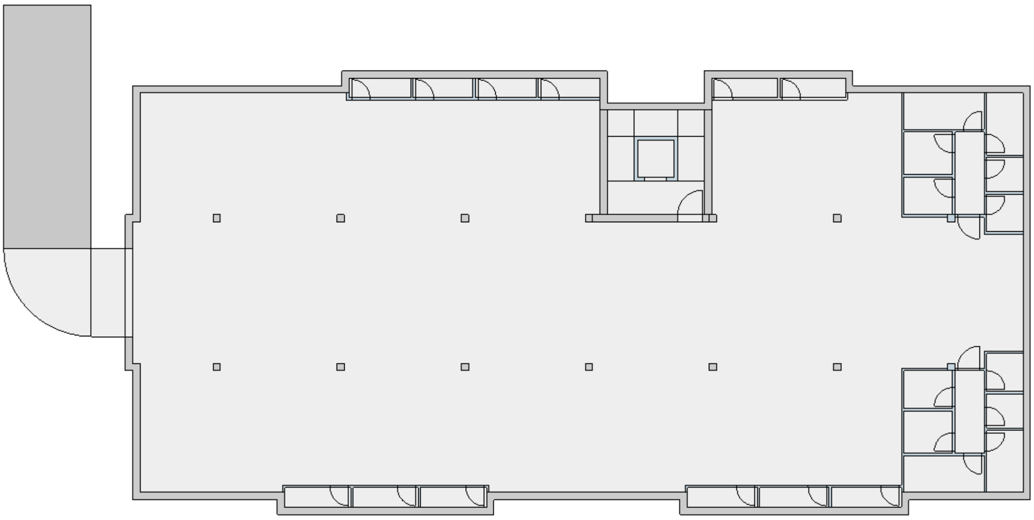


Figure 2.6 - Garage floor plan

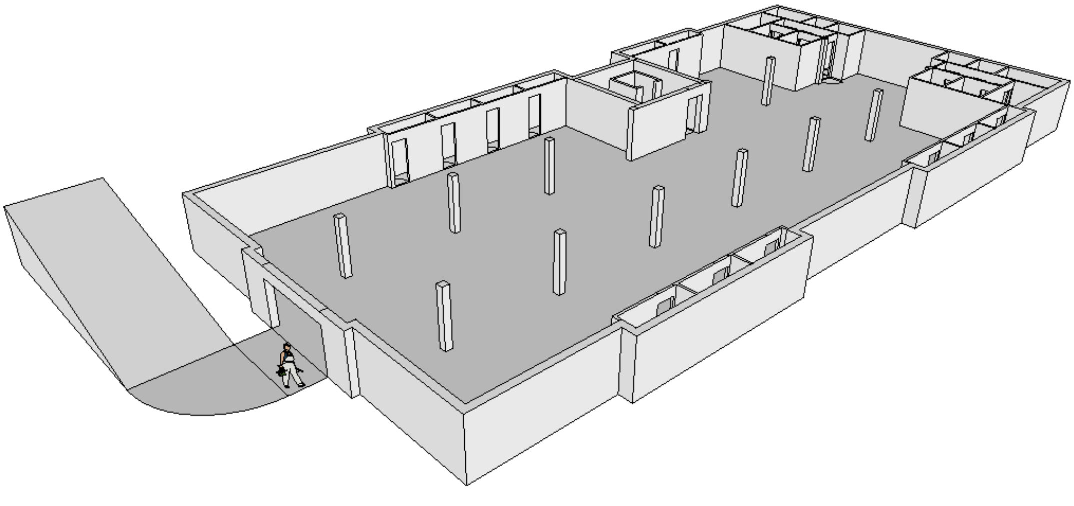


Figure 2.7 - 3D representation of the garage

2.2.2 Ground floor

Ground floor has a net floor area of 557 m^2 and a global volume of 1559 m^3, of which 491 m^2 and 1375 m^3 represent the heated zone: the two entrances, and the common corridor are unheated.

In Figure 2.8 a map of the floor is presented; in Figure 2.9 a 3D representation.
The Table 2.1 displays the area and the volume of each room at the ground floor, and their geometrical dimensions of opaque and transparent surfaces.

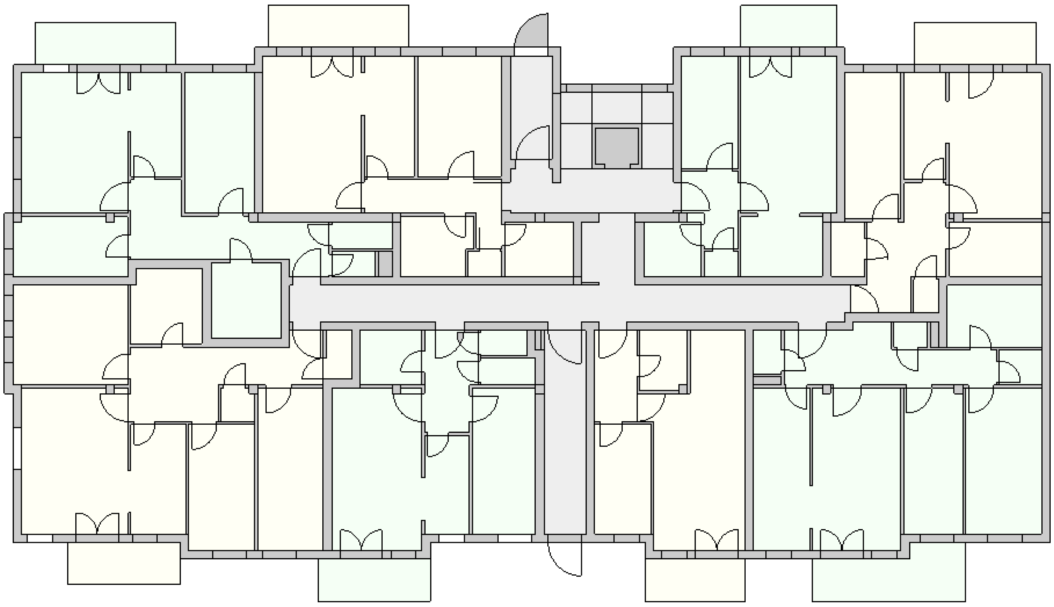


Figure 2.8 - Ground floor plan

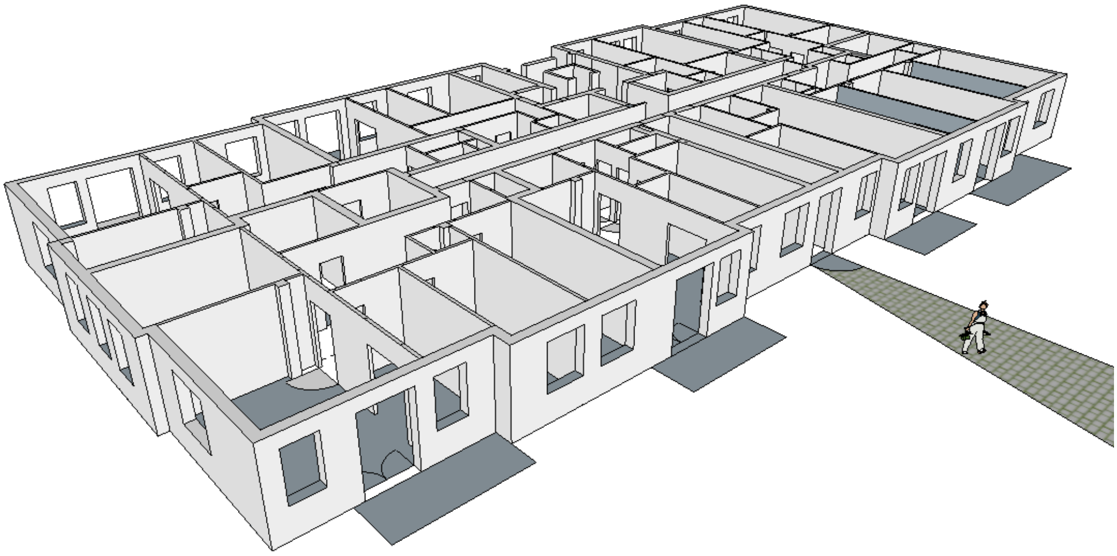


Figure 2.9 - 3D representation of the ground floor. The entrance is put in evidence.

Table 2.1 - Salient data for the ground floor apartments

Ground Floor				
ZONES	Net floor area [m^2]	Heated volume [m^3]	Glazed Area [m^2]	Envelope area [m^2]
LIVING_1	27.46	76.89	8.55	30.94
ROOM1_1	14.56	40.77	2.7	9.94
ROOM2_1	10.57	29.60	1.8	6.58
ROOM3_1	13.63	38.16	1.8	6.58
CORR_1	14.52	40.66		
TOILET_1	6.76	18.93		
WC_1	1.65	4.62		
CLOSET_1	1.48	4.14		
LIVING_2	24.25	67.90	6.3	15.4
ROOM_2	11.7	32.76	1.8	6.3
CORR_2	6.77	18.96		
TOILET_2	4.29	12.01		
WC_2	1.56	4.37		
CLOSET_2	1.93	5.40		
LIVING_3	23.19	64.93	4.95	10.78
ROOM_3	7.8	21.84	1.35	5.6
CORR_3	5.03	14.08		
TOILET_3	3.6	10.08		
LIVING_4	29.96	83.89	6.3	16.38
ROOM1_4	10.86	30.41	1.8	5.88
ROOM2_4	14.04	39.31	1.8	22.12
CORR_4	13.01	36.43		
TOILET_4	7.37	20.64		6.16
WC_4	1.15	3.22		
CLOSET1_4	1.62	4.54		
CLOSET2_4	1.88	5.26		3.5
LIVING_5	22.95	64.26	4.86	28.28
ROOM_5	10.4	29.12	1.8	5.6
CORR_5	10.52	29.46		
TOILET_5	6.44	18.03		5.46
WC_5	1.15	3.22		
CLOSET_5	2.42	6.78		
LIVING_6	25.43	71.20	4.95	11.2
ROOM_6	8	22.40	1.8	8.4
CORR_6	4.77	13.36		
TOILET_6	4	11.20		
WC_6	1.16	3.25		
LIVING_7	27.49	76.97	6.3	16.8
ROOM_7	12.9	36.12	1.8	8.4
CORR_7	10.45	29.26		
TOILET_7	5.29	14.81		
WC_7	1.16	3.25		
CLOSET_7	4.78	13.38		
LIVING_8	25.81	72.27	8.55	29.96
ROOM1_8	12.5	35.00	1.8	7
ROOM2_8	8.7	24.36	1.35	6.02
CORR_8	13.96	39.09		
TOILET_8	6.83	19.12		
WC_8	1.4	3.92		
CLOSET_8	2.12	5.94		
CORRIDOR0	30.39	85.09		
STAIRWELL0	18.81	52.67	4.455	11.2
ENTRY1	10.88	30.46	2.88	4.2
ENTRY2	5.55	15.54	2.88	7
TOT	*556.9*	*1559.3*	*82.6*	*295.7*

2.2.3 First and second floor

The first and the second floor have a net floor area of 555 m^2 , of which 510 m^2 represent the heated zone: the common corridor and the stairwell are unheated.

The Table 2.2 displays the area and the volume of each room at the ground floor, and their geometrical dimensions of opaque and transparent surfaces.
In Figure 2.10 a map of the floors is presented; in Figure 2.11 a 3D representation.

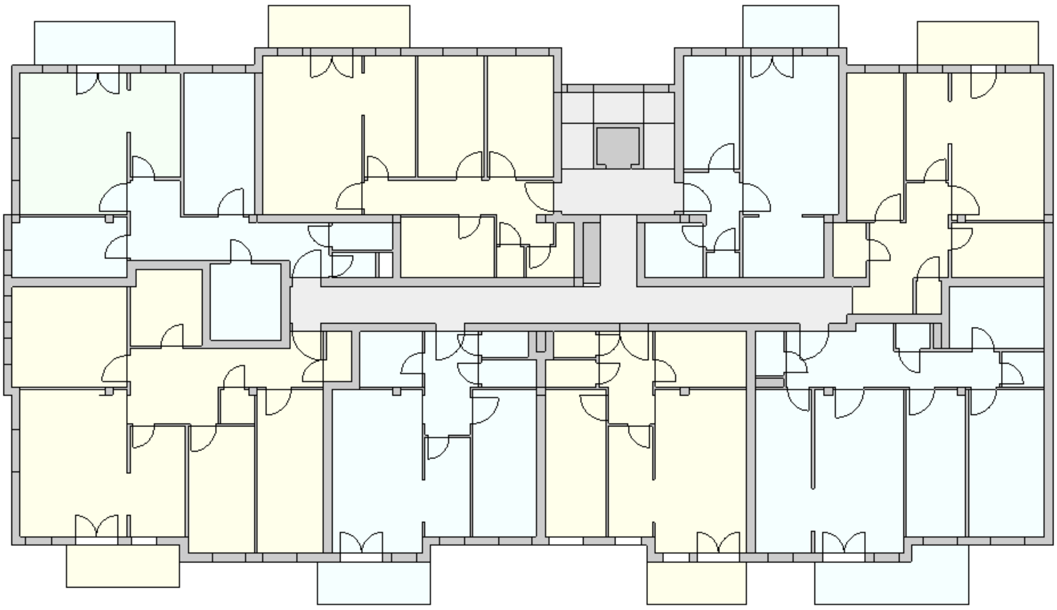


Figure 2.10 - First and second floor plan

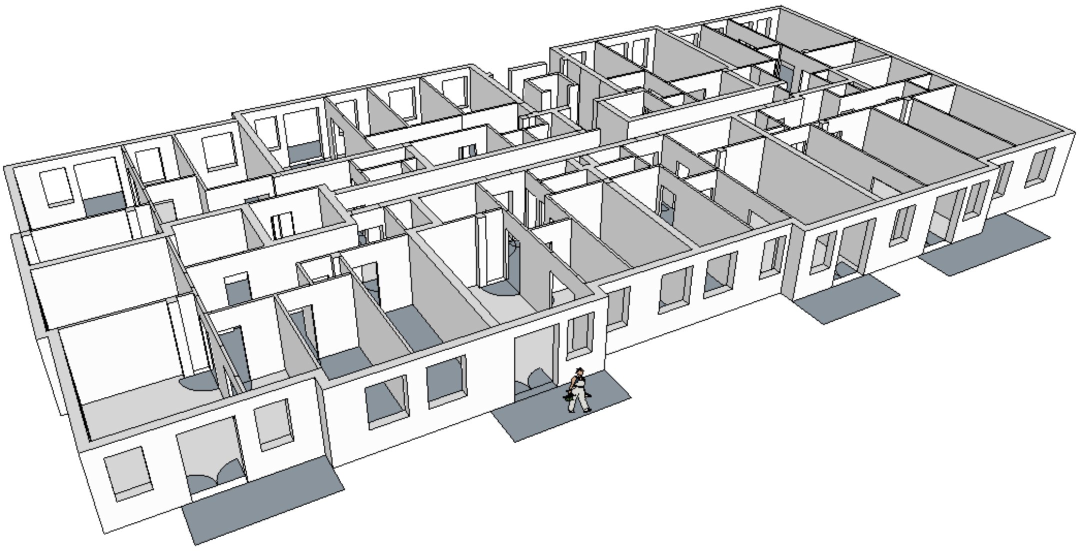


Figure 2.11 - 3D representation of first and second floor

Table 2.2 - Salient data for the first and second floor apartments

First&Second Floor				
ZONES	Net floor area $[m^2]$	Heated volume $[m^3]$	Glazed Area $[m^2]$	Envelope area $[m^2]$
LIVING_9	27.46	76.89	8.55	30.94
ROOM1_9	14.56	40.77	2.7	9.94
ROOM2_9	10.57	29.60	1.8	6.58
ROOM3_9	13.63	38.16	1.8	6.58
CORR_9	14.52	40.66		
TOILET_9	6.76	18.93		
WC_9	1.65	4.62		
CLOSET_9	1.48	4.14		
LIVING_10	24.25	67.90	6.3	15.40
ROOM_10	11.7	32.76	1.8	6.30
CORR_10	6.77	18.96		
TOILET_10	4.29	12.01		
WC_10	1.56	4.37		
CLOSET_10	1.93	5.40		
LIVING_11	25	70.00	6.3	15.40
ROOM_11	11.18	31.30	1.8	6.02
CORR_11	5.97	16.72		
TOILET_11	6.34	17.75		
WC_11	1.43	4.00		
CLOSET_11	1.79	5.01		
LIVING_12	29.96	83.89	6.3	16.38
ROOM1_12	10.86	30.41	1.8	5.88
ROOM2_12	14.04	39.31	1.8	22.12
CORR_12	13.01	36.43		
TOILET_12	7.37	20.64		6.16
WC_12	1.15	3.22		
CLOSET1_12	1.62	4.54		
CLOSET2_12	1.88	5.26		3.50
LIVING_13	22.95	64.26	4.86	28.28
ROOM_13	10.4	29.12	1.8	5.60
CORR_13	10.52	29.46		
TOILET_13	6.44	18.03		5.46
WC_13	1.15	3.22		
CLOSET_13	2.42	6.78		
LIVING_14	25.43	71.20	4.95	11.20
ROOM_14	8	22.40	1.8	8.40
CORR_14	4.77	13.36		
TOILET_14	4	11.20		
WC_14	1.16	3.25		
LIVING_15	27.49	76.97	6.3	16.80
ROOM1_15	10.1	28.28	1.8	9.38
ROOM2_15	10.1	28.28	1.8	6.58
CORR_15	10.45	29.26		
TOILET_15	7.1	19.88		
WC_15	1.12	3.14		
CLOSET_15	2.42	6.78		
LIVING_16	25.81	72.27	8.55	29.96
ROOM1_16	12.5	35.00	1.8	7.00
ROOM2_16	8.7	24.36	1.35	6.02
CORR_16	13.96	39.09		
TOILET_16	6.83	19.12		
WC_16	1.4	3.92		
CLOSET_16	2.12	5.94		
CORRIDOR1	30.39	85.09		
STAIRWELL1	14.92	41.78	4.455	11.20
TOT	*555.4*	*1555.1*	*80.4*	*297.1*

2.2.4 Attic

The attic floor present the same planimetry as the first and the second floor (Figure 2.10), it has the same global area of 555 m^2, of which 510 m^2 are heated, but volumes are minor: a total of 1516 m^3 ; 1390 m^3 heated (the common corridor and the stairwell are unheated).

The Table 2.3 displays the area and the volume of each room at the ground floor, and their geometrical dimensions of opaque and transparent surfaces.

A 3D representation is reported in Figure 2.12

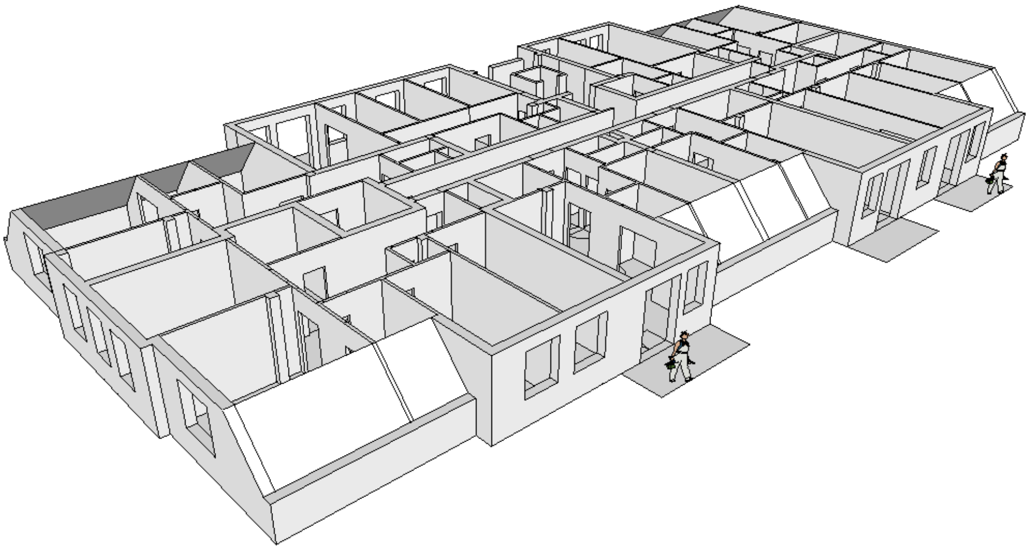


Figure 2.12 - 3D representation of the attic; the mansarded surfaces are put in evidence

Table 2.3 - Salient data for the attic floor apartments

Attic					
ZONES	Net floor area [m^2]	Heated volume [m^3]	Glazed Area [m^2]	Envelope area [m^2]	Roof Area [m^2]
LIVING_25	27.46	70.16	6.114	20.43	12.58
ROOM1_25	14.56	40.77	2.7	9.94	
ROOM2_25	10.57	29.60	1.8	7.73	5.05
ROOM3_25	13.63	38.16	1.8	6.58	5.05
CORR_25	14.52	40.66			
TOILET_25	6.76	18.93			
WC_25	1.65	4.62			
CLOSET_25	1.48	4.14			
LIVING_26	24.25	66.06	6.04	12.15	3.44
ROOM_26	11.7	30.17	1.68	6.30	4.84
CORR_26	6.77	18.96			
TOILET_26	4.29	12.01			
WC_26	1.56	4.37			
CLOSET_26	1.93	5.40			
LIVING_27	25	68.21	6.04	12.23	3.33
ROOM_27	11.18	28.83	1.68	6.02	4.62
CORR_27	5.97	16.72			
TOILET_27	6.34	17.75			
WC_27	1.43	4.00			
CLOSET_27	1.79	5.01			
LIVING_28	29.96	83.28	6.3	16.38	
ROOM1_28	10.86	28.00	1.68	2.52	4.52
ROOM2_28	14.04	36.20	1.68	16.65	5.81
CORR_28	13.01	36.43			
TOILET_28	7.37	20.64		6.16	
WC_28	1.15	3.22			
CLOSET1_28	1.62	4.54			
CLOSET2_28	1.88	5.26		3.50	
LIVING_29	22.95	58.62	3.276	19.29	10.54
ROOM_29	10.4	26.82	1.68	2.40	4.30
CORR_29	10.52	29.46			
TOILET_29	6.44	18.03		5.46	
WC_29	1.15	3.22			
CLOSET_29	2.42	6.78			
LIVING_30	25.43	71.20	4.95	12.35	
ROOM_30	8	22.40	1.8	8.40	
CORR_30	4.77	13.36			
TOILET_30	4	11.20			
WC_30	1.16	3.25			
LIVING_31	27.49	76.97	6.3	16.80	
ROOM1_31	10.1	28.28	1.8	9.38	
ROOM2_31	10.1	28.28	1.8	6.58	
CORR_31	10.45	29.26			
TOILET_31	7.1	19.88			
WC_31	1.12	3.14			
CLOSET_31	2.42	6.78			
LIVING_32	25.81	65.71	6.114	19.69	12.26
ROOM1_32	12.5	32.12	1.68	3.00	5.38
ROOM2_32	8.7	24.36	1.35	6.02	
CORR_32	13.96	39.09			
TOILET_32	6.83	19.12			
WC_32	1.4	3.92			
CLOSET_32	2.12	5.94			
CORRIDOR3	30.39	85.09			
STAIRWELL3	14.92	41.78	4.455	11.20	
TOT	*555.4*	*1516.1*	*72.7*	*247.2*	*81.7*

2.3 Opaque surfaces: walls and roof

For the purpose of modelling, it has been necessary evaluate the different types of masonry used in the building. Stratigraphy used to construct the building were available.

For the subsequent redevelopments it is externally added a layer of insulation, gradually increasing thickness step by step.

Table 2.4 - Legend symbols

Value	Symbol	Unit
Thickness	s	m
Thermal conductivity	λ	W/mK
Thermal conductivity-TRNSYS input	λ-Trnsys	kJ/hmK
Thermal resistance	R	m^2K/W
Specific thermal capacity	T.C.*	J/kgK
Density	ρ	kg/m^3
Thermal capacity-MIRAGE input	T.C.	MJ/m^3K

Table 2.5 - Stratigraphy of the external wall

External walls							
Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	*m^2K/W*	*J/kgK*	*kg/m^3*	*MJ/m^3K*
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
B30 bricks	0.3	0.64	2.304		1000	1000	1
cement mortar	0.01	0.93	3.348		1000	2200	2.2
External surface resistance*	-	-	-	0.041	-	-	-
R_layers Σ(dj/λj)	0.4918	*m^2K/W*					
Rtot = Rsi+Σ(dj/λj) + Rse	0.664	*m^2K/W*					
U-value = 1/Rtot	**1.506**	***W/m^2K***					
** Calculations according to the standard UNI EN ISO 6946: 2008*							

Table 2.6 - Stratigraphy of the insulated slab

Slab between ground floor and cellar							
Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	*m^2K/W*	*J/kgK*	*kg/m^3*	*MJ/m^3K*
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
EPS	0.02	0.042	0.1512		1000	33	0.033
reinforced concrete	0.2	1.55	5.28		1000	2400	2.4
estrich concrete	0.03	1.28	4.608		1000	2400	2.4
tiles	0.007	1.05	3.78		1000	2000	2
Internal surface resistance*	-	-	-	0.131	-	-	-
R_layers Σ(dj/λj)	0.6477	*m^2K/W*					
Rtot = Rsi+Σ(dj/λj) + Rsi	0.910	*m^2K/W*					
U-value = 1/Rtot	**1.099**	***W/m^2K***					
** Calculations according to the standard UNI EN ISO 6946: 2008*							

Table 2.7 - Stratigraphy of the slab between floors

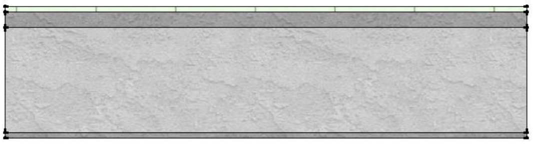
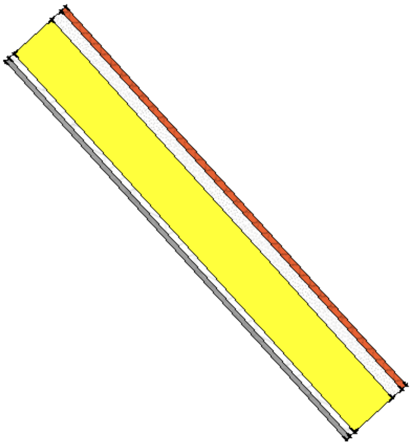
Slab between floors							
Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	*m^2K/W*	*J/kgK*	*kg/m^3*	*MJ/m^3K*
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
reinforced concrete	0.2	1.55	5.28		1000	2400	2.4
estrich concrete	0.03	1.28	4.608		1000	2400	2.4
tiles	0.007	1.05	3.78		1000	2000	2
Internal surface resistance*	-	-	-	0.131	-	-	-
R_layers Σ(dj/λj)	0.1715	*m^2K/W*					
Rtot = Rsi+Σ(dj/λj) + Rsi	0.433	*m^2K/W*					
U-value = 1/Rtot	**2.307**	***W/m^2K***					
** Calculations according to the standard UNI EN ISO 6946: 2008*							

Table 2.8 - Stratigraphy of the roof

External roof							
Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	m^2K/W	*J/kgK*	kg/m^3	MJ/m^3K
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
plasterboard	0.0125	0.24	0.864		1000	950	0.95
glass wool	0.1	0.044	0.1584		1000	60	0.06
plastic leaf	0.001	0.21	0.756		1000	970	0.97
air layer	0.025	-	-	0.07	1000	1.2	0.0012
roof tiles	0.0125	1.28	4.608		1000	1000	1
External surface resistance*	-	-	-	0.131	-	-	-

R_layers Σ(dj/λj)	2.4217	m^2K/W	
Rtot = Rsi+Σ(dj/λj) + Rsi	2.594	m^2K/W	
U-value = 1/Rtot	**0.386**	W/m^2K	
** Calculations according to the standard UNI EN ISO 6946: 2008*			

About windows, we have no data available, except for the value of thermal transmittance, equal to $U_{windows} = 2.2\ W/m^2K$.

2.4 Thermal bridges

Heat makes its way from the heated space towards the outside. In doing so, it follows the path of least resistance. A thermal bridge is a localised area of the building envelope where the heat flow is increased in comparison with adjacent areas, if there is a difference in temperature between the inside and the outside.

The effects of thermal bridges are:

- Higher energy consumption: due to the thermal outflow at the balcony connection, heat is drawn from every room resulting in a significant rise in heating costs and energy consumption.
- Mold formation: interior temperatures of the adjacent rooms can drop well below the dew point. This leads to condensation, deteriorates plaster and paintwork and is an ideal condition for harmful mold formation! If there is sustained exposure to condensation, the building is subject to serious deterioration.
- Uncomfortable living space: cold surface temperatures cause uncomfortable living space for occupants.

A general overview is possible if the procedure for determining the transmission heat losses H_T of the building envelope is considered. The following equation makes a distinction between one-dimensional, two-dimensional and three-dimensional heat flows.

$$H_T = \sum\nolimits_i A_i \, U_i + \sum\nolimits_k l_k \, \psi_k + \sum\nolimits_j x_j$$

where

- A_i area of the building components, in m^2;
- U_i thermal transmittance of component i of the building envelope, $W/(m^2K)$;
- l_k length of the linear thermal bridge k, in m;
- ψ_k thermal trasmittance of the linear thermal bridge k, in $W/(mK)$;
- x_j thermal trasmittance of the point thermal bridge k, in W/K.

Planar regular building components such as the roof areas and exterior walls have the largest share of the total heat flow. For these, heat transfer can be considered one-dimensional with good approximation. The reason for this is that no cross-flows occur in them on account of their homogeneous layered structure.

The two-dimensional and three-dimensional heat flow proportion of the building envelope is expressed by thermal bridges. They are defined by geometric, constructive and/or material modification and usually exhibit a higher heat flow rate and lower surface temperatures than adjacent standard building components. They occur particularly at the component joints, edges, transitions and penetrations of the standard building components. They are depicted by the linear thermal transmittance ψ with the unit $W/(mK)$ and the point thermal transmittance x in W/K.

Thermal bridges can significantly increase the building energy demand for heating and cooling. Thermal bridging is specific to the design and specification and can be complex and time consuming to calculate. For this reason, some countries allow a default thermal bridging value to be used, based upon a percentage (typically 15%) of the overall heat loss calculation.

It is assumed that heat flow simulations are associated with an uncertainty of ca. 5 %, other methods such as the use of thermal bridge catalogues are even associated with an uncertainty of up to 20 % (DIN EN ISO 14683, Section 5.1).

However, as a detailed thermal bridging calculation has been undertaken, will be calculated the different thermal bridges with a finite element method software, according to UNI EN ISO 10211.

Point thermal bridges are relate to a negligible component of the total heat flow, and are therefore not taken into account in the considered project.

2.4.1 Calculating thermal bridges according to UNI EN ISO 10211

The standard defines the specifications of the two-dimensional and three-dimensional geometric models of a thermal bridge for numerical calculation of heat flows, necessary to calculate building total heat losses.

In addition to the linear/point thermal transmittance calculation and temperature factor at the internal surface, ISO standard defines the limits of the geometric model and the rules to be adopted for its subdivision, the thermal boundary conditions, the thermal values.

Thermal bridge must be delimited by construction planes positioned:

- at symmetry plane, if this is less than d_{min} by the central element
- at d_{min} by the central element if there are symmetry planes closer
- d_{min} is the higher of 1 m and three times the thickness of the side considered
- in the ground according to a certain pattern

In according to UNI EN ISO 10211, 2D-dimensional model (Figure 2.13) heat flow refers to the length in meters of linear thermal bridge is calculated as:

$$\Phi = L_{2D}\ (\theta_i - \theta_e) \qquad [W/m]$$

where:

- L_{2D} thermal coupling coefficient obtained from a 2D calculation of the component $[W/mK]$;
- θ_i internal temperature;
- θ_e external temperature.

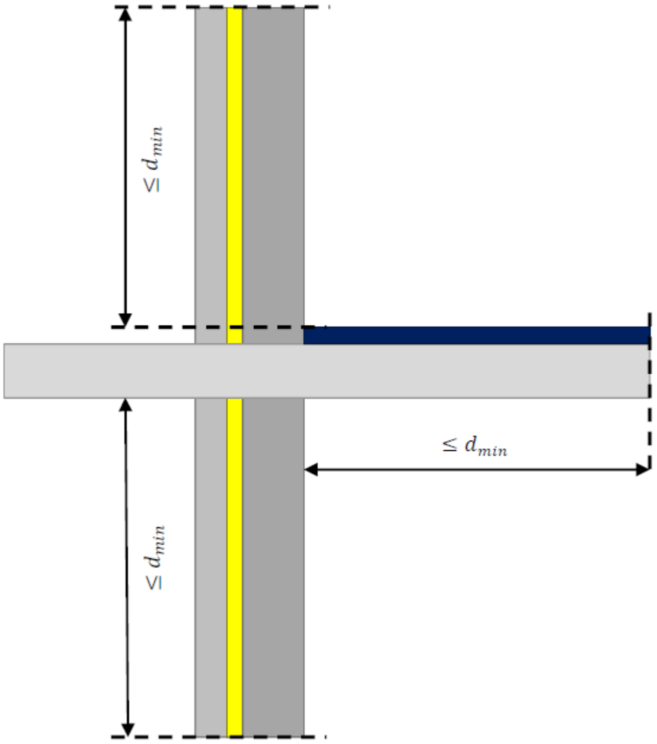


Figure 2.13 - Construction planes of 2D model

Linear thermal transmittance ψ of thermal bridge is calculated as:

$$\psi = L_{2D} - \Sigma(U \times l) \qquad [W/mK]$$

where:

- L_{2D} thermal coupling coefficient obtained from a 2D calculation of the component $[W/mK]$
- U thermal transmittance of the component $[W/m^2K]$
- l length over which U applies $[m]$

2.4.2 FEMM 4.2 - Mirage

FEMM is a suite of programs for solving steady-state heat flow problems, besides low frequency electromagnetic problems, linear/nonlinear magnetostatic problems, linear/nonlinear time harmonic magnetic problems, and linear electrostatic problems.

The heat flow problems address by FEMM are essentially steady-state heat conduction problems. These problems are represented by a temperature gradient, and heat flux density. FEMM bring results for temperature T over a user-defined domain with user-defined heat sources and boundary conditions.

There are four types of boundary conditions for heat flow problems:

- *Fixed Temperature:* the temperature along the boundary is set to a prescribed value.
- *Heat Flux:* The heat flux, f, across a boundary is prescribed. This boundary condition can be represented mathematically as: $k\frac{\partial T}{\partial n} + f = 0$, where n represents the direction normal to the boundary.
- *Convection:* Convection occurs if the boundary is cooled by a fluid flow. This boundary condition can be represented as: $k\frac{\partial T}{\partial n} + h(T - T_0) = 0$, where h is the "heat transfer coefficient" and *To* is the ambient cooling fluid temperature.
- *Radiation:* Heat flux via radiation can be described mathematically as: $k\frac{\partial T}{\partial n} + \beta\, ksb\,(T^4 - T_0^4) = 0$, where *beta* is the emissivity of the surface (a dimensionless value between 0 and 1) and ksb is the Stefan-Boltzmann constant.

If no boundary conditions are explicitly defined, each boundary defaults an insulated condition (*i.e.* no heat flux across the boundary). However, a non-derivative boundary condition must be defined somewhere (or the potential must be defined at one reference point in the domain) so that the problem has a unique solution.

Although the differential equations of interest appear relatively compact, it is very difficult to get closed-form solutions for all but the simplest geometries. This is why finite element analysis is used: the idea of finite elements is to break the problem down into a large number regions, each with a simple geometry (e.g. triangles). For example, Figure 2.14 shows the stratigraphy of a corner's section, broken down into triangles. Over these simple regions, the "true" solution for the desired potential is approximated by a very simple function.

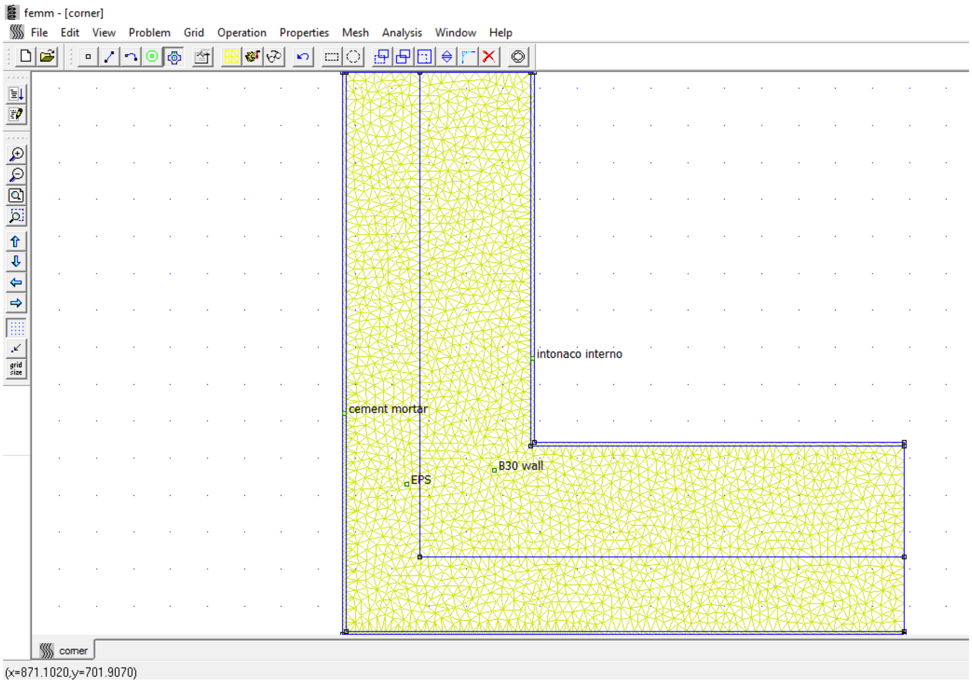


Figure 2.14 - Triangulation of a corner

If enough small regions are used, the approximate potential closely matches the exact solution. The advantage of breaking the domain down into a number of small elements is that the problem becomes transformed from a small but difficult to solve problem into a big but relatively easy to solve problem.

Specifically, FEMM discretizes the problem domain using triangular elements. Over each element, the solution is approximated by a linear interpolation of the values of potential at the three vertices of the triangle. The linear algebra problem is formed by minimizing a measure of the error between the exact differential equation and the approximate differential equation as written in terms of the linear trial functions.

In the following chapters the principals typologies of thermal bridges of our building are analysed. The first step is identify the more important thermal bridges of the building -as shown in Figure 2.15-; then their 2D section planes are drawn in AutoCAD; finally those sections are imported in FEMM, obtaining the ψ value of the selected thermal bridge.

Are below described the principals thermal bridges analysed, with the results (Table 2.9 - Table 2.22) and isotherm graph obtained by the software (Figure 2.16 - Figure 2.29).

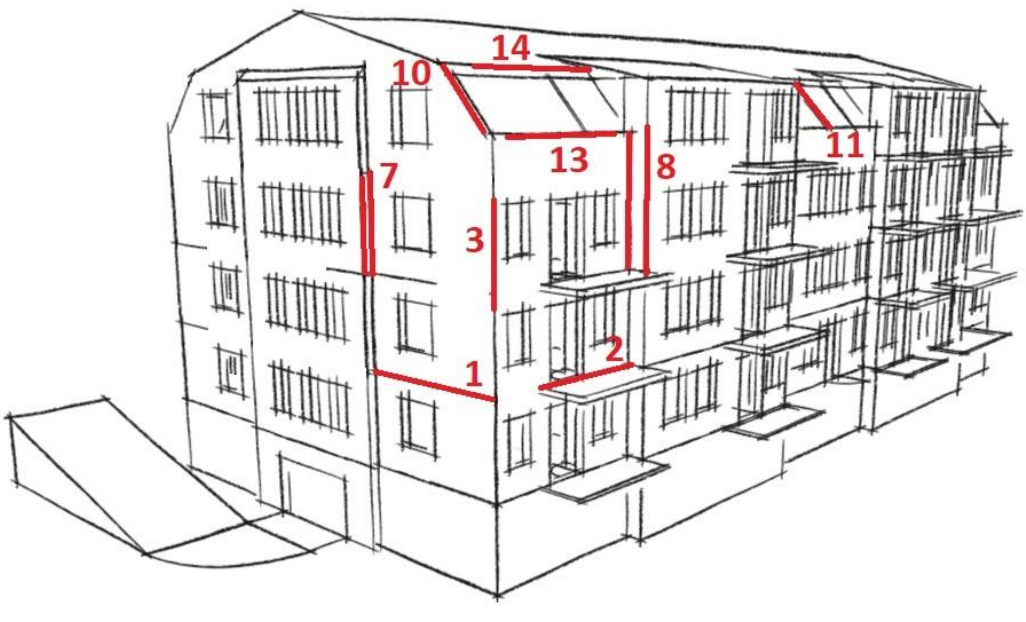


Figure 2.15 - The main thermal bridges analyzed

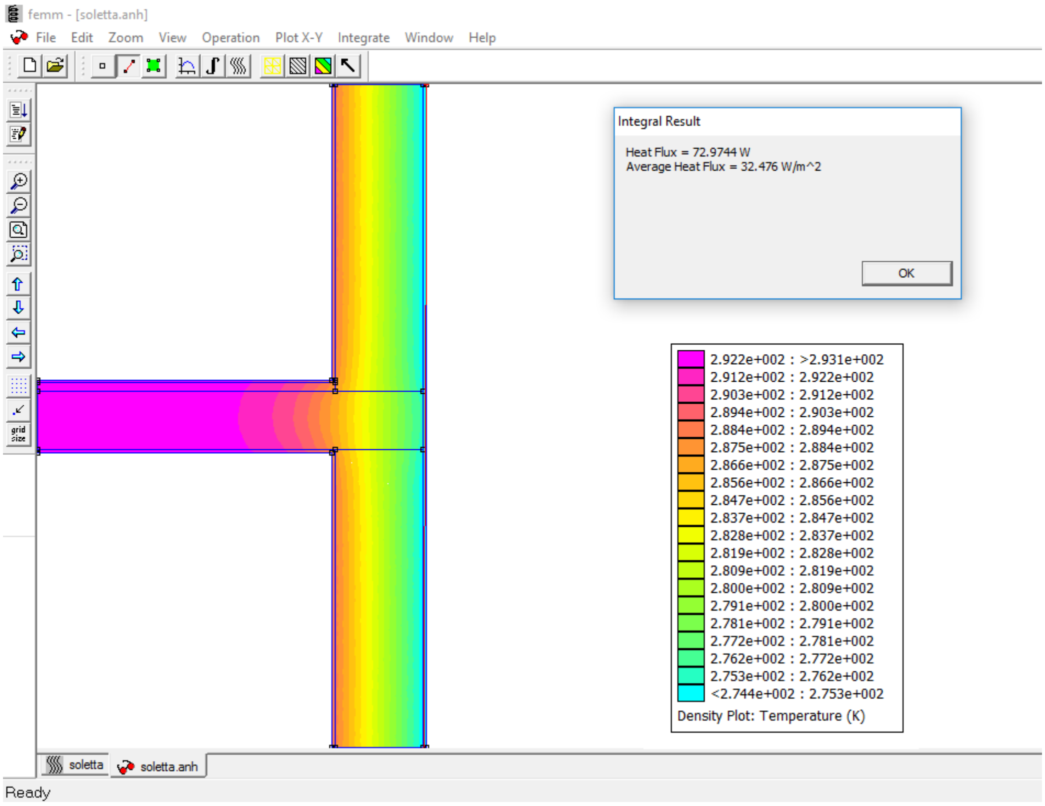
The only type of thermal bridge that has NOT been entered is the one associated with the junction of windows and doors frames on the wall. The first reason is that the exact stratigraphy of this junction were not available; the second reason is that is easy to bypass this problem, simply considering an higher U-value for the windows.

2.4.3 Typologies of thermal bridges analyzed

2.4.3.1 Ceiling

Table 2.9 - Ceiling thermal bridge

CBR_SOLAIO		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
ΦI = Ht (Ti-Te)	72.97	W/m
L2D = ΦI/(Ti-Te)	3.6485	W/mK
Ψ internal	0.636	W/mK
= L2D – ΣUi*Lj = 3.226 – 1.506*1 - 1.506*1		
resistance	0.44	hmK/kJ



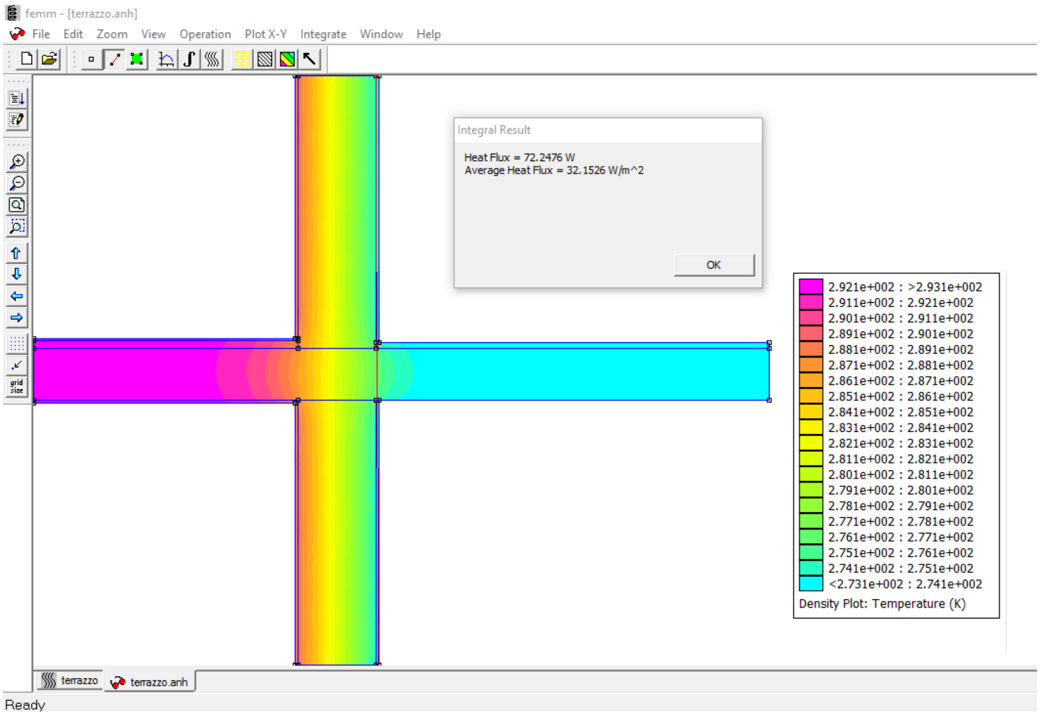
Heat Flux = 72.9744 W
Average Heat Flux = 32.476 W/m^2

Figure 2.16 - Ceiling thermal bridge

2.4.3.2 Terrace

Table 2.10 - Terrace thermal bridge

TERRACE		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
ΦI = Ht (Ti-Te)	72.24	W/m
L2D = ΦI/(Ti-Te)	3.612	W/mK
Ψ internal	0.599	W/mK
= L2D – ΣUi*Lj = 3.612 – 1.506*1 - 1.506*1		
resistance 0&3floor	0.93	hmK/kJ
resistance 1&2 floor	0.46	hmK/kJ



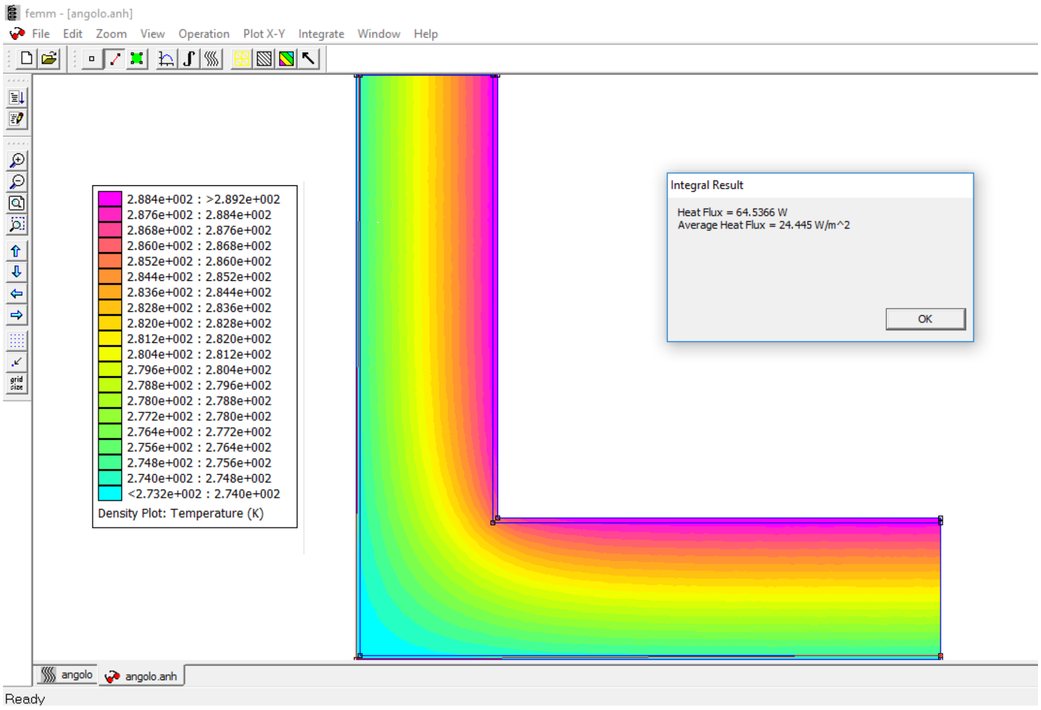
Heat Flux = 72.2476 W
Average Heat Flux = 32.1526 W/m^2

Figure 2.17 - Terrace thermal bridge

2.4.3.3 Corner

Table 2.11 - Corner thermal bridge

CORNER		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
ΦI = Ht (Ti-Te)	<u>64.53</u>	W/m
L2D = ΦI/(Ti-Te)	3.2265	W/mK
Ψ internal	0.214	W/mK
= L2D – ΣUi*Lj = 3.226 – 1.506*1 - 1.506*1		
resistance	1.30	hmK/kJ



2.884e+002 : >2.892e+002
2.876e+002 : 2.884e+002
2.868e+002 : 2.876e+002
2.860e+002 : 2.868e+002
2.852e+002 : 2.860e+002
2.844e+002 : 2.852e+002
2.836e+002 : 2.844e+002
2.828e+002 : 2.836e+002
2.820e+002 : 2.828e+002
2.812e+002 : 2.820e+002
2.804e+002 : 2.812e+002
2.796e+002 : 2.804e+002
2.788e+002 : 2.796e+002
2.780e+002 : 2.788e+002
2.772e+002 : 2.780e+002
2.764e+002 : 2.772e+002
2.756e+002 : 2.764e+002
2.748e+002 : 2.756e+002
2.740e+002 : 2.748e+002
<2.732e+002 : 2.740e+002
Density Plot: Temperature (K)

Integral Result

```
Heat Flux = 64.5366 W
Average Heat Flux = 24.445 W/m^2
```

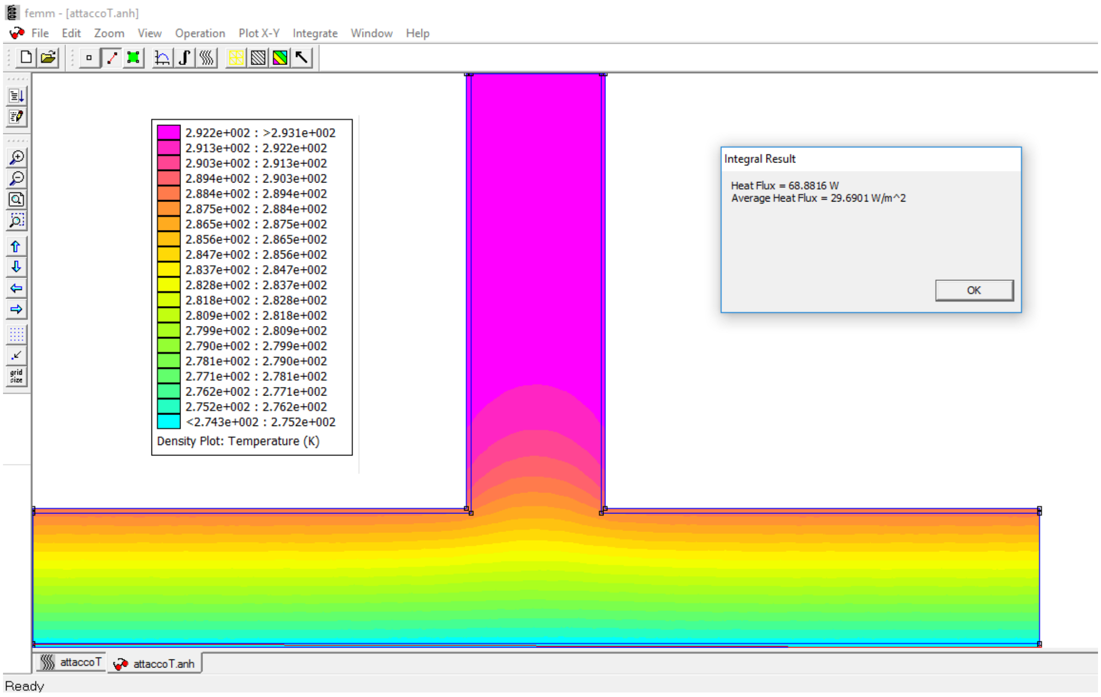
Figure 2.18 - Corner thermal bridge

2.4.3.4 Intersection between external wall and the internal wall between 2 different apartments

Thickness = 30 cm

Table 2.12 - T30 thermal bridge

T30		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
ΦI = Ht (Ti-Te)	66.88	W/m
L2D = ΦI/(Ti-Te)	3.344	W/mK
Ψ internal	0.331	W/mK
= L2D – ΣUi*Lj = 3.344 – 1.506*1 - 1.506*1		
resistance	1.68	hmK/kJ



Heat Flux = 68.8816 W
Average Heat Flux = 29.6901 W/m^2

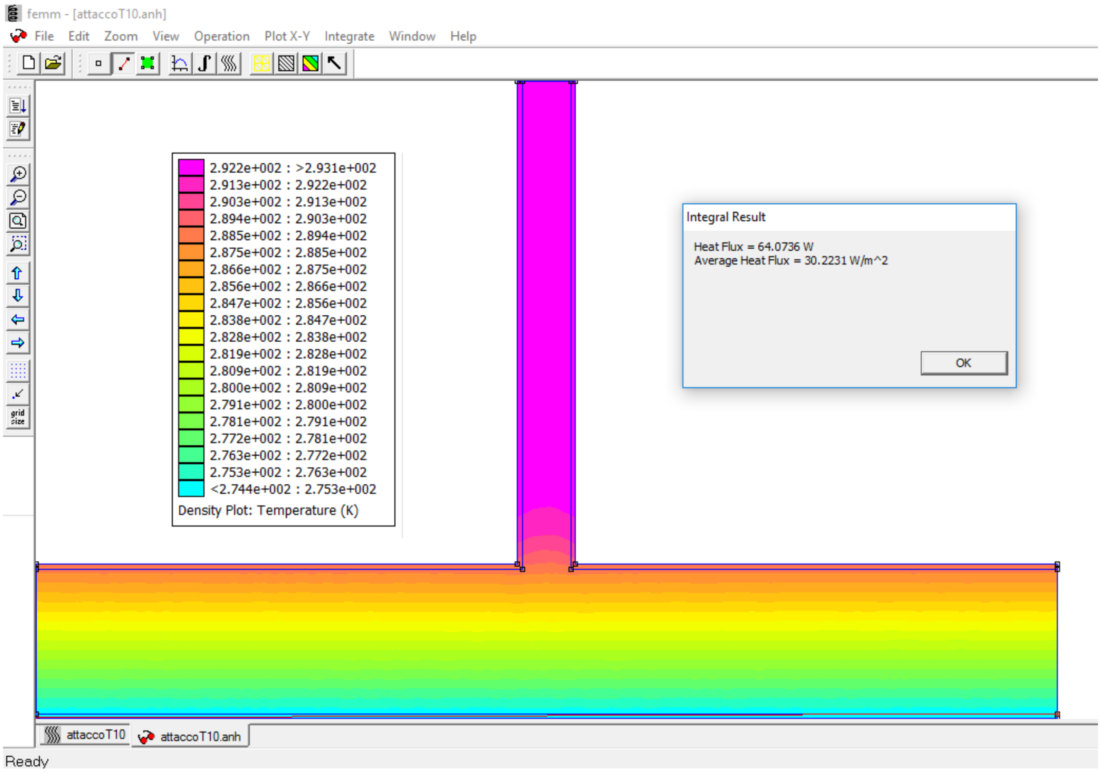
Figure 2.19 - T30 thermal bridge

2.4.3.5 Intersection between the external wall and the internal wall between 2 different rooms of a same apartments

Thickness = 10 cm

Table 2.13 - T10 thermal bridge

T10		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
ΦI = Ht (Ti-Te)	64.07	W/m
L2D = ΦI/(Ti-Te)	3.2035	W/mK
Ψ internal	0.191	W/mK
= L2D – ΣUi*Lj = 3.20 – 1.506*1 - 1.506*1		
resistance	2.91	hmK/kJ



Integral Result

Heat Flux = 64.0736 W
Average Heat Flux = 30.2231 W/m^2

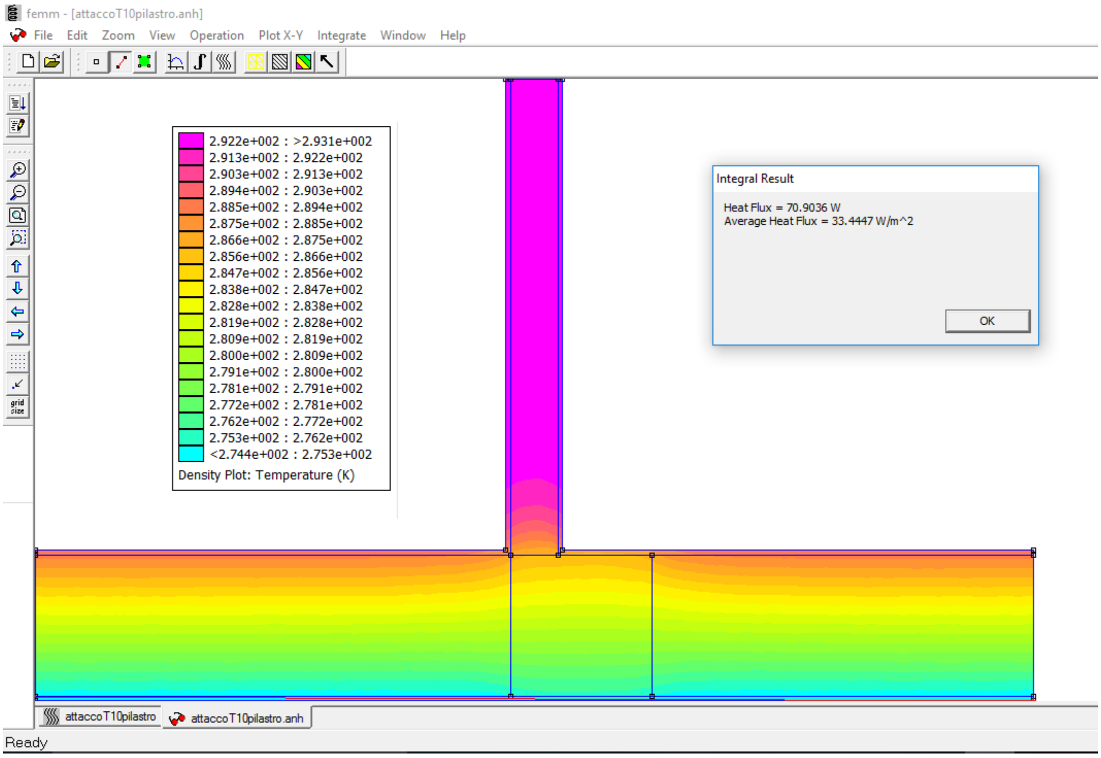
Figure 2.20 - T10 thermal bridge

2.4.3.6 Intersection with pillar between the external wall and the internal wall between 2 different rooms of a same apartments.

Only for side facing north-east; Thickness = 10 cm.

Table 2.14 - T10+pillar thermal bridge

T10+PILLAR		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
Φl = Ht (Ti-Te)	70.9	W/m
L2D = Φl/(Ti-Te)	3.545	W/mK
Ψ internal	0.532	W/mK
= L2D – ΣUi*Lj	= 3.20 – 1.506*1 - 1.506*1	
resistance	**1.04**	hmK/kJ



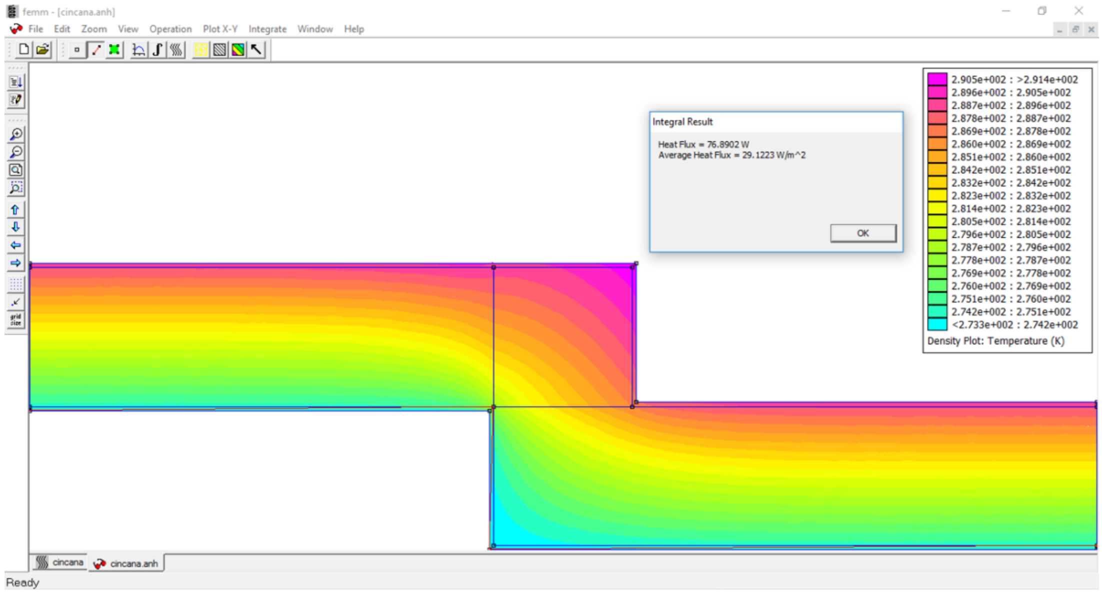
Heat Flux = 70.9036 W
Average Heat Flux = 33.4447 W/m^2

Figure 2.21 - T10+pillar thermal bridge

2.4.3.7 Discontinuity on external wall facing south-west

Table 2.15 - Gimkana thermal bridge

GIMKANA		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	0.3	m
Φl = Ht (Ti-Te)	76.89	W/m
L2D = Φl/(Ti-Te)	3.8445	W/mK
Ψ internal	0.380	W/mK
= L2D – ΣUi*Lj = 3.601 – 1.506*1 - 1.506*1 - 1.506*0.3		
resistance	**1.46**	hmK/kJ



Integral Result

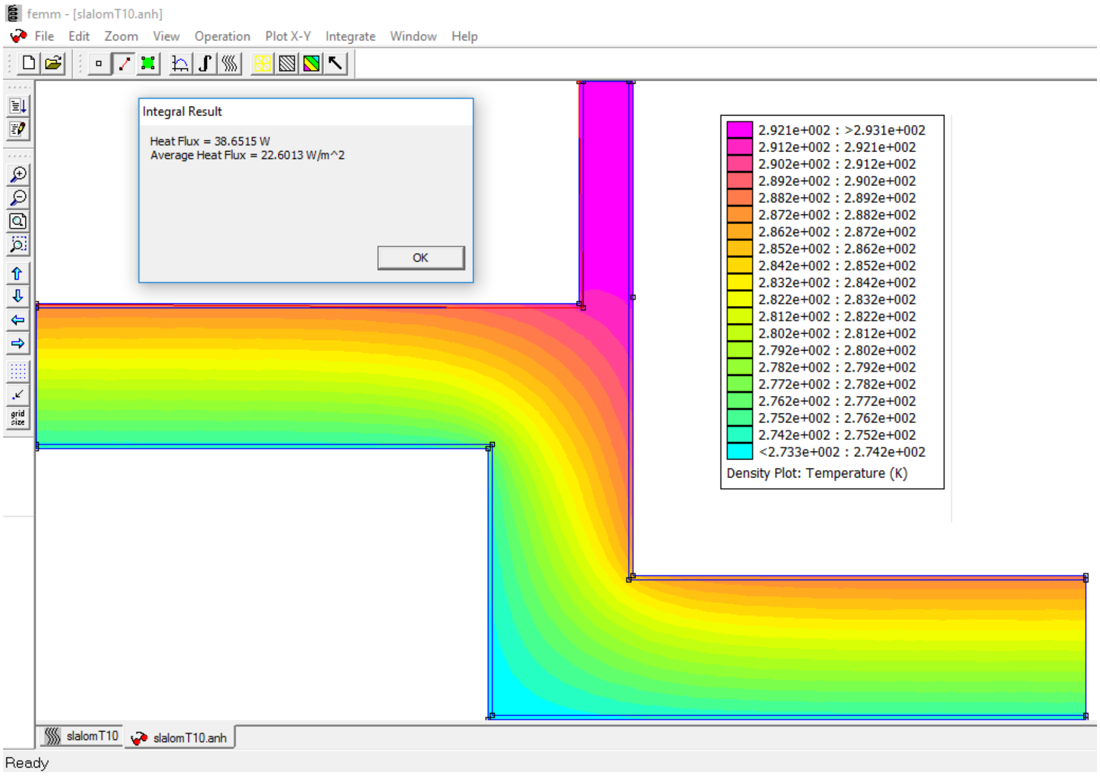
Heat Flux = 76.8902 W
Average Heat Flux = 29.1223 W/m^2

Figure 2.22 - Gimkana thermal bridge

2.4.3.8 Discontinuity on external wall (60 cm) with intersection with a 10 cm internal wall

Table 2.16 - Slalom thermal bridge

SLALOM+T10 --- NB: SX			**SLALOM+T10 --- NB: DX**		
Internal Temperature External temperature	20 0	°C °C	Internal Temperature External temperature	20 0	°C °C
internal Lenght Li external Lenght Le	1 -	m m	internal Lenght Li external Lenght Le	1 0.6	m m
ΦI = Ht (Ti-Te) *L2D = ΦI/(Ti-Te)*	*38* *1.9*	*W/m* *W/mK*	*ΦI = Ht (Ti-Te)* *L2D = ΦI/(Ti-Te)*	*53.74* *2.687*	*W/m* *W/mK*
Ψ internal *= L2D – ΣUi*Lj = 1.9 – 1.506*1*	*0.394*	*W/mK*	*Ψ internal* *= L2D – ΣUi*Lj = 2.68 – 1.506*1 - 1.506*0.6*	*0.277*	*W/mK*
resistance	**1.41**	hmK/kJ	resistance	**2.01**	hmK/kJ



Integral Result

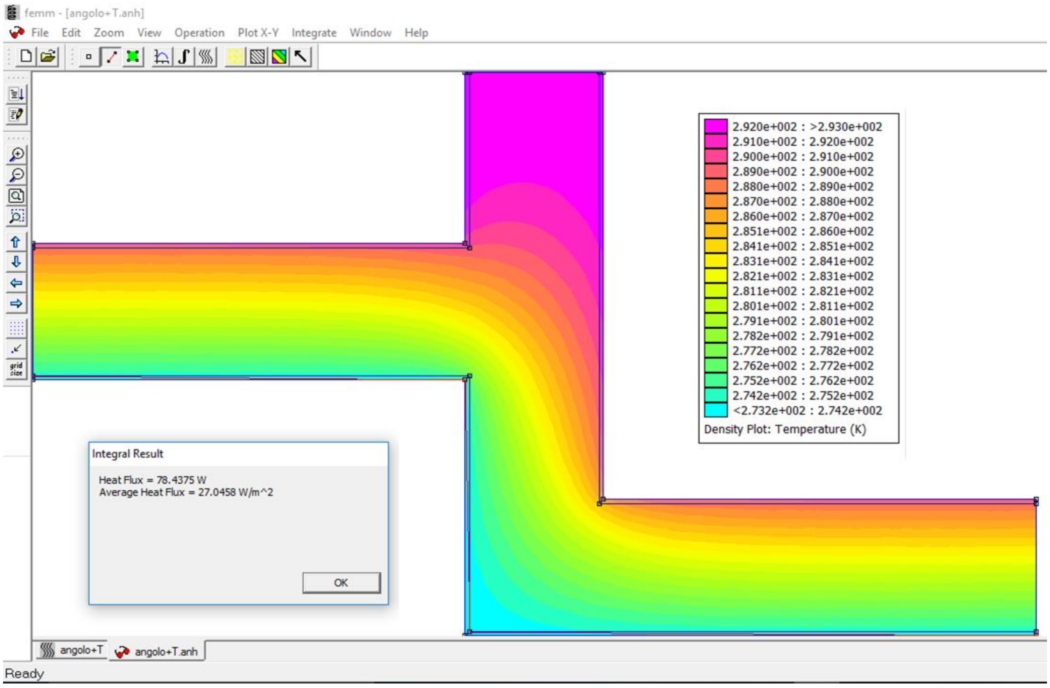
Heat Flux = 38.6515 W
Average Heat Flux = 22.6013 W/m^2

Figure 2.23 - Slalom thermal bridge

2.4.3.9 Discontinuity on external wall (60 cm) with intersection with a 30 cm internal wall

Table 2.17 - Stairwell thermal bridge

SLALOM+T30 --- NB: SX			**SLALOM+T30 --- NB: DX**		
Internal Temperature	20	°C	Internal Temperature	20	°C
External temperature	0	°C	External temperature	0	°C
internal Lenght Li	1	m	internal Lenght Li	1	m
external Lenght Le	0.6	m	external Lenght Le	0.6	m
ΦI = Ht (Ti-Te)	*36*	*W/m*	*ΦI = Ht (Ti-Te)*	*54.25*	*W/m*
L2D = ΦI/(Ti-Te)	*1.8*	*W/mK*	*L2D = ΦI/(Ti-Te)*	*2.7125*	*W/mK*
Ψ internal	*0.294*	*W/mK*	*Ψ internal*	*0.302*	*W/mK*
*= L2D – ΣUi*Lj = 1.8 – 1.506*1*			*= L2D – ΣUi*Lj = 2.71 - 1.506*1 - 1.506*0.6*		
resistance	1.89	hmK/kJ	resistance	1.84	hmK/kJ



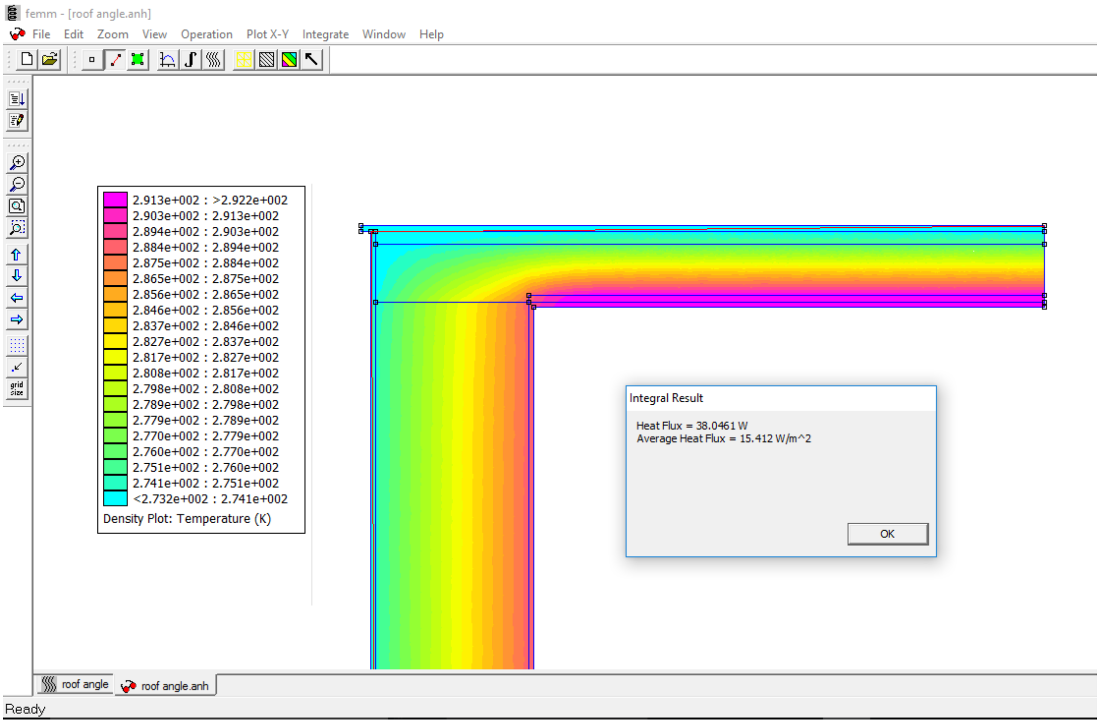
```
Heat Flux = 78.4375 W
Average Heat Flux = 27.0458 W/m^2
```

Figure 2.24 - Stairwell thermal bridge

2.4.3.10 Perpendicular junction between the vertical external walls and the inclinate roof

Table 2.18 - Roof corner thermal bridge

ROOF CORNER		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
ΦI = Ht (Ti-Te)	38.84	W/m
L2D = ΦI/(Ti-Te)	1.942	W/mK
Ψ internal	0.050	W/mK
= L2D – ΣUi*Lj = 1.942 – 1.506*1 - 0.386*1		
resistance	5.55	hmK/kJ



```
Integral Result
Heat Flux = 38.0461 W
Average Heat Flux = 15.412 W/m^2
```

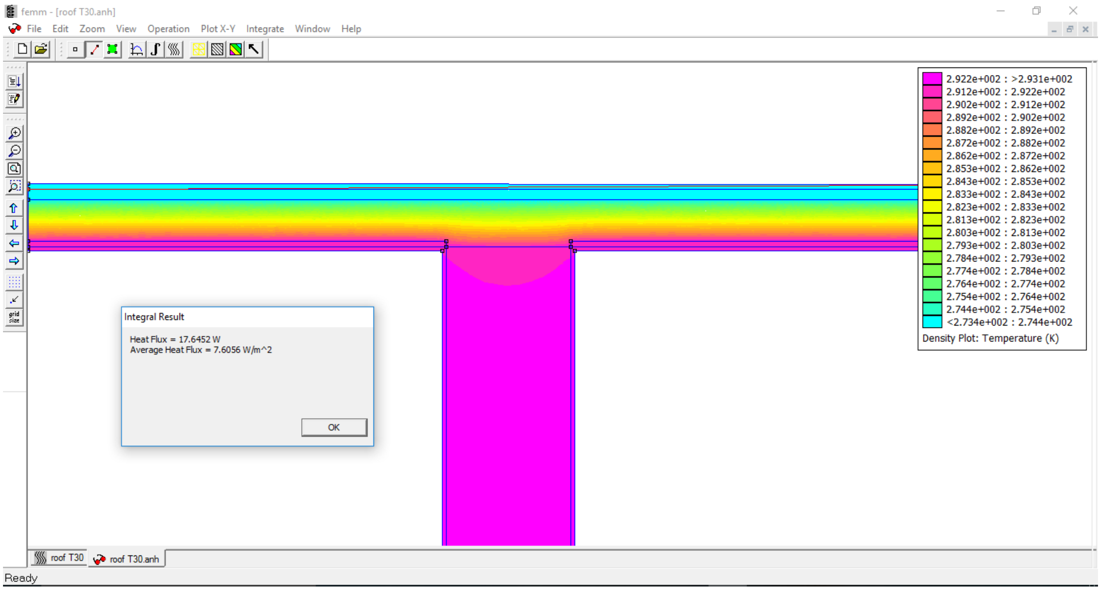
Figure 2.25 - Roof corner thermal bridge

2.4.3.11 Junction between the pitch of the roof and the internal wall between 2 different apartments

Thickness = 30 cm

Table 2.19 - Roof T30 thermal bridge

ROOF T30		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
Φl = Ht (Ti-Te)	17.64	W/m
L2D = Φl/(Ti-Te)	0.882	W/mK
Ψ internal	0.111	W/mK
= L2D – ΣUi*Lj = 0.882 – 0.386*1 - 0.386*1		
resistance	**5.01**	hmK/kJ



```
Integral Result
Heat Flux = 17.6452 W
Average Heat Flux = 7.6056 W/m^2
```

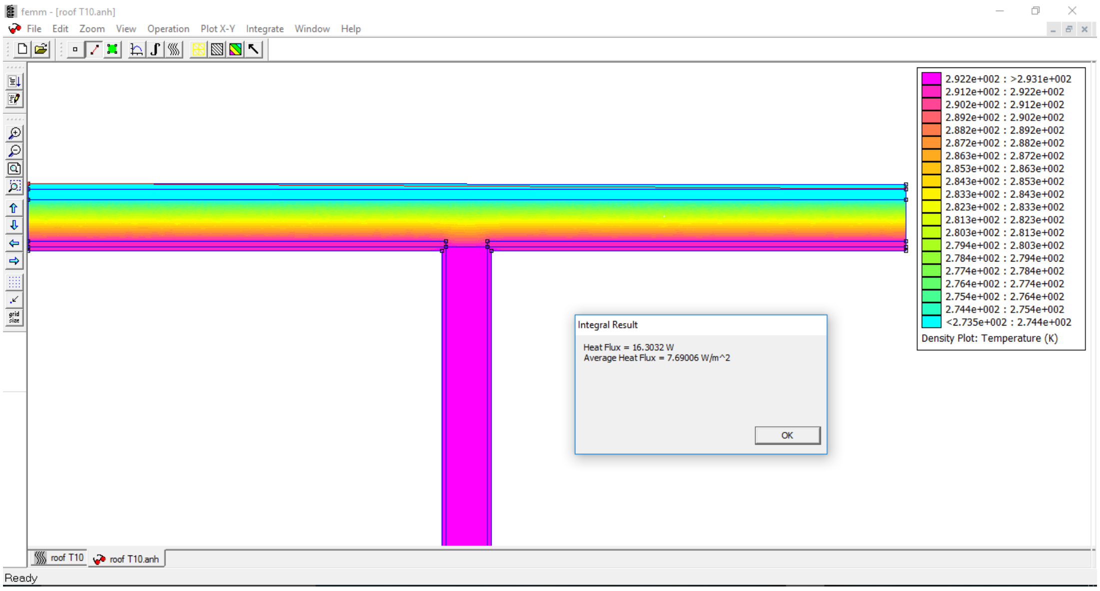
Figure 2.26 - Roof T30 thermal bridge

2.4.3.12 Junction between the pitch of the roof and the internal wall between 2 different rooms of a same apartments

Thickness = 10 cm

Table 2.20 - Roof T10 thermal bridge

ROOF T10		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	-	m
ΦI = Ht (Ti-Te)	<u>16.30</u>	W/m
L2D = ΦI/(Ti-Te)	0.81515	W/mK
Ψ internal	0.044	W/mK
= L2D – ΣUi*Lj = 0.815 – 0.386*1 - 0.386*1		
resistance	**12.61**	hmK/kJ



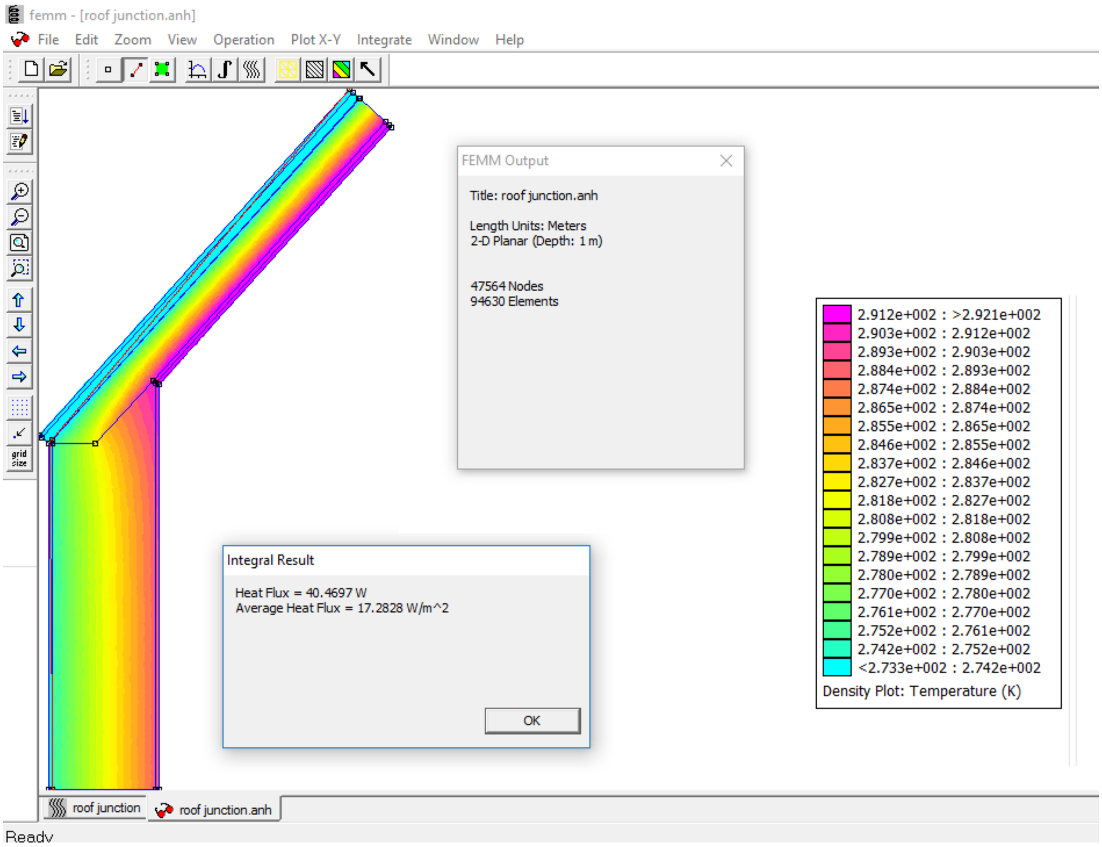
```
Heat Flux = 16.3032 W
Average Heat Flux = 7.69006 W/m^2
```

Figure 2.27 - Roof T10 thermal bridge

2.4.3.13 junction between the vertical external walls and the inclinate roof

Table 2.21 - Roof 48 thermal bridge

ROOF-WALL JUNCTION		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	1	m
ΦI = Ht (Ti-Te)	40.46	W/m
L2D = ΦI/(Ti-Te)	2.023	W/mK
Ψ internal	0.131	W/mK
= L2D – ΣUi*Lj = 1.2.023 – 1.506*1 - 0.386*1		
resistance	2.12	hmK/kJ



FEMM Output

Title: roof junction.anh

Length Units: Meters
2-D Planar (Depth: 1 m)

47564 Nodes
94630 Elements

Integral Result

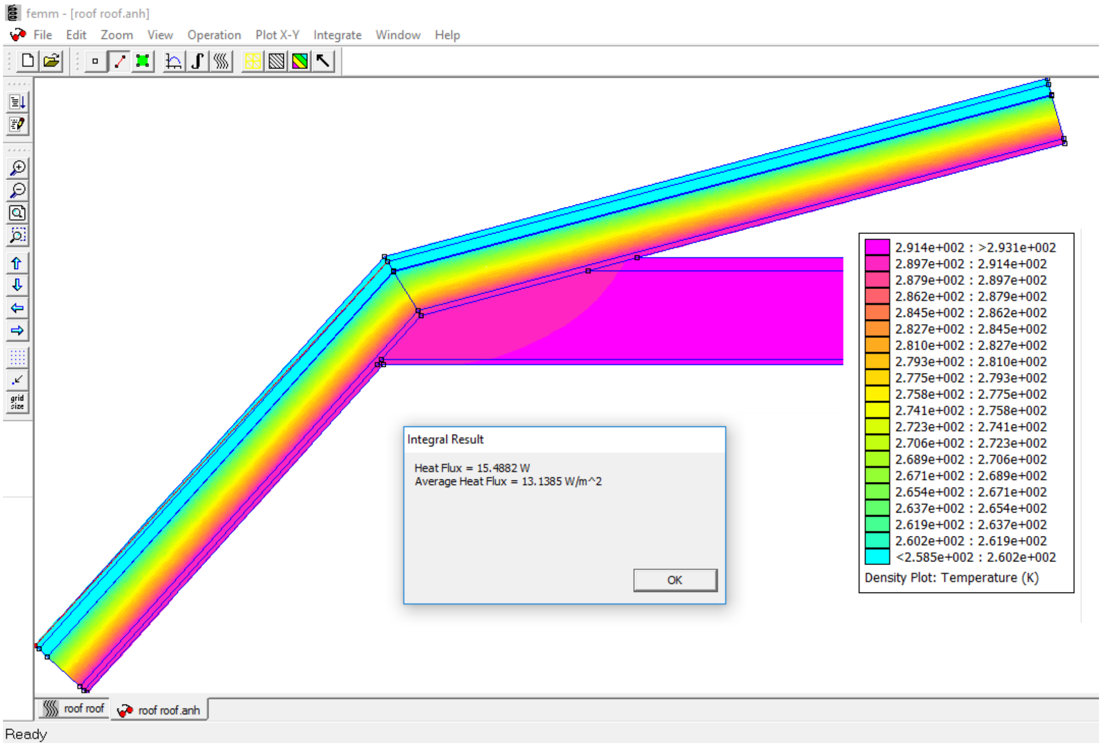
Heat Flux = 40.4697 W
Average Heat Flux = 17.2828 W/m^2

Figure 2.28 - Roof 48 thermal bridge

2.4.3.14 Junction between the two different pitch of the roof, 48° and 15°

Table 2.22 - Roof 15 thermal bridge

ROOF 60		
Internal Temperature	20	°C
External temperature	0	°C
internal Lenght Li	1	m
external Lenght Le	1	m
Φl = Ht (Ti-Te)	15.48	W/m
L2D = Φl/(Ti-Te)	0.774	W/mK
Ψ internal	0.388	W/mK
= L2D – ΣUi*Lj = 1.942 – 1.506*1 - 0.386*1		
resistance	0.72	hmK/kJ



Integral Result

Heat Flux = 15.4882 W
Average Heat Flux = 13.1385 W/m^2

Figure 2.29 - Roof 15 thermal bridge

2.5 Ventilation

In all the kitchens there is extraction of exhaust air –when in function- with an air change rate of $n = 3\ vol^{-1}$. Air extracted from kitchens is replaced by air from the outside, entering the apartments from a ventilating opening realized in the external wall, to avoid dangerous accumulations of gas, in case of a malfunction of the stove. (Figure 2.30)

All bathrooms are blind, so -when utilized-, forced ventilation for exhaust air is provided, with an air change ratio of $ACH = 5\ n^{-1}$. Air extracted from toilets and WC is replaced by air from the adjacent corridor, in its turn communicating with the kitchen.

Considering this layout of air flows (Figure 2.31), it is not possible to realize a simplified model of the whole building, considering one zone of the TRNSYS model for each apartment -simplifying the model-, because it would not be possible to integrate this airflows in the model. It will be therefore necessary to model every single room of the building and then create the coupling of the air flow.

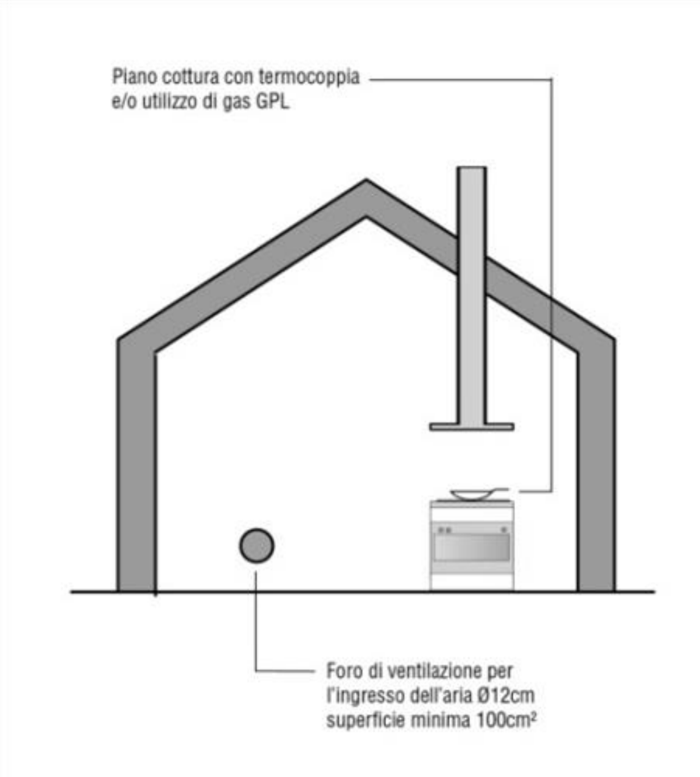


Figure 2.30 – Example of ventilating opening for the kitchens

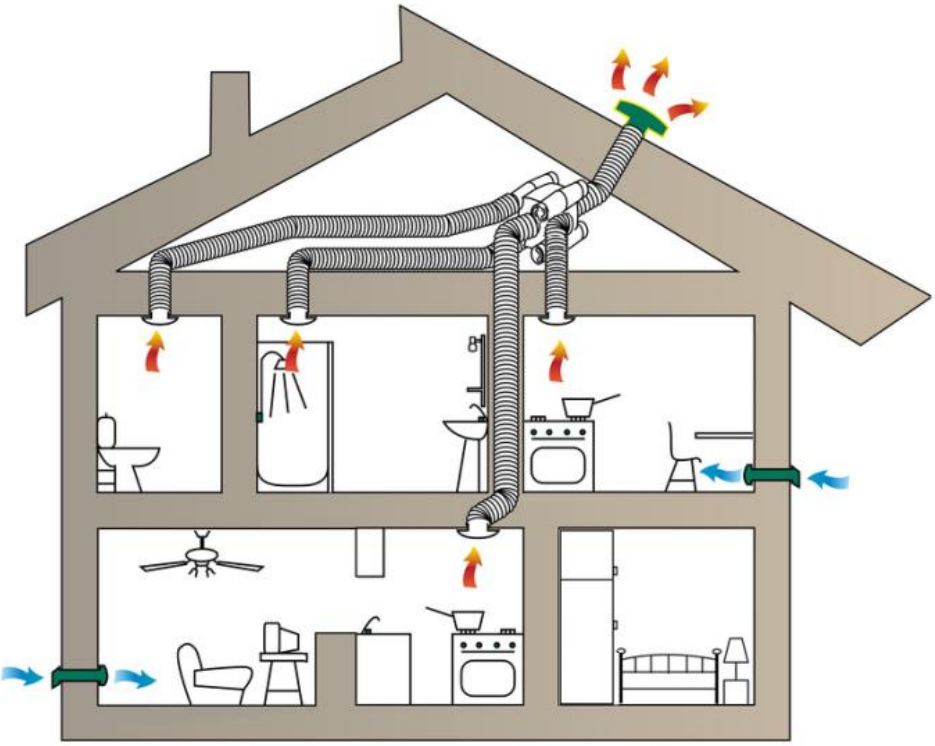


Figure 2.31 - Scheme for the operation of forced ventilation

3 Description of the model

In the following chapter is explained how to create the model of a building in TRNBuild from its stratigraphy and its representation in AutoCAD environment.

3.1 Presentation of the software

TRNSYS is a dynamic simulation software that allows to describe any behaviour of any physical system. This instrument is used by engineers all over the world allowing dynamic and also transient analysis of any kind of system.

It is commonly used for the study of various types of systems, from the energy analysis of a simple heat production system for heating or domestic hot water, until the simulation of the energy behaviour of multi-zone buildings and their installations, also integrating the control possibility and adjustment of the different variables involved to describe different control strategies of the plants.

The TRNSYS package includes its three main internal software applications:

- TRNBuild
- TrnSTUDIO (Simulation Study)
- TrnEDIT

In the present work will be used only the first two mentioned above.

3.1.1 TRNBuild

TRNBuild is the application software dedicated to the modelling of buildings. It allows to specify all the details of the individual areas that make up the structure, in particular the definition of:

- orientations of the various walls of the building;
- stratigraphy of the walls of the building;
- type of glass surfaces;
- internal heat gains (number occupants, lighting, heat, etc.);
- setting climate control.

This application will then be included in a type library, the type 56, which then returns the building mathematical model defined.

3.1.2 TrnSTUDIO

The application TrnSTUDIO (or more commonly Simulation Study) is the main graphical user interface of TRNSYS software. In this environment the simulation project requested is created, through a graphical interface intuitive and easy to understand.

Each project is created by dragging the components (type) from the library to the workspace and connecting them visually to each other with arrows.

Each component is characterized by inputs and outputs. Arrows allow to "transfer" the outputs to the inputs of a component, or to subsequent components. Finally, the simulation parameters (step time, start time, stop time, resolution method, etc.) must be set.

TRNSYS also has the ability to interface easily with other external software in common use (Text editor, Microsoft Excel, Matlab, etc.) for a more comfortable and rapid file processing in both input is output.

The key feature of the TRNSYS software, which allows its vast use, is its modular structure. The library of objects allows an immediate and easy understanding of the different simulation models in its interior. This library can be divided into two main categories of objects, defined as "Type":

1. Category types of modelling the physical behaviour of a real component (building, heat pumps, heat generators, thermal collectors, heat exchangers etc.);
2. Category of auxiliary types needed to build an interface with the user (plotter, printer, reader, etc.)

The first category is based on the physical-mathematical model description associated with the particular component. The goodness of the simulations is then bound to the particular mathematical model included within the particular type. In most of the cases result obtained deviates little from the experimental ones.

The second category is made up of a series of very useful components to process the data of input and output.

A quality of this software, which allows its use in any type of physical system, is the possibility of defining new models, in addition to the default ones present in the library. The software architecture is based on the file extension " .dll", written with the most common programming languages (C, C ++, Fortran, Pascal), so is possible also the change of the existing models and also the definition of new mathematical models depending on the user's specific needs, thus extending the potential of the simulation environment.

3.1.3 TRY

Most of the energy simulations (in particular, the simulations of renewable energy systems) require weather data inputs. TRNSYS accepts different types of weather data files made available in the literature by different laboratories and weather stations.

The test reference year (TRY) is the most comprehensive and realistic way to describe the climatic situation of a certain location. A TRY consists of a representation of the average year of reference of the locality, so the measurement of the main climatic variables represented to time schedule interval.

It will have 8760 values of a particular climatic variable, among which the temperature, the relative humidity, wind speed, the solar radiation in the direct and diffuse components incident and many else values. 8760 is the exact number of hours in a non-bisextil year.

A reliable and realistic TRY must be built over a period of several years, usually 10-15 years. However, some weather stations come to build an even TRY to measurements carried out in 20 years, with sampling intervals also below an hour. The amount of data to be managed becomes very high, but more realistic and representative of real conditions.

Multiple websites of major companies and weather stations make available the weather downloading files containing TRY to different locations, usually provincial capitals.

This project will consider the TRY of Debrecen, calculated in 20 years. (Figure 3.1)

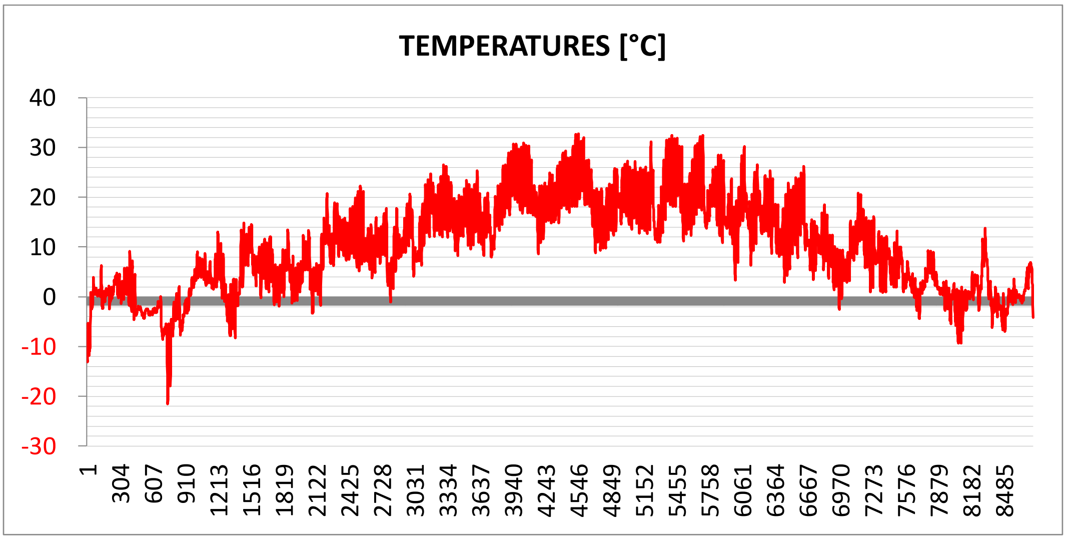


Figure 3.1: TRY of Debrecen, calculated in 20 years

TRY for a lot of cities all over the world can be found in the portal EnergyPlus [14], from where it can be downloaded in the .tmy2 format.

Thought TRNSYS reads unmodified TMY2 data files, to open that kind of files it has been necessary to open them creating a .xls macro file. The procedure followed can be found in the Trnsys website [15].

3.2 Modelling of the building in TRNSYS, type 56

As mentioned in paragraph 2.5, to create the model of the exhaust air aspiration system - necessary for the calculation of the energy needs of the building- it has been necessary to create a TRNSYS zone for each room of the building. It is therefore not possible to make the entire building model into a single type 56, as Trnsys build has a maximum limit of 999 modelled surfaces. This limit had been exceeded considering together all 4 floors of the building, for a total of 32 apartments plus common spaces.

It has been decided to divide the whole building into several blocks, associating a type 56 at each block. Is considered one model for the ground floor and the garage under it; a second model for the first and the second floor, that are identical, and a third one for the attic.

In this way is also possible to simplify the simulations, making them faster whenever it is necessary to change something in only one of the several floors of the building.

As will be shown in the following paragraphs, the floor between each level of the building is considered as an “identical boundary”. That means that is supposed to have the same conditions of temperature over the ceiling. This simplification can be done without any problem because the difference of temperature between corresponding rooms on adjacent floors will be minimal. Minimal differences are only between the ground and the first floor, because the differences into the planimetry due to the entrances at the ground floor, but the heat transfer is negligible.

Once the thermal zones and the areas that define them have been defined, the initial data required by the software to calculate system variables is entered. In the "REGIME DATA" section are entered parameters relating to:

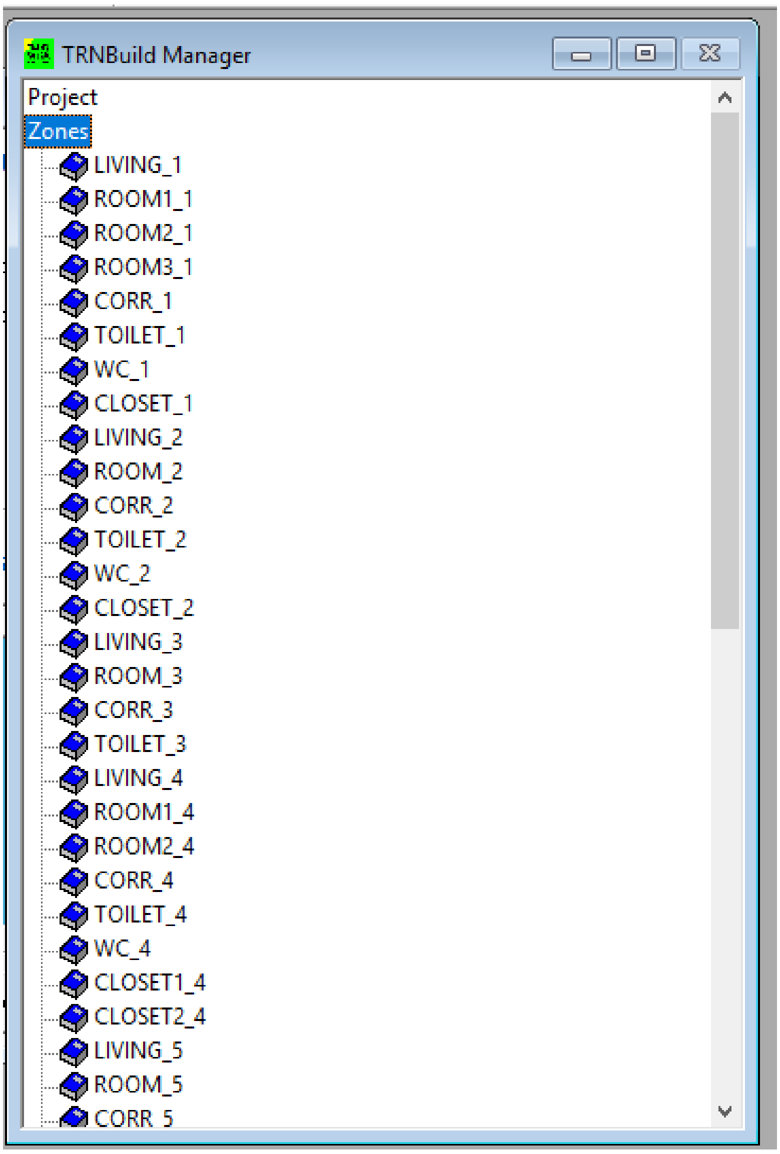
- Heating
- Cooling
- Ventilation
- Infiltration
- Humidity
- Internal loads

The plant's design parameters can be provided in three ways: by a constant set-point value, by a programmable schedule for daily or weekly values for daily values, or by external text input files.

3.3 The ZONE menu

The ZONE window contains all information describing a thermal zone of the building as shown in Figure 3.2.

In the TRNBuild manager it had to add all the zones of the model which will be developed. As mentioned above in paragraph 3.2, to obtain a result as precise as possible, it has been decided to consider one zone for each room of the model. It has been considered one model for the ground floor and the garage under it; a second model for the first and the second floors, that are identical, and a third one for the attic.



Project
Zones
- LIVING_1
- ROOM1_1
- ROOM2_1
- ROOM3_1
- CORR_1
- TOILET_1
- WC_1
- CLOSET_1
- LIVING_2
- ROOM_2
- CORR_2
- TOILET_2
- WC_2
- CLOSET_2
- LIVING_3
- ROOM_3
- CORR_3
- TOILET_3
- LIVING_4
- ROOM1_4
- ROOM2_4
- CORR_4
- TOILET_4
- WC_4
- CLOSET1_4
- CLOSET2_4
- LIVING_5
- ROOM_5
- CORR_5

Figure 3.2 - Thermal zone of the TRNSYS model of the ground floor

The data describing each zone can be divided into four main parts:

a) the required REGIME DATA,
b) the WALLs of the zone
c) the WINDOWs of the zone and
d) optional equipment data and operating specifications including INFILTRATION, VENTILATION, COOLING, HEATING, GAINS and COMFORT.

The following data is entered in the REGIME DATA portion of the ZONE window (Figure 3.3) :

- zone volume of the air within the zone
- thermal capacitance of zone air plus that of any mass not considered as walls (e.g. furniture,...). In order to simplify the input, this value is automatically set to a default value of $1.2 \times VOLUME$.
- initial temperature of the zone air
- initial relative humidity of the zone air

Infiltrations, ventilation, heating, cooling, gains are chose between the ones defined above, in the type manager.

It is finally necessary to enter all the walls related to the selected zone.
At least two surfaces must be attributed to each thermal zone. Each surface must be correctly allocated to the building space with the respective dimensions.

For each surface it must be then defined whether it is external, internal, adjacent, or "boundary":

- An external surface is a separation between the thermal zone and the external environment; it is associated with the face of the building, and must be defined by spatial orientation with respect to the cardinal axes and the inclination with respect to a horizontal reference plane (calculation of the view factor).

- An internal surface is simply representative of a partition wall; it does not affect the reciprocal behaviour of the thermal zones, but is indicative of the thermal capacity that is created in the area where it is inserted.

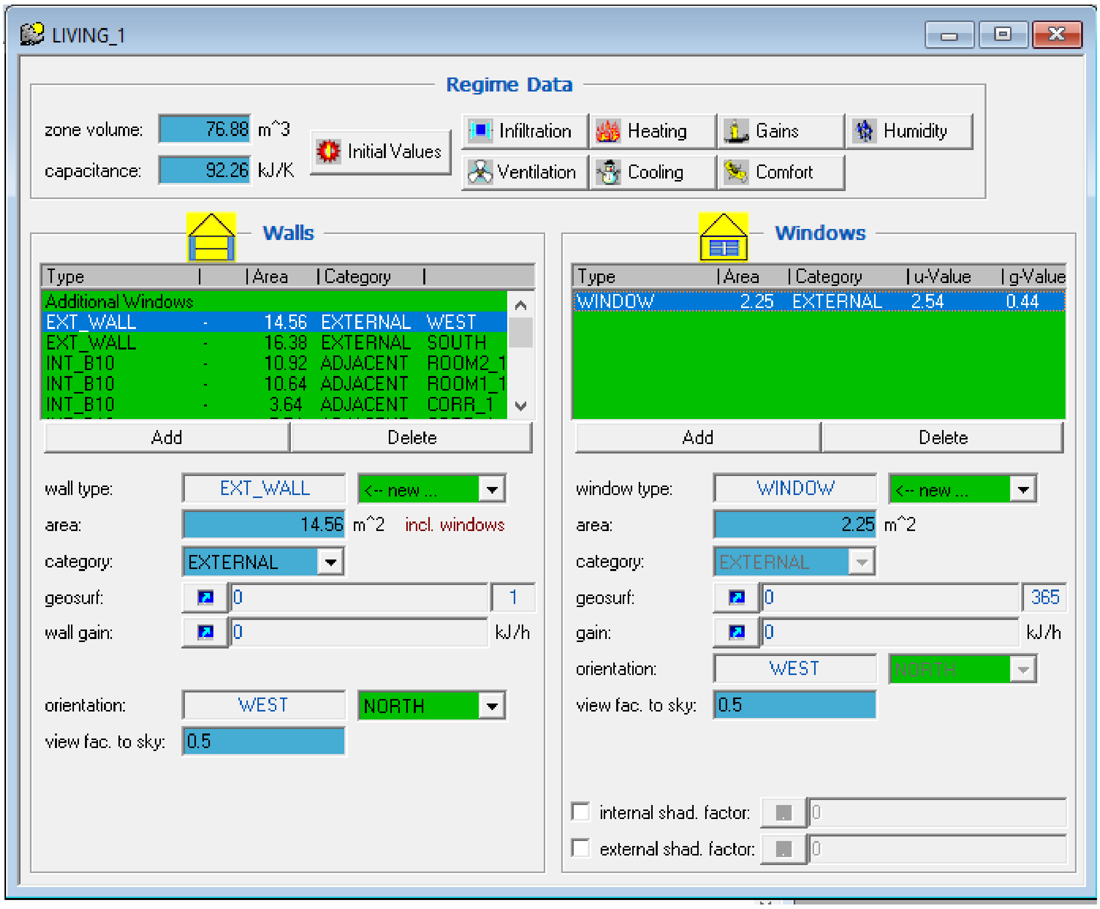
- An adjacent surface is instead separating between different thermal zones of the building: the area value for these surfaces will be common to two thermal zones.

- Finally, a boundary surface is in contact with an environment whose characteristics are imposed by the user, as is, for example, for the basement whose perimeter walls border with the temperature-set ground.

Type 56 also offers the possibility to define a certain energy flux to a certain wall surface. Also, thermally activated walls for cooling/heating can be integrated in Type 56, but this option is not used in our project.

A special external wall type to model thermal bridges is added to the wall description. In the following descriptions, the FRONT of a WALL is associated with the first layer given in the WALL TYPE definition. External walls are subjected to ambient conditions. The wall front is assumed to be at the inside of the zone.

For the distribution of direct solar radiation entering a zone explicit distribution factors can be defined by the user. The keyword GEOSURF represents the fraction of the total entering direct solar radiation that strikes the surface. The factors of view to the sky remain the default for an initial estimate of the needs of the building, so considering that all the walls see their portion of the sky, in the absence of natural and artificial obstacles (hills, trees, other buildings).



zone volume: 76.88 m^3
capacitance: 92.26 kJ/K

Type		Area	Category	
Additional Windows				
EXT_WALL	-	14.56	EXTERNAL	WEST
EXT_WALL	-	16.38	EXTERNAL	SOUTH
INT_B10	-	10.92	ADJACENT	ROOM2_1
INT_B10	-	10.64	ADJACENT	ROOM1_1
INT_B10	-	3.64	ADJACENT	CORR_1

wall type: EXT_WALL <-- new ...
area: 14.56 m^2 incl. windows
category: EXTERNAL
geosurf: 0 1
wall gain: 0 kJ/h
orientation: WEST NORTH
view fac. to sky: 0.5

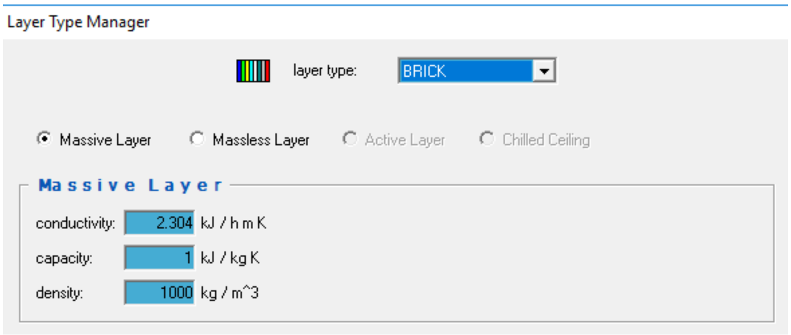
Type	Area	Category	u-Value	g-Value
WINDOW	2.25	EXTERNAL	2.54	0.44

window type: WINDOW <-- new ...
area: 2.25 m^2
category: EXTERNAL
geosurf: 0 365
gain: 0 kJ/h
orientation: WEST NORTH
view fac. to sky: 0.5
☐ internal shad. factor: 0
☐ external shad. factor: 0

Figure 3.3 - Zone window

3.4 Stratigraphy

The following schedule (Figure 3.4) provides the stratigraphy of opaque and transparent elements base that was used as a reference.


Layer Type Manager

layer type: BRICK

● Massive Layer ○ Massless Layer ○ Active Layer ○ Chilled Ceiling

Massive Layer

conductivity: 2.304 kJ / h m K

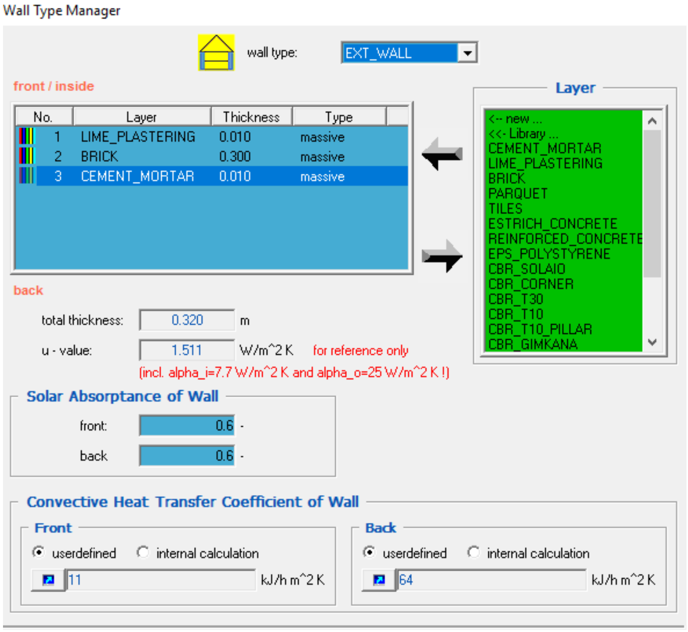
capacity: 1 kJ / kg K

density: 1000 kg / m^3

Figure 3.4 - “Layer Type Manager” interface: definition of type of material and it’s thermophysical properties.

After defining the materials present in the building, the different types of walls are defined as shown in stratigraphy (Figure 3.5), introducing the layers with its thickness starting from the inner side to the outer side ("Walls Type").

Are also requests the boundary conditions for each type of wall, in particular the convection coefficients, absorption and emission of radiation (only for the long-wave radiation, as it is the one that affects the radiation emission at room temperature), to both the inner side and external side of the wall. These coefficients were maintained by default from the TRNBuild.


Wall Type Manager

wall type: EXT_WALL

front / inside

No.	Layer	Thickness	Type
1	LIME_PLASTERING	0.010	massive
2	BRICK	0.300	massive
3	CEMENT_MORTAR	0.010	massive

back

total thickness: 0.320 m

u - value: 1.511 W/m^2 K for reference only

(incl. alpha_i=7.7 W/m^2 K and alpha_o=25 W/m^2 K !)

Solar Absorptance of Wall

front: 0.6 -

back 0.6 -

Convective Heat Transfer Coefficient of Wall

Front

● userdefined ○ internal calculation

11 kJ/h m^2 K

Back

● userdefined ○ internal calculation

64 kJ/h m^2 K

Figure 3.5 - “Wall Type Manager” interface: definition of type layers and its thickness composing the walls.

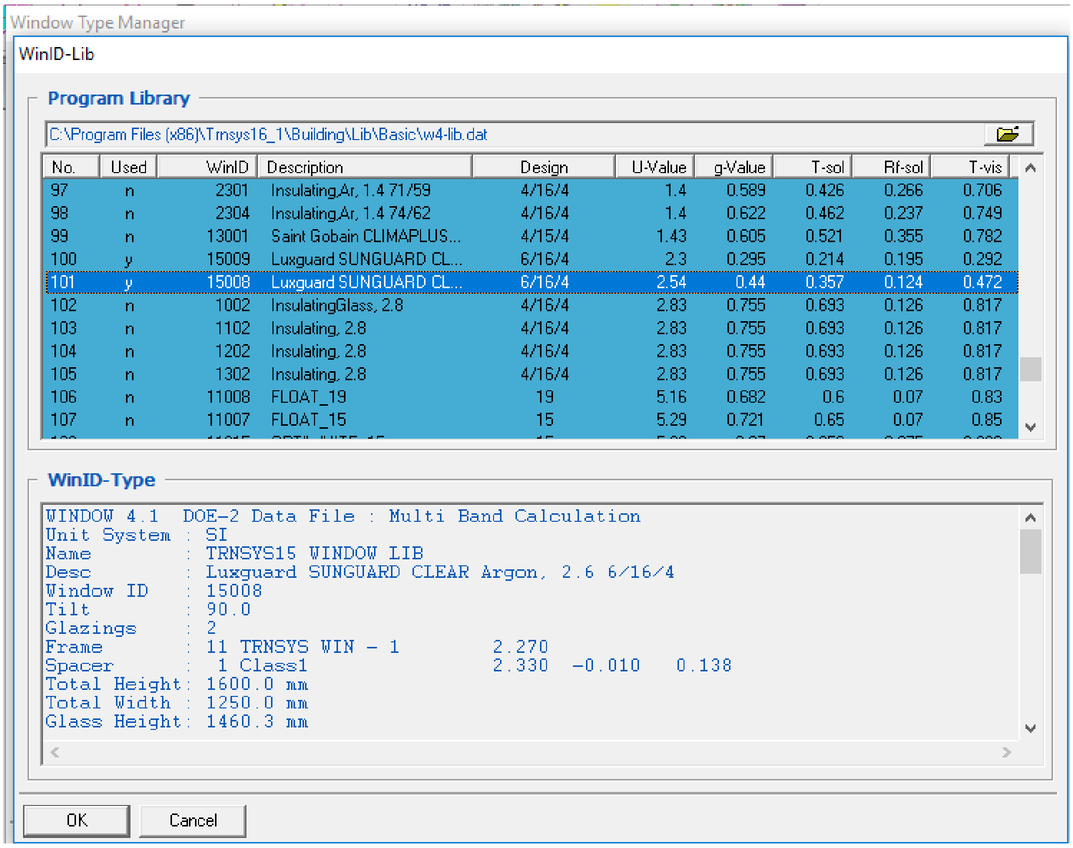
3.5 Windows

To complete the building model remains to associate windowed components and any access doors with the outside surfaces of the, through the "Window Type Manager" tool.

For the transparent elements ("Windows Layer"), is used the TRNSYS library types of windows ("Glazing"), a library which contains a lot of different models of windows (Figure 3.6).

The window type can be specified by using the pull-down menu on the right side. This menu offers the options of defining a new window type, selecting a window type out of a library or selecting a previously defined window type. The name of the selected window type appears in the display box. Also, TRNBUILD displays the U-value (describing window losses) the g-value (solar heat gain coefficient or SHGC) and other optical properties of the selected window.

It is possible to order those models in ascending or descending order, for each of those properties. Filtering those models in function to the U-value, is not choose the model with the closer value to the datasheet, but the following with a bigger U-value to include the contribution of thermal bridges in the junction between window and wall, as already mentioned in paragraph 2.4.2 .



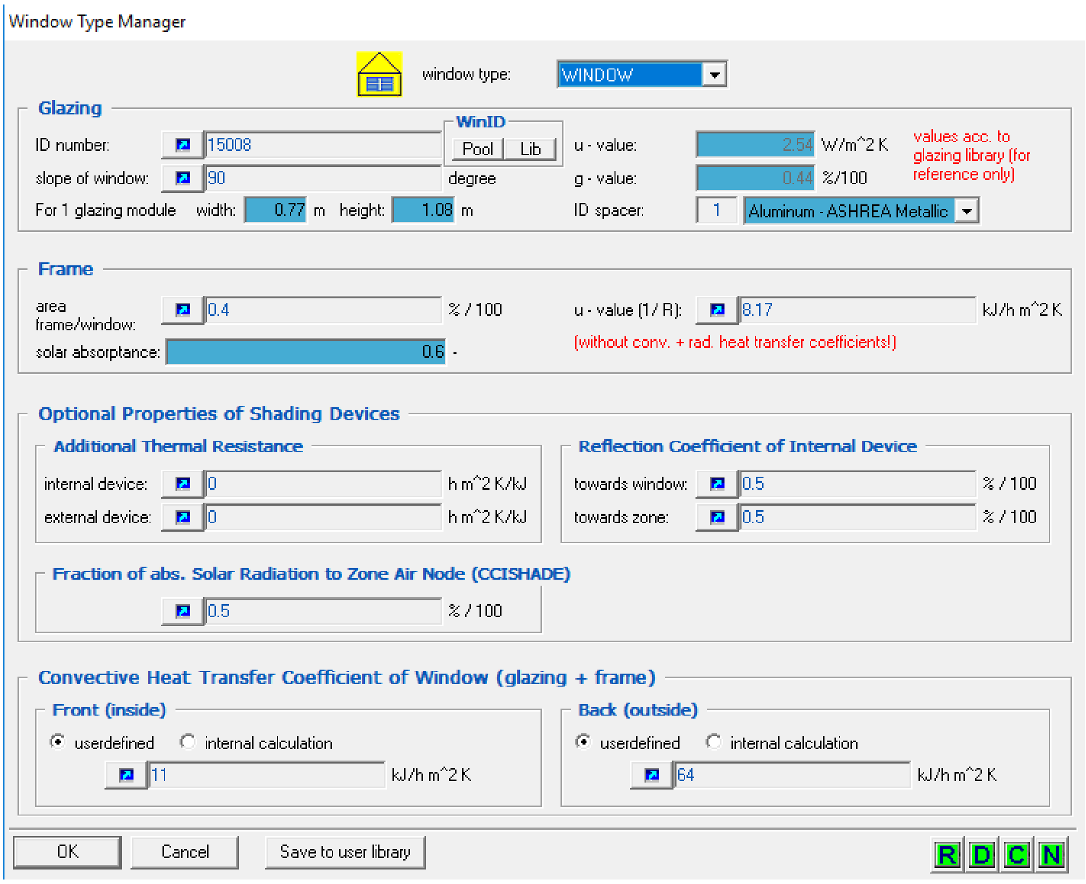
C:\Program Files (x86)\Trnsys16_1\Building\Lib\Basic\w4-lib.dat

No.	Used	WinID	Description	Design	U-Value	g-Value	T-sol	Rf-sol	T-vis
97	n	2301	Insulating,Ar, 1.4 71/59	4/16/4	1.4	0.589	0.426	0.266	0.706
98	n	2304	Insulating,Ar, 1.4 74/62	4/16/4	1.4	0.622	0.462	0.237	0.749
99	n	13001	Saint Gobain CLIMAPLUS...	4/15/4	1.43	0.605	0.521	0.355	0.782
100	y	15009	Luxguard SUNGUARD CL...	6/16/4	2.3	0.295	0.214	0.195	0.292
101	y	15008	Luxguard SUNGUARD CL...	6/16/4	2.54	0.44	0.357	0.124	0.472
102	n	1002	InsulatingGlass, 2.8	4/16/4	2.83	0.755	0.693	0.126	0.817
103	n	1102	Insulating, 2.8	4/16/4	2.83	0.755	0.693	0.126	0.817
104	n	1202	Insulating, 2.8	4/16/4	2.83	0.755	0.693	0.126	0.817
105	n	1302	Insulating, 2.8	4/16/4	2.83	0.755	0.693	0.126	0.817
106	n	11008	FLOAT_19	19	5.16	0.682	0.6	0.07	0.83
107	n	11007	FLOAT_15	15	5.29	0.721	0.65	0.07	0.85

```
WINDOW 4.1  DOE-2 Data File : Multi Band Calculation
Unit System : SI
Name        : TRNSYS15 WINDOW LIB
Desc        : Luxguard SUNGUARD CLEAR Argon, 2.6 6/16/4
Window ID   : 15008
Tilt        : 90.0
Glazings    : 2
Frame       : 11 TRNSYS WIN - 1         2.270
Spacer      :  1 Class1                 2.330  -0.010   0.138
Total Height: 1600.0 mm
Total Width : 1250.0 mm
Glass Height: 1460.3 mm
```

Figure 3.6 - TRNSYS library types of windows

The transmittance of the frame (Figure 3.7) is included manually ("Frame"). The area of frame-area of window ratio is decided measuring a similar model of window existing in Hungary [1].


Window Type Manager

window type: WINDOW

Glazing

ID number: 15008

slope of window: 90 degree

For 1 glazing module width: 0.77 m height: 1.08 m

u - value: 2.54 W/m^2 K

g - value: 0.44 %/100

ID spacer: 1 Aluminum - ASHREA Metallic

values acc. to glazing library (for reference only)

Frame

area frame/window: 0.4 % / 100

solar absorptance: 0.6 -

u - value (1/R): 8.17 kJ/h m^2 K

(without conv. + rad. heat transfer coefficients!)

Optional Properties of Shading Devices

Additional Thermal Resistance

internal device: 0 h m^2 K/kJ

external device: 0 h m^2 K/kJ

Reflection Coefficient of Internal Device

towards window: 0.5 % / 100

towards zone: 0.5 % / 100

Fraction of abs. Solar Radiation to Zone Air Node (CCISHADE)

0.5 % / 100

Convective Heat Transfer Coefficient of Window (glazing + frame)

Front (inside)

● userdefined ○ internal calculation

11 kJ/h m^2 K

Back (outside)

● userdefined ○ internal calculation

64 kJ/h m^2 K

Figure 3.7 - TRNSYS Window Type Manager

---

[1] The dimensions of the windows considered are w=150 cm, h=120 cm.

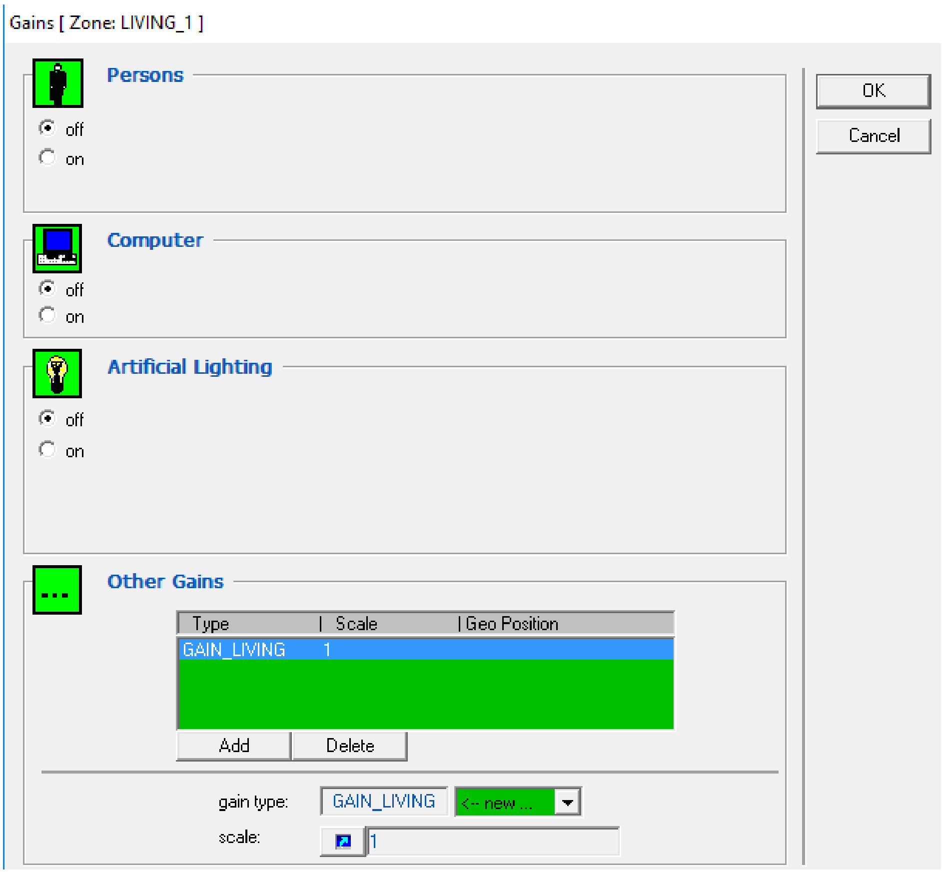
The window has two wings. The frame is 12 cm wide all around the perimeter, and 18 cm in the middle; those values correspond to a frame area of 0,7632 m^2.

Because the window area is 1,2*1,5=1,8 m2, the frame area will be 42,4%;
in the TRNSYS simulation it has been considered a value equal to 40%

3.6 Internal gains

Hungarian regulation provides the procedure for the evaluation the overall energy demand of a building [10]. This regulation suggests a conventional value of about 5 W/m^2 of heated area in order to assess the amount of internal gains of a residential building. The internal gains of a dwelling are typically due to the presence of people, to appliances and personal computers, electrical devices, lighting systems, hot water supply and to cooking.

The Gain type manager of Trnsys (Figure 3.8) requires a power input expressed in kJ/hr, and not a specific power (W/m^2) as provided by the requirement. For this reason the average heat gain for each categories of room (living room, bedroom, bathroom, toilet, closet and corridor) is calculated.


Gains [Zone: LIVING_1]

Persons
● off
○ on

Computer
● off
○ on

Artificial Lighting
● off
○ on

Other Gains

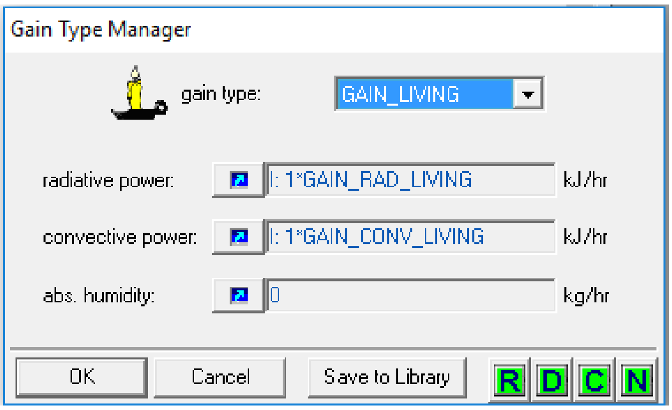
Type	Scale	Geo Position
GAIN_LIVING	1	

gain type: GAIN_LIVING

scale: 1

Figure 3.8 - –"Gain Type Manager" interface. Definition of internal contributions of a room.

Are considered both convective and radiative exchanges related to the presence of people inside the room, divided by a 85-15% ratio. Possible internal sources of moisture are not considered (Figure 3.9).



Gain Type Manager

gain type: GAIN_LIVING

radiative power: I: 1*GAIN_RAD_LIVING kJ/hr

convective power: I: 1*GAIN_CONV_LIVING kJ/hr

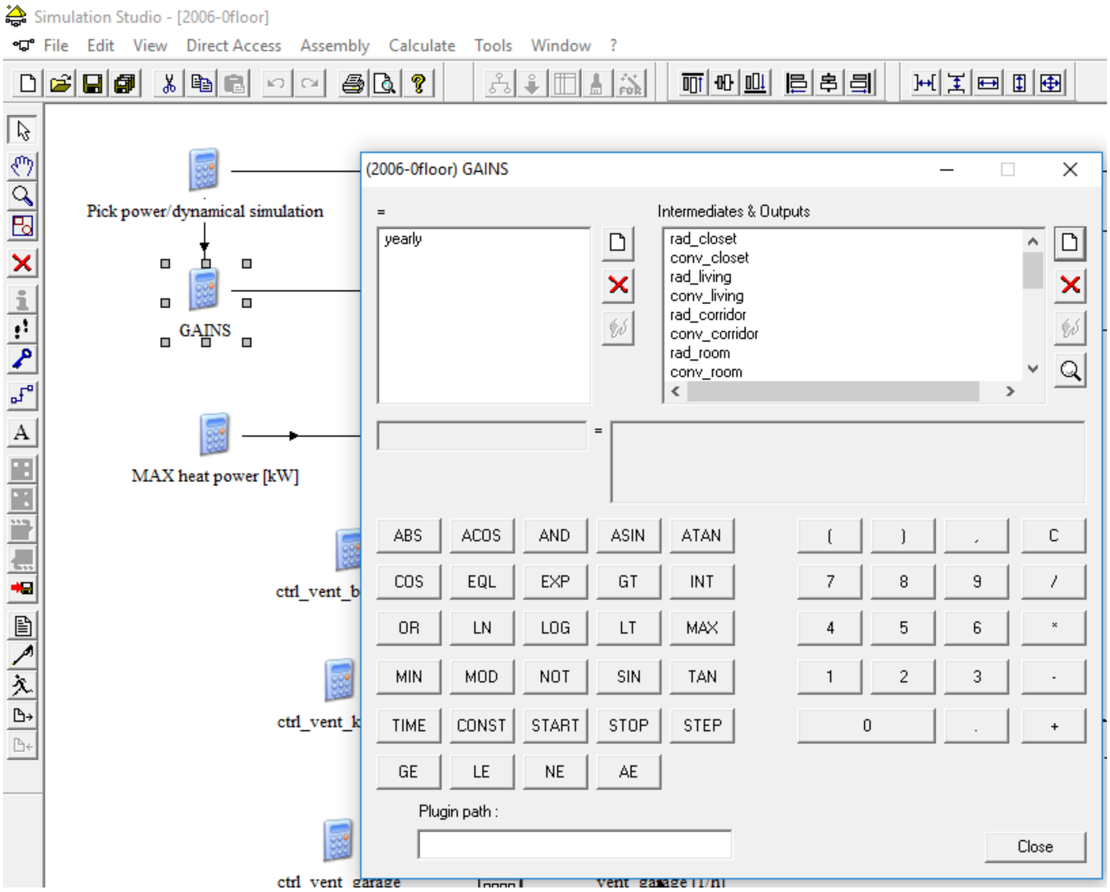
abs. humidity: 0 kg/hr

Figure 3.9 – "Gain Type Manager" interface.
Definition of radiative and convective power depending on an external variable..

Table 3.1 - Calculation of convective and radiant heat gains

(Average values)	*Surface*	*Gains*			
	m^2	*W*	*kJ/h*	***kJ/h,conv.***	***kJ/h,rad.***
toilet	6.1	30.7	111	***94***	***17***
wc	1.3	6.6	24	***20***	***4***
kitchen	26.0	130.2	469	***398***	***70***
corr	9.9	49.7	179	***152***	***27***
room1	11.2	55.8	201	***171***	***30***
room2	5.4	27.1	98	***83***	***15***
room3	1.7	8.5	31	***26***	***5***
closet	2.0	9.8	35	***30***	***5***
corridor	30.4	152.0	547	***465***	***82***
stairwell	14.9	74.6	269	***228***	***40***
entry1	10.9	54.4	196	***166***	***29***
entry2	5.6	27.8	100	***85***	***15***

The values from Table 3.1 are set as inputs from Trnsys studio, so is very simple change this settings to see the simulation with different heating loads, as shown in Figure 3.10.



yearly

rad_closet
conv_closet
rad_living
conv_living
rad_corridor
conv_corridor
rad_room
conv_room

Figure 3.10 - Setting heat gains as inputs depending on an external variable.

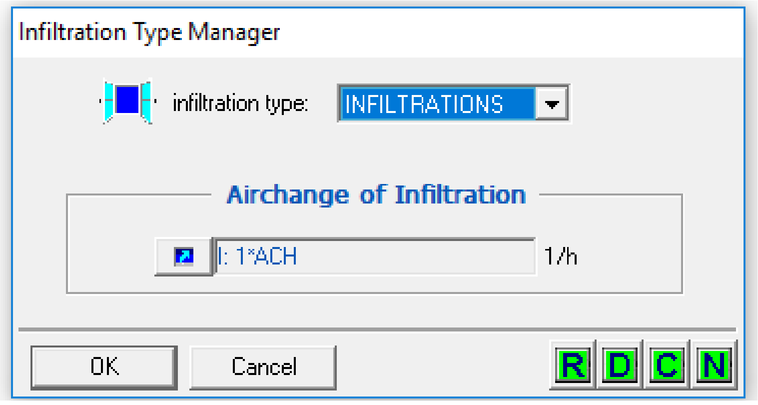
3.7 Infiltrations and natural ventilation

An Air Change rate per Hour in dwellings with a value of $ACH = 0.6$ [16] is considered. This value is obtained summing an $ACH = 0.3$ for infiltrations -always present and due to the infiltrations between windows frames- and $ACH = 0.3$ for natural ventilation, that is the air change due to the opening of windows [17].

It is therefore considered a value of $ACH = 0.6$ for all the rooms with windows, supposing $ACH_{infiltration} = 0.3$ and $ACH_{natural\ ventilation} = 0.3$

$ACH = 0$ is set for bathrooms, toilets and closets. In the first two rooms there is forced ventilation with expulsion of exhaust air. In closets any kind of ventilation is expected.

In the section "Infiltration type managers" (Figure 3.11) the air exchange rate is provided as an external input from Trnsys studio, so is possible to change this value very easily. The inputs values and air changes are incorporated with a constant value: this means implicitly that considering a continuous operation of the building throughout the year.


Infiltration Type Manager

infiltration type: INFILTRATIONS

Airchange of Infiltration

I: 1*ACH 1/h

Figure 3.11 - "Infiltration Type Manager" interface.
Definition of the air exchange depending on an external variable.

3.8 Ventilation

The data in our possession state that the building has an average air change rate of $ACH_{average} = 0.9\ vol/h$, which can be used for energy calculations. In fact the exhaustion ventilators that occurs in kitchens, bathrooms and toilets are working only for short period of time during a day. For this short periods the ACH is higher, respectively of 3 and 5 vol/h. But in other periods, when those rooms are not used the exhaust system is turned off.

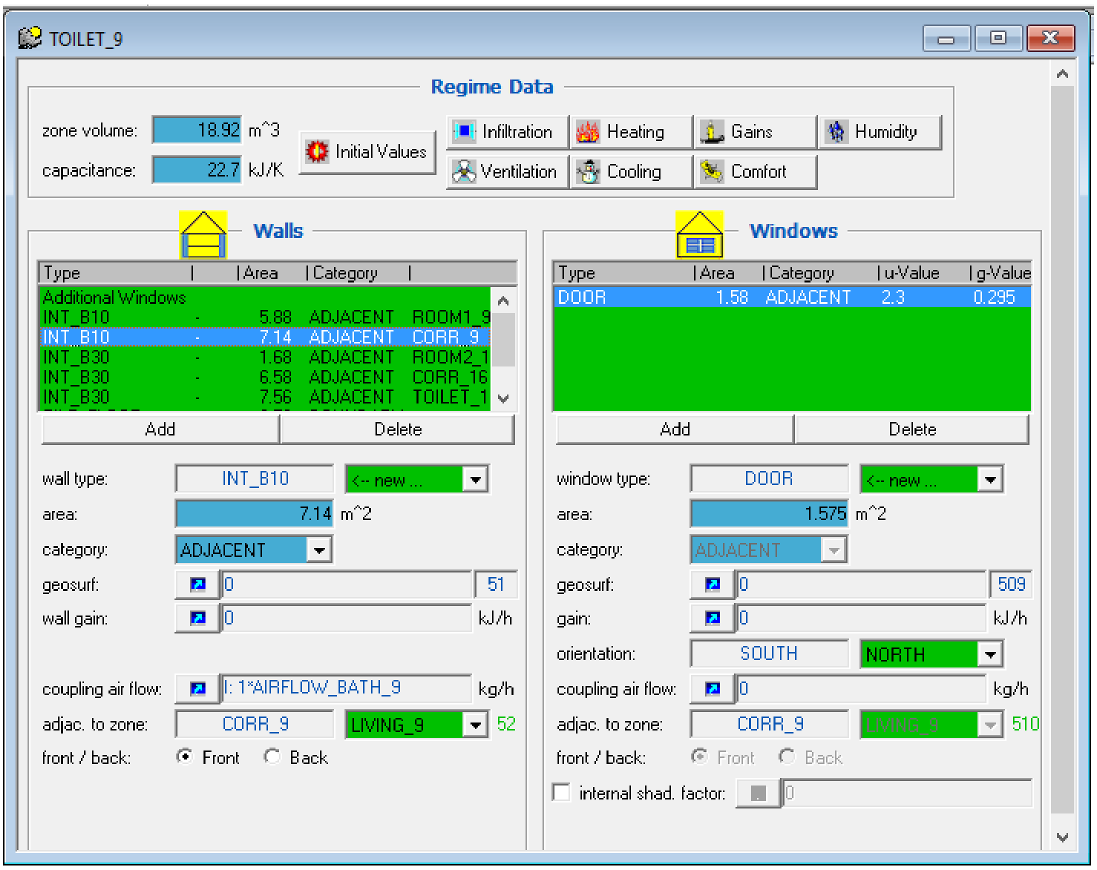
It is therefore necessary to mediate this values to find the number of hours in which ventilation is active in toilets and kitchens. Calculations are reported in annex A.2, Calculation of ACH.

To obtain an average air change rate of 0.9, an operation time of 3 hour/day for kitchen, and 2.5 hour/day for toilets and bathrooms has been assumed the daily schedule are the following:

- for the kitchen, half an hour in the morning, at 8am; 1 hour at midday; 1.5 hour for dinner, from 20 pm;
- for the bathroom, one hour in the morning, at 8 am, and one hour and half in the evening, from 10 pm.

Those values are entered in a "Timer tool" present in Trnsys studio (Figure 3.13), that is connected to the adequate mass air flow. This tool allows to decide an index for each hour of the day. Since is not possible to set the 30 minutes of powered ventilation, it is decided to utilize an index from 0 to 1 with 2 intervals, where index 0 means no powered ventilation; index 1 means full powered ventilation, and ½ means one half of the total air flow. The effects of those simplification are suppose negligible, since there are no big differences of the external air temperature between 30 minutes of the journey.

Air supply to kitchen is directly aspirated from outdoor. Air exhausted from the bathroom is instead replaced with fresh air coming from the corridor; this air is it itself coming from the kitchen, where there is an aperture communicating with the outdoor. (Figure 3.12)



zone volume: 18.92 m^3

capacitance: 22.7 kJ/K

Type		Area	Category	
Additional Windows				
INT_B10	-	5.88	ADJACENT	ROOM1_9
INT_B10	-	7.14	ADJACENT	CORR_9
INT_B30	-	1.68	ADJACENT	ROOM2_1
INT_B30	-	6.58	ADJACENT	CORR_16
INT_B30	-	7.56	ADJACENT	TOILET_1

wall type: INT_B10 <-- new ...

area: 7.14 m^2

category: ADJACENT

geosurf: 0 51

wall gain: 0 kJ/h

coupling air flow: I: 1*AIRFLOW_BATH_9 kg/h

adjac. to zone: CORR_9 LIVING_9 52

front / back: ● Front ○ Back

Type	Area	Category	u-Value	g-Value
DOOR	1.58	ADJACENT	2.3	0.295

window type: DOOR <-- new ...

area: 1.575 m^2

category: ADJACENT

geosurf: 0 509

gain: 0 kJ/h

orientation: SOUTH NORTH

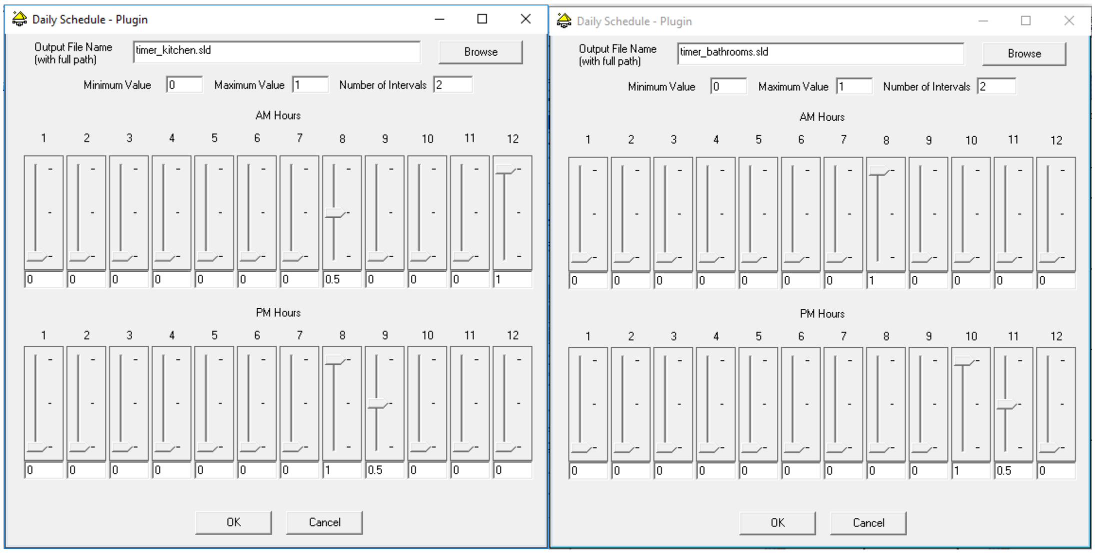
coupling air flow: 0 kg/h

adjac. to zone: CORR_9 LIVING_9 510

front / back: ● Front ○ Back

☐ internal shad. factor: 0

Figure 3.12 - Coupling air flow schedule



Output File Name (with full path) timer_kitchen.sld

Minimum Value 0 Maximum Value 1 Number of Intervals 2

	1	2	3	4	5	6	7	8	9	10	11	12
AM Hours	0	0	0	0	0	0	0	0.5	0	0	0	1
PM Hours	0	0	0	0	0	0	0	1	0.5	0	0	0

Output File Name (with full path) timer_bathrooms.sld

Minimum Value 0 Maximum Value 1 Number of Intervals 2

	1	2	3	4	5	6	7	8	9	10	11	12
AM Hours	0	0	0	0	0	0	0	1	0	0	0	0
PM Hours	0	0	0	0	0	0	0	0	0	1	0.5	0

Figure 3.13 - Daily schedule timer tool for kitchen and bathroom

For the garage the German VDI 2053 normative [18] in used. In case of family houses the garage ventilation can be natural or mechanical.

In case of mechanical ventilation the fresh air flow should be calculated according to the no. of cars, type of cars, driving distance, etc. As a general rule of thumb the air changes per hour in a storage garage should be least $ACH = 4\, vol/h$.

But this is not a continuous operation of the fan: mechanical ventilation systems for enclosed parking garages are not required to operate continuously where the system is arranged to operate automatically upon detection of a concentration of carbon monoxide of 25 parts per million (ppm) by approved automatic detection devices.

Automatic operation of the system shall not reduce the ventilation rate below $0.05\, cfm/sqft$ ($0.00025\, m^3/s\, m^2$) of the floor area and the system shall be capable of producing a ventilation rate of $1.5\, cfm/sqft$ ($0.0076\, m^3/s\, m^2$) of floor area.

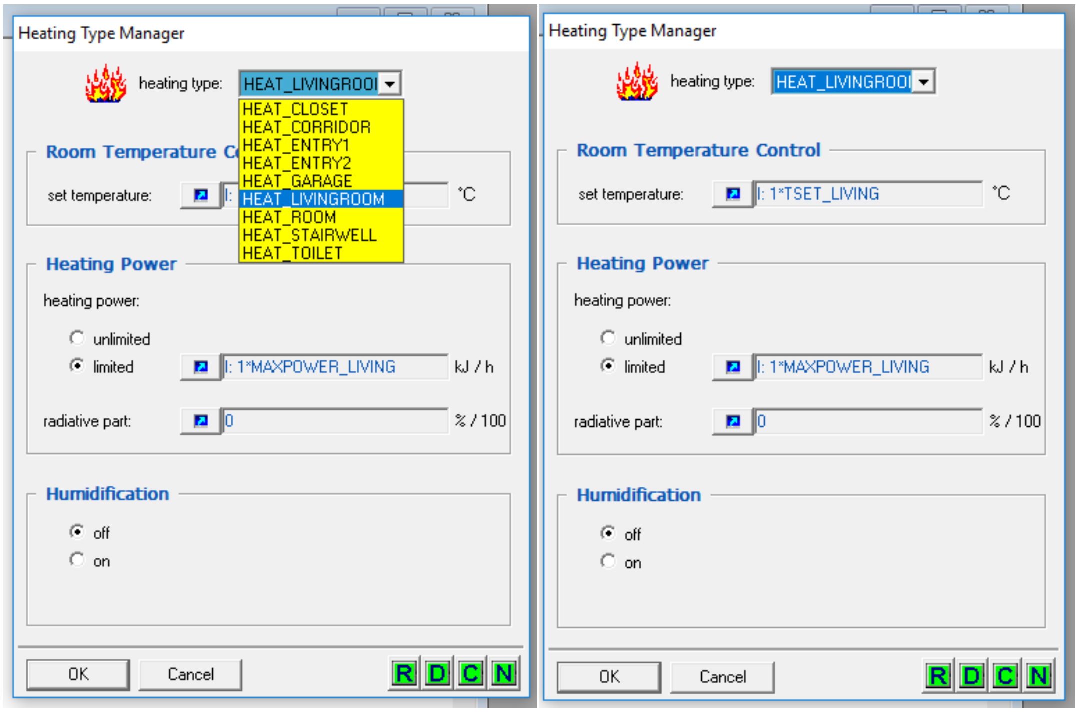
To obtain an average $ACH \cong 1$, it has been established the hours of the day with ventilation ON assuming that the ACH=4 is realized (4 times for 1 hour)/day. For the rest of time the ACH will be 0.5. This will give: $(4\, hours * 4 + 20\, hours * 0.5)/24\, hour = 1$.

To model the operation of this type of ventilation with TRNSYS, with two different values of ACH, it has been decided to add an $ACH = 0.5\, vol/h$ in the “infiltrations menu” always ON, and adding forced ventilation with an $ACH = 3.5\, vol/h$ (3.5+0.5 = 4, the value is necessary to obtain when ventilation is ON) working for 4 hours a day.

However, in practice, for garages in family houses, mainly natural (stack) ventilation is used. [19]

3.9 Heating and cooling

The heating requirement of any zone subject to idealized heating control can be determined by specifying a heating type. In the "Heating type manager" (Figure 3.14) is set the temperature for every room of the building. The minimum comfort temperature used in Hungary is 24 °C for kitchen, living room, toilets and bathrooms; 16°C for the common corridor and the stairwell; 20°C for the others heated environments of the building.



heating type: HEAT_LIVINGROOM

set temperature: I: 1*TSET_LIVING °C

heating power:
○ unlimited
● limited I: 1*MAXPOWER_LIVING kJ / h

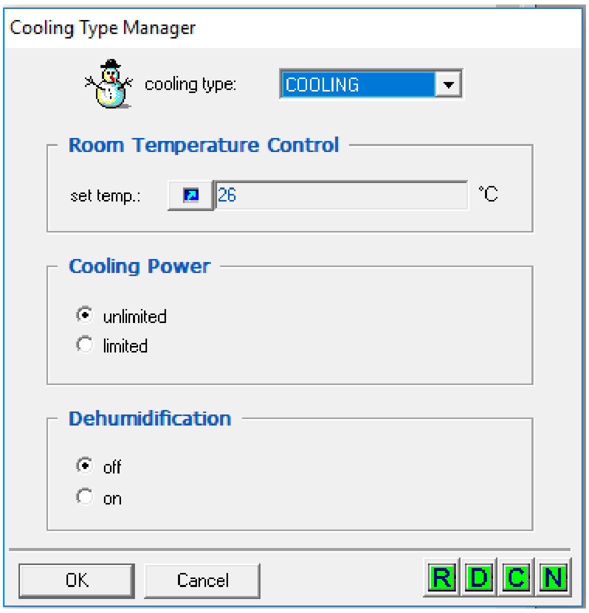
radiative part: 0 % / 100

Humidification:
● off
○ on

Figure 3.14 - Heating Type Manager" interface. Defining the internal temperature of the heated rooms.

The maximum heating power for each typologies of room is set from an external input from Trnsys studio. This value have been intentionally set very high so will not interfere with the simulation. If desired, is possible to set a lower value and see how does the temperatures of the different rooms will change.

Lastly is considered also the “cooling type manager”, setting a maximum temperature in every rooms of 26°C (Figure 3.15).



Cooling Type Manager

cooling type: COOLING

Room Temperature Control

set temp.: 26 °C

Cooling Power

● unlimited
○ limited

Dehumidification

● off
○ on

Figure 3.15 - Cooling Type Manager" interface. Defining the maximum setpoint temperature

3.10 Diagram simulation in Simulation Studio

Once defined the model of the building in TRNBuild, in the Simulation Studio environment - the main software interface- is constructed the scheme to allow the calculation of net energy requirements and temperatures that evolve within the thermal zones.

A TRNSYS project is built by selecting and dragging the various components (selected from a list provided by the software) within the workspace, then graphically connecting the components and setting global simulation parameters. Each "type" is described by a mathematical model and requires a set of parameters or input and output values to connect to. Depending on the complexity of the task to be performed, functions can be entered manually or by using external calculation codes.

The mathematic model of the Type has a black-box structure with INPUT, OUTPUT and PARAMETERS, as shown in Figure 3.16.

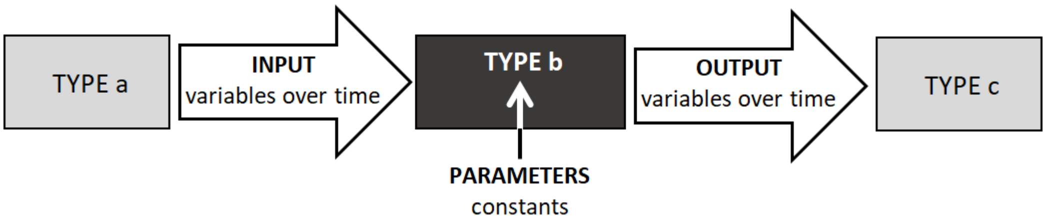
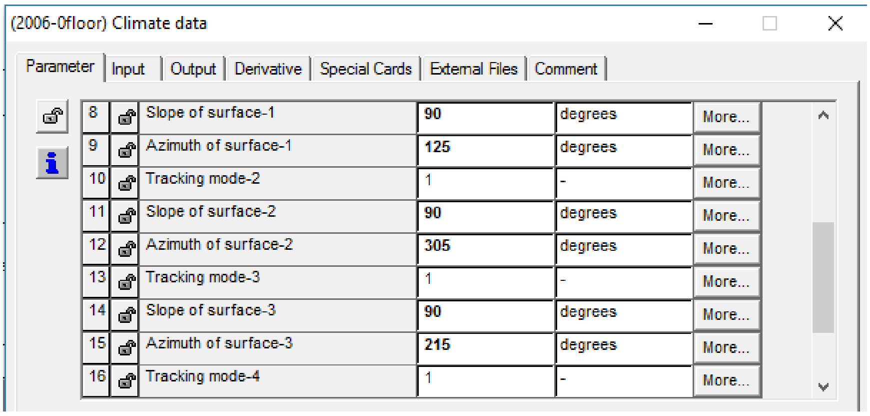


Figure 3.16 - Black-box structure of the type

The "**Type 15 – Climate data**" allows, giving the climate data file suitably processed input (HUN_Debrecen.txt), to return the temperature variable values and Hourly power need to ensure the correct temperature set in the rooms of the building, implemented in the type 56.

Besides this, in this type are defined the orientations (azimuth and slope) of all the surfaces of the building, to calculate the components of the radiation that strikes perpendicular to each surfaces, as the input data from the climate file radiation are referred to a generic horizontal plane (Figure 3.17).

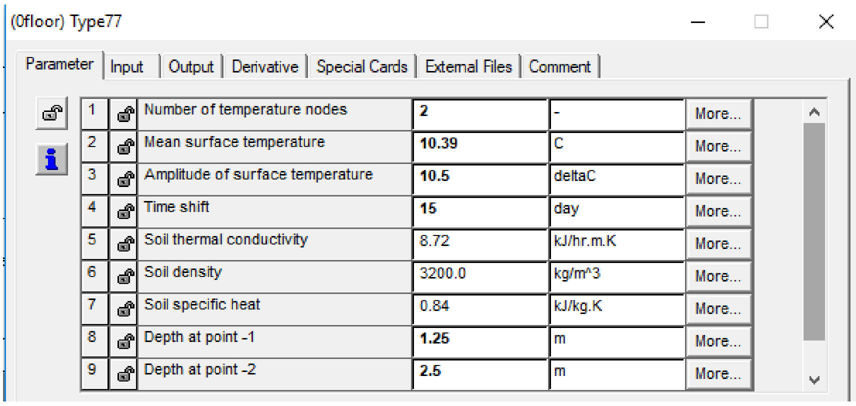
These variables, leaving the type 15, provide inputs when connected to the respective surfaces of the type 56.



8	Slope of surface-1	90	degrees	More...
9	Azimuth of surface-1	125	degrees	More...
10	Tracking mode-2	1	-	More...
11	Slope of surface-2	90	degrees	More...
12	Azimuth of surface-2	305	degrees	More...
13	Tracking mode-3	1	-	More...
14	Slope of surface-3	90	degrees	More...
15	Azimuth of surface-3	215	degrees	More...
16	Tracking mode-4	1	-	More...

Figure 3.17 - - Interface in Simulation Studio of the Type15

As the climate file provides only air temperature, and the underground temperature is needed to calculate the heat losses of the underground garage, **Type 77** will be used. This Type provides a simplified trend of underground temperatures: knowing the mean surface temperature and the time shift, that is the day of the year with the lowest temperature, will return as output a sinusoidal temperature trend of the soil at a certain depth, during the whole year. Not knowing the composition of the soil, has been considered the prefixed values of soil thermal conductivity and soil density (Figure 3.18).



1	Number of temperature nodes	2	-	More...
2	Mean surface temperature	10.39	C	More...
3	Amplitude of surface temperature	10.5	deltaC	More...
4	Time shift	15	day	More...
5	Soil thermal conductivity	8.72	kJ/hr.m.K	More...
6	Soil density	3200.0	kg/m^3	More...
7	Soil specific heat	0.84	kJ/kg.K	More...
8	Depth at point -1	1.25	m	More...
9	Depth at point -2	2.5	m	More...

Figure 3.18 - Interface of Type77

Without knowing more precise constructive details of the garage, it was done as follow:

In a same TRNSYS model were built both the ground floor and the garage under it.

The apartments at the ground floor have:

- an identical boundary as ceiling;
- walls adjacent to others rooms at the same floor;
- walls facing outdoor;
- a floor (the insulated one) facing to the garage.

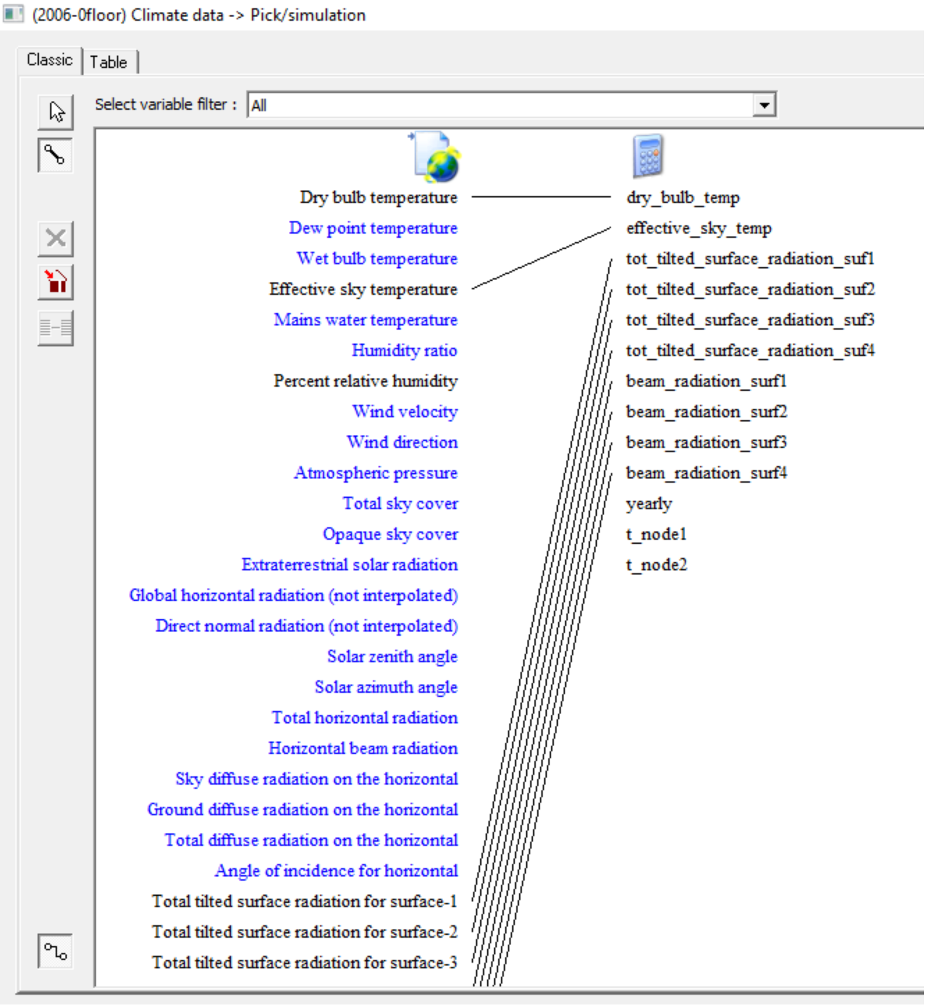
So the garage has the following boundary conditions:

- on the top, the insulated floor facing the apartments at ground floor;
- on the sides and for the floor, the same external wall used in the whole building are considered, but with a boundary condition:

with type77 on Trnsys the temperatures of the soil at -1,75m and -2.5 m are calculated;

- for the floor the boundary temperature at -2.5m (depth of the floor garage) is considered;
- for the walls of the garage, the boundary temperature at -1.75m (is the half depth of the walls).

Figure 3.19 illustrates the graphical interface for connecting the outputs of a type as inputs of the next type, very intuitive and easy to understand:



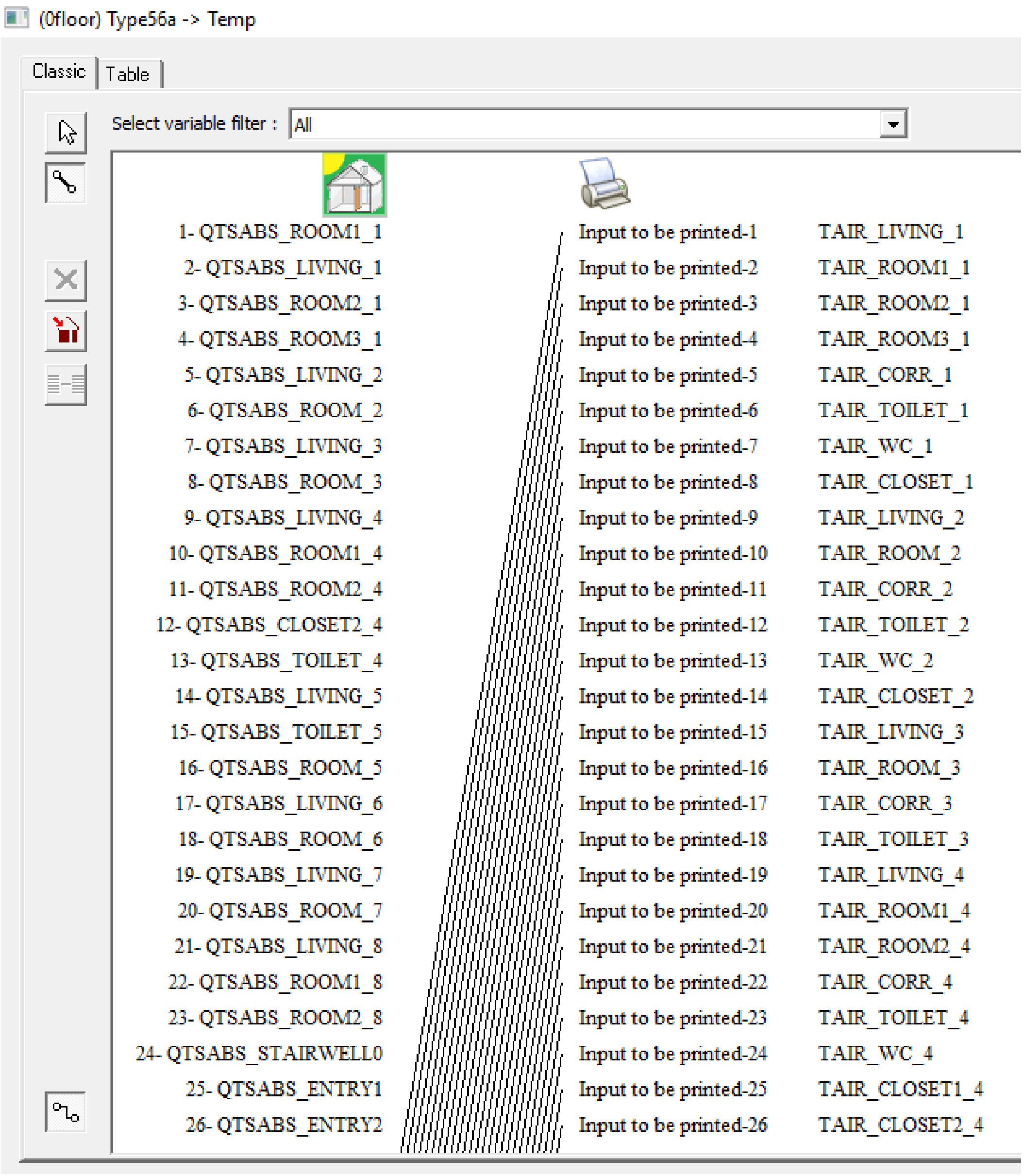
(2006-0floor) Climate data -> Pick/simulation

Select variable filter : All

Figure 3.19 - Graphical interface connection in TRNSYS Studio

Finally it is useful to print the results of simulations both in text format and graphically by TRNEXE; the variables of the desired variables can be viewed by comparing up to nine outputs simultaneously for each axis.

Type 65 is a graph plotter, allowing us to plot results directly on the display. The "type 25" is a real plotter, allowing to print the simulation results on a ".txt" file. The variables that you want to graph or print are set through the connections of the outputs of the type 56 to the type 65 (Figure 3.20). An example of output is shown in Figure 3.21.



(0floor) Type56a -> Temp

Select variable filter : All

1- QTSABS_ROOM1_1	Input to be printed-1	TAIR_LIVING_1
2- QTSABS_LIVING_1	Input to be printed-2	TAIR_ROOM1_1
3- QTSABS_ROOM2_1	Input to be printed-3	TAIR_ROOM2_1
4- QTSABS_ROOM3_1	Input to be printed-4	TAIR_ROOM3_1
5- QTSABS_LIVING_2	Input to be printed-5	TAIR_CORR_1
6- QTSABS_ROOM_2	Input to be printed-6	TAIR_TOILET_1
7- QTSABS_LIVING_3	Input to be printed-7	TAIR_WC_1
8- QTSABS_ROOM_3	Input to be printed-8	TAIR_CLOSET_1
9- QTSABS_LIVING_4	Input to be printed-9	TAIR_LIVING_2
10- QTSABS_ROOM1_4	Input to be printed-10	TAIR_ROOM_2
11- QTSABS_ROOM2_4	Input to be printed-11	TAIR_CORR_2
12- QTSABS_CLOSET2_4	Input to be printed-12	TAIR_TOILET_2
13- QTSABS_TOILET_4	Input to be printed-13	TAIR_WC_2
14- QTSABS_LIVING_5	Input to be printed-14	TAIR_CLOSET_2
15- QTSABS_TOILET_5	Input to be printed-15	TAIR_LIVING_3
16- QTSABS_ROOM_5	Input to be printed-16	TAIR_ROOM_3
17- QTSABS_LIVING_6	Input to be printed-17	TAIR_CORR_3
18- QTSABS_ROOM_6	Input to be printed-18	TAIR_TOILET_3
19- QTSABS_LIVING_7	Input to be printed-19	TAIR_LIVING_4
20- QTSABS_ROOM_7	Input to be printed-20	TAIR_ROOM1_4
21- QTSABS_LIVING_8	Input to be printed-21	TAIR_ROOM2_4
22- QTSABS_ROOM1_8	Input to be printed-22	TAIR_CORR_4
23- QTSABS_ROOM2_8	Input to be printed-23	TAIR_TOILET_4
24- QTSABS_STAIRWELL0	Input to be printed-24	TAIR_WC_4
25- QTSABS_ENTRY1	Input to be printed-25	TAIR_CLOSET1_4
26- QTSABS_ENTRY2	Input to be printed-26	TAIR_CLOSET2_4

Figure 3.20 - Connections between different Type in Simulation Studio

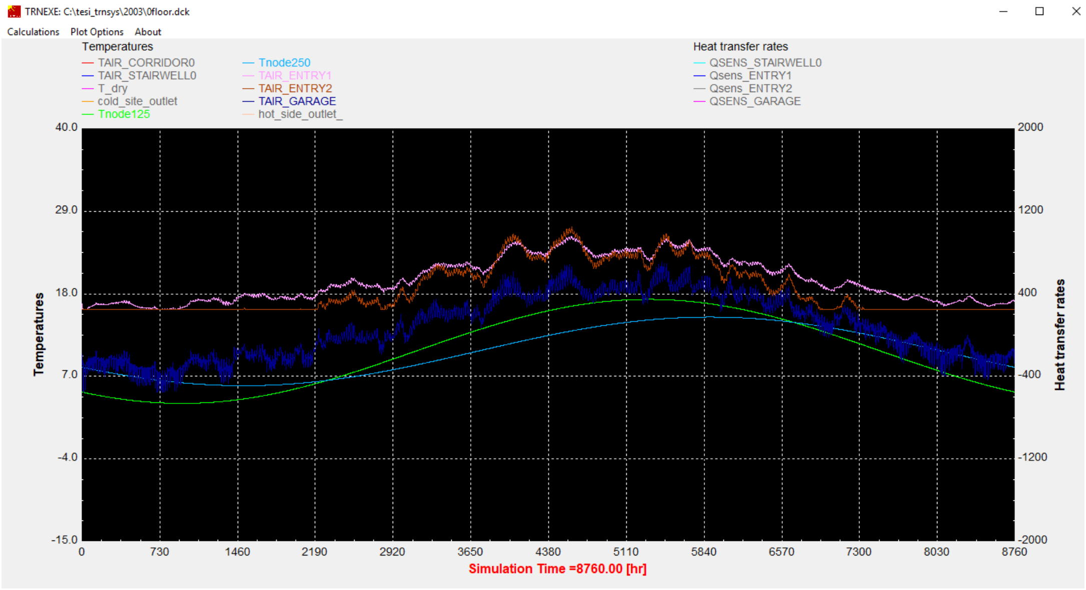


Figure 3.21 - Example of output from the plotter

The simulation scheme of our building is given in the following Figure 3.22:

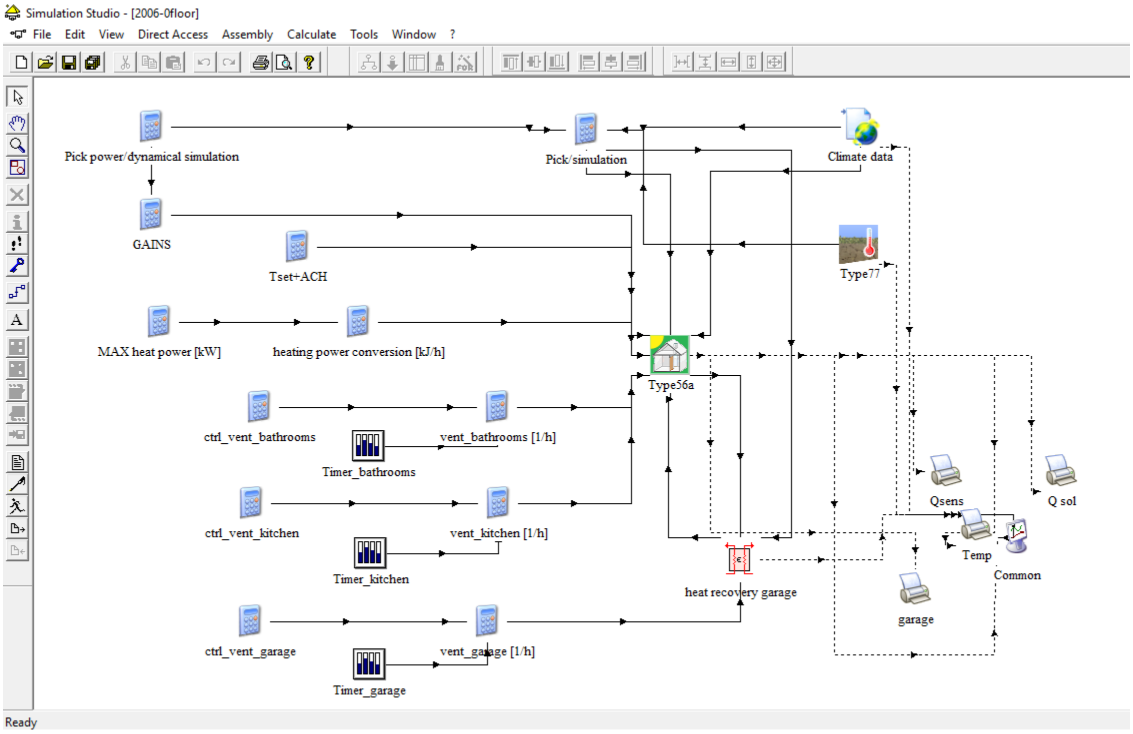


Figure 3.22 - Interface in Simulation Studio of the simulation scheme of the ground floor of the building

4 Pre-retrofit analysis

4.1 Building Peak heating power

To correctly dimensioning the size of the heating system of the building, it was necessary to realize a simulation with extreme winter conditions.

Those conditions are the following:

- -15°C as external temperature;
- no solar and internal gains;
- forced ventilation turned on.

A first simulation shows that with those conditions, the temperature that the garage reaches is equal to -7.8°C, much colder than the minimum temperature allowed.

It is therefore necessary to provide an heating system also in the garage, to obtain a minimum temperature of 5°C.

To limit the heat power needed, is taken into consideration an heat recovery for the mechanical ventilation part.

For the simulation of the original building, it has been taken into account a value of efficiency of 60%. This value will be increased in the following energy refurbishments of the building, using an heat recover with 75% efficiency in year 2006 and 85% in year 2015.

In this way, the following results are obtained:

- With the heat exchanger, air enters the garage at -3°C and no more at -15;
- Air at 5°C in the garage (setpoint temperature, reached thanks to the heating system) go in the heat exchanger and is expelled at a temperature of -7°C.
- Maximum heat power needed (with ventilation always ON) is 17 kW.

The maximum heating power needed in those condition is reported in Annex A.3; following is reported an extract in Table 4.1.

Table 4.1 - Maximum heating power (2003)

TOT 1 floor	72.5	kW
TOT 2 floor	56.3	kW
TOT 3 floor	56.3	kW
TOT 4 floor	54.5	kW
TOT BUILDING =	**239.6**	**kW**

Values in living rooms/kitchens are very high, the reason why is that, due to the high ACH, heating system has to heat air from the external temperature of -15°C to the internal temperature, set at 24°C.

4.2 Rating heating demand

In the previous chapter it is presented the simulation procedure that is followed to allow the calculation of the heating time profile of a building complex.

In the following will be summarized the results of the net energy requirement of the building heating.

In Annex A.4 can be found the full results; here in Table 4.2 an extract:

Table 4.2 - Heating and cooling demand of the building (2003)

APARTMENTS	**2223** m^2	
heating	**289766.15**	*kWh/year*
	128.30	kWh/m^2y
cooling	**17591.13**	*kWh/year*
	7.91	kWh/m^2y
GARAGE	**617** m^2	
heating	**109.65**	*kWh/year*
	0.18	kWh/m^2y

4.3 Primary energy need

To compare energy consumptions between two buildings, which may use different sources of energy to heat the volumes namely, an indicator commonly used is primary energy. Primary energy represents the real amount of energy used to produce the energy used by the final user, called the on-site energy. For energy sources such as gas or fuel oil the primary energy is equal to the onsite energy multiplied for the conversion efficiency of the system used for heating. For electricity, losses are to be considered from electricity production to its distribution and its storage (combustion yield, turbine efficiency, transmission losses…). The ratio of primary energy/onsite energy varies also with the type of energy source. For Hungarian regulations a factor equal to 2.5 is need [10].

In order to trace the gross primary energy, losses related to delivery, distribution, regulation, accumulation (if present), generation should generally be considered. The choice of which leaks should be considered may, however, vary depending on the type of building under consideration and the type of plant.

Following the Hungarian regulations [10], primary energy need for the building can be calculated as follow:

$$E_{primary} = E_f + E_{HMV} + E_{LT} + E_{hu}$$

where:

- E_f is the primary energy need for the heating of the building;
- E_{HMV} is the primary energy need for the domestic hot water;
- E_{LT} is the primary energy need for ventilation;
- E_{hu} is the primary energy need for cooling.

Those factors are calculate as follow:

$$E_f = (q_f + q_{f,h} + q_{f,v} + q_{f,s}) * \sum (C_k \, \alpha_k \, e_f) + (E_{FSz} + E_{Ft} + q_{k,v}) * e_v$$

where:

- q_f is the specific yearly heating need $[kWh/m^2y]$;
- $q_{f,h}$ is a coefficient related to the typology of control in the heating system. For 2003 a value equal to 3.3 kWh/m^2y is considered, representative of "*Termosztatikus szelepek és mas ananyos szabalyozok 2K*"
- $q_{f,v}$ is a coefficient related to the water temperature provided by the heating system. This value is expressed in function of the floor area of the building. For 2003 a value equal to 2.5 kWh/m^2y is considered, representative of water supply at 90°C, and its return to the boiler at 70°C, with a ΔT of 20°C.
- $q_{f,s}$ is a coefficient representative to the accumulation heat losses. It's supposed equal to zero.
- C_k is a coefficient relative to the typology of boiled used, and is equal to $1/\eta$. Also this value is expressed in function of net floor area of the building. For 2003 a value equal to 1.16 $[-]$ is considered, representative of a *constant temperature boiler*.
- α_k is a coefficient representative of the percentage of heating provided by a single heat source. Is different from zero only if more than a single heating source is used.

- e_f is the primary energy transformation factor for gas. Its value is equal to 1.
- E_{FSz} represent the electrical consumption of the recirculation pumps. In 2003, for "*Allando fordulatu szivattyu 90/70°C*", that is a system with pump with constant speed and a ΔT of 20°C, the value of $0.28\ kWh/m^2y$ is used.
- E_{Ft} represent the electrical consumption for heating the water accumulation with an electric resistance. In our simulation will be equal to zero.
- $q_{k,v}$ is the electricity need for the controls. Parametrized in function of the net floor area, its value is equal to $0.18\ kWh/m^2y$.
- e_v is the primary energy transformation factor for electricity. Its value is equal to 2.5

$$E_{HMV} = \left(q_{HMV} + q_{HMV,v} + q_{HMV,t}\right) * \sum (C_k\ \alpha_k\ e_{HMV}) + (E_C + E_K) * e_v$$

where:

- q_{HMV} is the heat need for DHW. Following Hungarian legislation, its value is $30\ \frac{kWh}{m^2y}\ for\ the\ first\ 80\ m^2 + 15\frac{kWh}{m^2y}$
- $q_{HMV,v}$ is representative of the heat losses during the distribuition. It's equal to $12\%\ q_{HMV}$.
- $q_{HMV,t}$ is representative of the heat losses on storage tanks. It's equal to $4\%\ q_{HMV}$;
- C_k is a coefficient relative to the typology of boiled used, and is equal to $1/\eta$. This value is expressed in function of net floor area of the building. For 2003 a value equal to $1.26\ [-]$ is considered, representative of a constant temperature boiler.
- α_k is a coefficient representative of the percentage of heating provided by a single heat source. Is different from zero only if more than a single heating source is used.
- e_{HMW} is the primary energy transformation factor for heat source used. As is actually used only gas, its value is equal to 1.
- E_C represent the electrical consumption of the recirculation pumps. A value of $0.14\ kWh/m^2y$ is used, parametrized in function of the net floor area.
- E_K is the electricity need for the controls. Parametrized in function of the net floor area, its value is equal to $0.069\ kWh/m^2y$.
- e_v is the primary energy transformation factor for electricity. Its value is equal to 2.5.

$$E_{LT} = \sum (E_{vent} \times e_v) \times \frac{1}{A_v}$$

with

$$E_{vent} = \left(\frac{V_{LT} \times \Delta p_{LT}}{3600 \times \eta_{\mathrm{vent}}}\right) \times \mathrm{Z_{a,LT}}$$

where

- V_{LT} is the hourly volumetric rate of exhausted air, expressed in m^3/h;
- Δp_{LT} are the pression losses of the ventilation system, expressed in $Pascal$.

For the apartment ventilation was considered: air channels for exhaustion, air inlet and outlet elements; for garage ventilation: air channels introduction and exhaustion, heat recuperator H3 (later H2 in 2015), air filter F5, noise attenuators (2 pieces: one for air introduction branch and one for air exhaustion branch), air inlet and air outlet elements.

Were used the values reported in Table 4.3:

Table 4.3 - Pressure losses of the various elements

apartment ventilation	**ΔPa**
air channels for exhaustion	*200*
air inlet, outlet elements	*50*
TOT	***250***
Garage ventilation:	***ΔPa***
air channels introduction	*300*
air channels exhaustion	*200*
heat recuperator H3	*150*
air filter F5	*150*
noise attenuators	*100*
air inlet, outlet element	*50*
TOT	***950***

- η_{vent} is the efficiency of the electric motors of the ventilators; for small motors used in kitchen and bathrooms is used a 0.4 value; in the garage is supposed a bigger motor with efficiency equal to 0.55.
- $Z_{\text{a,LT}}$ represent the period of working of the ventilators; it’s equal to $N° \frac{hours}{day} \times 365 \frac{days}{year} / 1000$

$$E_{hu} = \frac{Q_{hu} \times e_{hu}}{A_n}$$

where

- Q_h is the energy demand for cooling, expressed in $[kWh/m^2y]$;
- e_{hu} is the conversion factor from electric energy to cooling energy, and it’s equal to e_v/EER.
- EER is consider equal to 3 for 2003.

The energy demand of the garage (heating and ventilation) must be taken into account into the total primary energy consumption of the building. However, the set point temperature in the garage is much lower than in the other spaces of the building, and considering the few hours in which the heating is turned on (the energy need of the garage is only 109.65 kWh/y, 0.18 kWh/m^2y), it has been decided to consider in a separate way the heated volume of the garage from the apartments.

It has been calculate separately the heating and ventilation energy demand for the garage and relying on these values the primary energy consumption of the garage alone (25.59 kWh/m^2a);
then the primary energy consumptions (heating, DHW, ventilation and cooling) for the rest of the building.

The sum between those two components is the Primary Energy need of the whole existing building (2003), with the value of $TOT\ 2003 = 253.52\ kWh/m^2y$ (Table 4.4), based on which the energy category of the building can be determined.

Table 4.4 - Primary energy need of the building (2003)

	FLAT			**GARAGE**		
HEATING	E_f =	56.71	kWh/m^2y	E_f =	8.08	kWh/m^2y
DHW	E_{HMV} =	49.98	kWh/m^2y			
VENTILATION	E_{LT} =	11.98	kWh/m^2y	E_{LT} =	17.51	kWh/m^2y
COOLING	E_{hu} =	9.25	kWh/m^2y			
TOT 2003 =		**253.52**	**kWh/m^2y**			

With a total primary energy need of 253.52 kWh/m^2y, the presented building is in a G category, as can be seen from the Table 4.5.

Table 4.5 - Energy categories for residential buildings following Hungarian regulations

Classification	**kWh/m^2y**	**Textual characterization of the quality class**
AA++	<40	Minimal need of energy
AA+	40-60	Extremely energy efficient
AA	61-80	Better than the requirement for nearly zero energy demand
BB	81-100	Meets the requirements for nearly zero energy requirements
CC	101-130	Modern building
DD	131-160	Almost moderd building
EE	161-200	Better than average
FF	201-250	Average building
GG	**251-310**	**Almost average building**
HH	311-400	Weak thermal properties
II	401-500	Bad thermal properties
JJ	>500	Very bad thermal properties

4.4 CO_2 emissions

Hungarian normative “A CO_2 megtakarítás számítása” [20] provides formulas used to calculate the CO_2 emissions of the building.

Heating:

$$F_{CO2,f} = \left(q_f + q_{f,h} + q_{f,v} + q_{f,s}\right) * \sum \left(C_k \, \alpha_k \, f_{CO2,f}\right) + \left(E_{FSz} + E_{Ft} + q_{k,v}\right) * f_{CO2,v}$$

Domestic hot water:

$$F_{CO2,HMV} = \left(q_{HMV} + q_{HMV,v} + q_{HMV,t}\right) * \sum \left(C_k \, \alpha_k \, f_{CO2,f}\right) + \left(E_C + E_K\right) * f_{CO2,v}$$

Ventilation:

$$F_{CO2,LT} = \sum \left(E_{vent} \times f_{CO2,v}\right) \times \frac{1}{A_v}$$

Cooling:

$$F_{CO2,HU} = \frac{Q_{hu} \times f_{CO2,v}}{SEER \times A_n}$$

As you can see, those formulas are quite similar to the ones used to calculate the primary energy needs of the building; all the variables have already been defined in the previous chapter, except for $f_{CO2,f}$ and $f_{CO2,v}$.

- $f_{CO2,f}$ is the transformation factor for gas. It is equal to $203 \ g_{CO2}/kWh$;
- $f_{CO2,v}$ is the transformation factor for electricity. It is equal to $365 \ g_{CO2}/kWh$.

Those values brings to the following results (Table 4.6):

Table 4.6 - CO_2 emissions of the building (2003)

	FLAT			**GARAGE**		
HEATING	$F_{CO2,f}$ =	31.75	kg_{CO2}/m^2y	$F_{CO2,f}$ =	1.57	kg_{CO2}/m^2y
DHW	$F_{CO2,HMV}$ =	10.11	kg_{CO2}/m^2y			
VENTILATION	$F_{CO2,LT}$ =	1.75	kg_{CO2}/m^2y	$F_{CO2,LT}$ =	2.56	kg_{CO2}/m^2y
COOLING	$F_{CO2,hu}$ =	1.35	kg_{CO2}/m^2y			
TOT 2003 =		**49.09**	$\mathbf{kg_{CO2}/m^2y}$			

5 Energy retrofitting plans developed

5.1 Refurbishment according to the requirements established in 2006

The first step of this work is to satisfy the first requirement published after the construction of our building. The satisfaction of this requirement, published in 2006, provide the fulfilment of 3 criteria.

1st level requirement: are defined the overall heat transfer coefficients:

- external walls: $U = 0.45\ W/m^2\,K$
- external roof: $U = 0.25\ W/m^2\,K$
- slab between heated space and attic: $U = 0.30\ W/m^2\,K$
- windows: $U = 1.60\ W/m^2\,K$
- attic windows (mounted inclined in the roof): $U = 1.70\ W/m^2\,K$
- slab above the cellar: $U = 0.50\ W/m^2\,K$

2nd level requirement: specific heat loss (rapported to the heated volume). This is valuated in function of the ratio $\frac{\text{building envelope}}{\text{heated volume}}$

- $A/V\ < 0.3\ \rightarrow\ q_m = 0.2\ [W/m^3K]$
- $0.3\ \leq\ A/V\ \leq 1.3\ \rightarrow\ q_m = 0.38 \times (A/V) + 0.086\ [W/m^3K]$
- $A/V >\ 1.3\ \rightarrow\ q_m = 0.58\ [W/m^3K]$

3rd level requirement is about total primary energy consumption. This is calculated again in function of the building envelope/heated volume ratio.

- $A/V\ < 0.3\ \rightarrow\ E_p = 110\ \ [kWh/m^2a]$
- $0.3\ \leq\ A/V\ \leq 1.3\ \rightarrow\ E_p = 120 \times (A/V) + 74\ \ [kWh/m^2a]$
- $A/V >\ 1.3\ \rightarrow\ E_p = 230\ \ [kWh/m^2a]$

To satisfy the first requirement, is necessary to add or increase the thickness of the insulation layer of the external building elements until requirements are fulfilled.

The first solution reported in Table 5.1 is tried.

Table 5.1 - Increase of the insulation thickness (2006)

SURFACE	U normative	Insulation	U actual
External walls	0.45 W/m^{2}K	+8 cm EPS	0.391 W/m^{2}K
Roof	0.25 W/m^{2}K	+8 cm ROCKWOOL	0.227 W/m^{2}K
Slab attic	0.3 W/m^{2}K	+14 cm EPS	0.272 W/m^{2}K
Slab cellar	0.5 W/m^{2}K	+6cm EPS	0.447 W/m^{2}K
Walls on ground	0.45 W/m^{2}K	+8cm EPS	0.391 W/m^{2}K
Slab on ground	0.5 W/m^{2}K	+8cm EPS	0.447 W/m^{2}K

Table 5.2 - Stratigraphy of the external wall (2006)

External walls

Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	*m^2K/W*	*J/kgK*	*kg/m^3*	*MJ/m^3K*
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
B30 bricks	0.3	0.64	2.304		1000	1000	1
EPS	*0.08*	0.042	0.1512		1000	33	0.033
cement mortar	0.01	0.93	3.348		1000	2200	2.2
External surface resistance*	-	-	-	0.041	-	-	-

R_layers Σ(dj/λj)	2.3966	*m^2K/W*
Rtot = Rsi+Σ(dj/λj) + Rse	2.569	*m^2K/W*
U-value = 1/Rtot	**0.389**	***W/m^2K***

** Calculations according to the standard UNI EN ISO 6946: 2008*

Table 5.3 - Stratigraphy of the insulated slab in the cellar (2006)

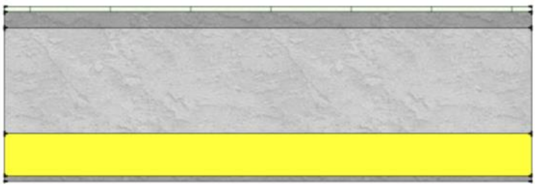
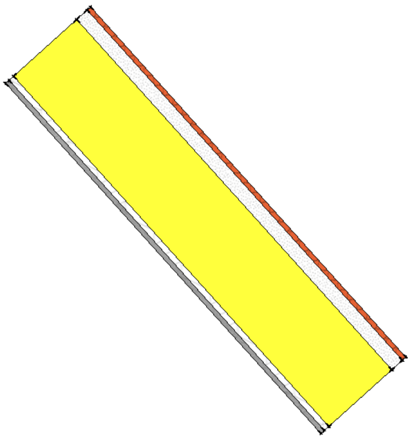
Slab between ground floor and cellar							
Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	*m^2K/W*	*J/kgK*	*kg/m^3*	*MJ/m^3K*
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
EPS	*0.08*	0.042	0.1512		1000	33	0.033
reinforced concrete	0.2	1.55	5.28		1000	2400	2.4
estrich concrete	0.03	1.28	4.608		1000	2400	2.4
tiles	0.007	1.05	3.78		1000	2000	2
Internal surface resistance*	-	-	-	0.131	-	-	-
R_layers Σ(dj/λj)	2.0762	*m^2K/W*					
Rtot = Rsi+Σ(dj/λj) + Rsi	2.248	*m^2K/W*					
U-value = 1/Rtot	**0.445**	***W/m^2K***					
** Calculations according to the standard UNI EN ISO 6946: 2008*							

Table 5.4 - Stratigraphy of the insulated slab to the under-roof (2006)

Slab between heated spaces and under-roof							
Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	*m^2K/W*	*J/kgK*	*kg/m^3*	*MJ/m^3K*
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
EPS	*0.14*	0.042	0.1512		1000	33	0.033
reinforced concrete	0.2	1.55	5.28		1000	2400	2.4
estrich concrete	0.03	1.28	4.608		1000	2400	2.4
tiles	0.007	1.05	3.78		1000	2000	2
Internal surface resistance*	-	-	-	0.131	-	-	-

R_layers Σ(dj/λj)	3.5048	*m^2K/W*	
Rtot = Rsi+Σ(dj/λj) + Rsi	3.677	*m^2K/W*	
U-value = 1/Rtot	**0.272**	***W/m^2K***	
** Calculations according to the standard UNI EN ISO 6946: 2008*			

Table 5.5 - Stratigraphy of the roof (2006)

External roof							
Layers	**s**	**λ**	**λ-Trnsys**	**R**	**T.C.***	**ρ**	**T.C.**
	m	*W/mK*	*kJ/hmK*	*m^2K/W*	*J/kgK*	*kg/m^3*	*MJ/m^3K*
Internal surface resistance*	-	-	-	0.131	-	-	-
lime plastering	0.01	0.81	2.916		1000	1400	1.4
plasterboard	0.0125	0.24	0.864		1000	950	0.95
glass wool	*0.18*	0.044	0.1584		1000	60	0.06
plastic leaf	0.001	0.21	0.756		1000	970	0.97
air layer	0.025	-	-	0.07	1000	1.2	0.0012
roof tiles	0.0125	1.28	4.608		1000	1000	1
External surface resistance*	-	-	-	0.131	-	-	-
R_layers Σ(dj/λj)	4.2399	*m^2K/W*					
Rtot = Rsi+Σ(dj/λj) + Rsi	4.412	*m^2K/W*					
U-value = 1/Rtot	**0.227**	***W/m^2K***					
** Calculations according to the standard UNI EN ISO 6946: 2008*							

Using the new thickness of the insulation all the thermal bridges are re-drawn in Autocad, then imported them in mirage, and finally the new ψ value of the thermal bridges with the new insulation are calculated (Table 5.6).

Table 5.6- Values of thermal bridges (2006)

THERMAL BRIDGES 2006		
SOLAIO	0.110	W/mK
CORNER	0.171	W/mK
T30	0.121	W/mK
T10	0.049	W/mK
T10+PILLAR	0.064	W/mK
GIMKANA	0.052	W/mK
SLALOM+T10 --- NB: SX	0.203	W/mK
SLALOM+T10 --- NB: DX	0.071	W/mK
SLALOM+T30 --- NB: SX	-0.002	W/mK
SLALOM+T30 --- NB: DX	0.079	W/mK
STAIRWELL --- NB: DX	0.210	W/mK
TERRACE	0.653	W/mK
ROOF CORNER	0.072	W/mK
ROOF T30	0.016	W/mK
ROOF T10	0.027	W/mK
ROOF-WALL JUNCTION	0.013	W/mK
ROOF 60	0.189	W/mK
ROOF 15	0.085	W/mK

A new simulation with TRNSYS is made, modifying the following changes:

- the layer’s stratigraphy is updated, adding more insulation when required, as shown in Table 5.1
- the thermal bridge values are updated with the values shown in Table 5.6
- the efficiency of the heat recuperator in garage is increased to a value equal to 75%

In the following, the results of the net energy requirement of the building heating are summarized.

In Annex A.5 can be found the full results; in Table 5.7 an extract:

Table 5.7 - Heating and cooling demand of the building (2006)

APARTMENTS	**2223** *m^2*	
heating	**118385.62**	*kWh/year*
	53.25	*kWh/ m^2y*
cooling	**56944.26**	*kWh/year*
	25.62	*kWh/ m^2y*
GARAGE	**617** *m^2*	
heating	**120.85**	*kWh/year*
	0.20	*kWh/ m^2y*

The second requirement request a maximum specific heat loss rapported to the heated volume equal to

$$q_m = 0.38 \times (A/V) + 0.086\ [W/m^3K]$$

Since the external area is 2950 m^2, and the heated volume is equal to 8264 m^3, the A/V ratio is equal to 0.3570.

The maximum specific heat loss must therefore be equal to

$$q_m = 0.38 \times (0.3570) + 0.086 = 0.222\ [W/m^3K]$$

Following the Hungarian legislation [10], q_m is calculate as follow:

$$q_m = \frac{1}{V} \times \left[\Sigma(A \times U) + \Sigma(\mathrm{l} \times \psi) - \frac{Q_{sd} - Q_{sid}}{72}\right]$$

where

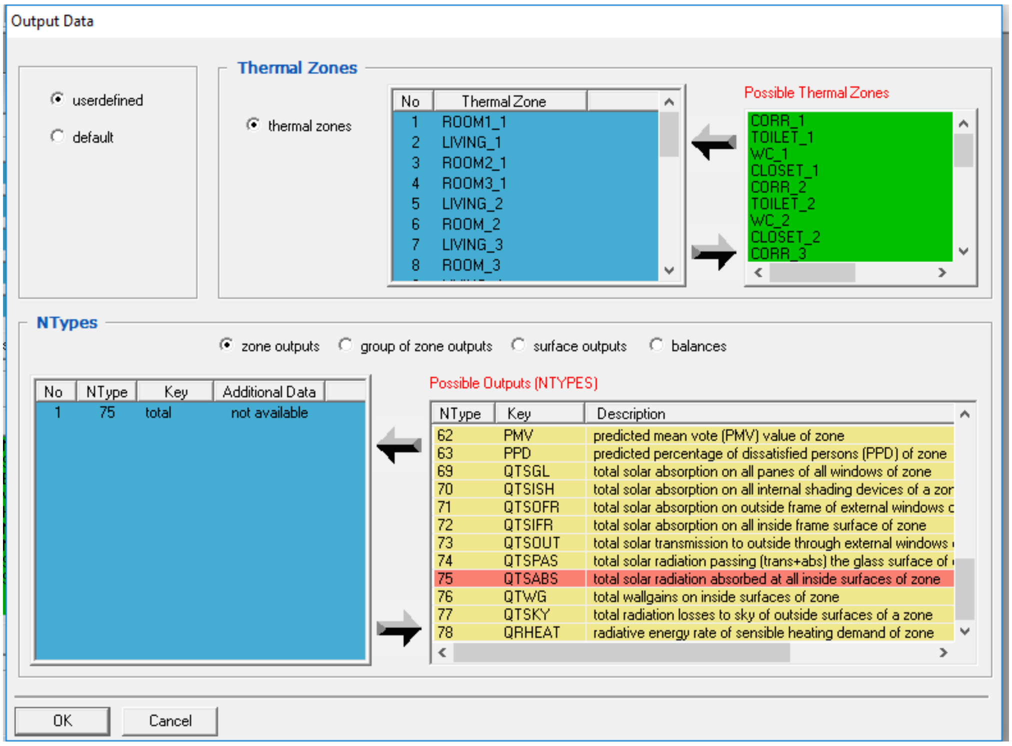
- V is the heated volume, and is equal to 9440 m^3
- $\Sigma(A \times U) + \Sigma(\mathrm{l} \times \psi)$ are the transmission heat losses over (t_i-t_e)
- Q_{sd} and Q_{sid} are respectively direct and indirect solar gains
- 72 are the degrees day (average value in Hungary: 72000 hK).

Transmission losses are calculated thanks to an Excel file.

$$\Sigma(A \times U) + \Sigma(\mathrm{l} \times \psi) = 2281.79\ \frac{W}{K}$$

Indirect solar gains Q_{sid} are supposed equal to zero;

Direct solar gains Q_{sd} are calculated from Trnsys, printing the values of QTABS (Figure 5.3), defined as “total solar radiation absorbed at all inside surfaces of zone” (Figure 5.1).



● userdefined
○ default

● thermal zones

No	Thermal Zone
1	ROOM1_1
2	LIVING_1
3	ROOM2_1
4	ROOM3_1
5	LIVING_2
6	ROOM_2
7	LIVING_3
8	ROOM_3

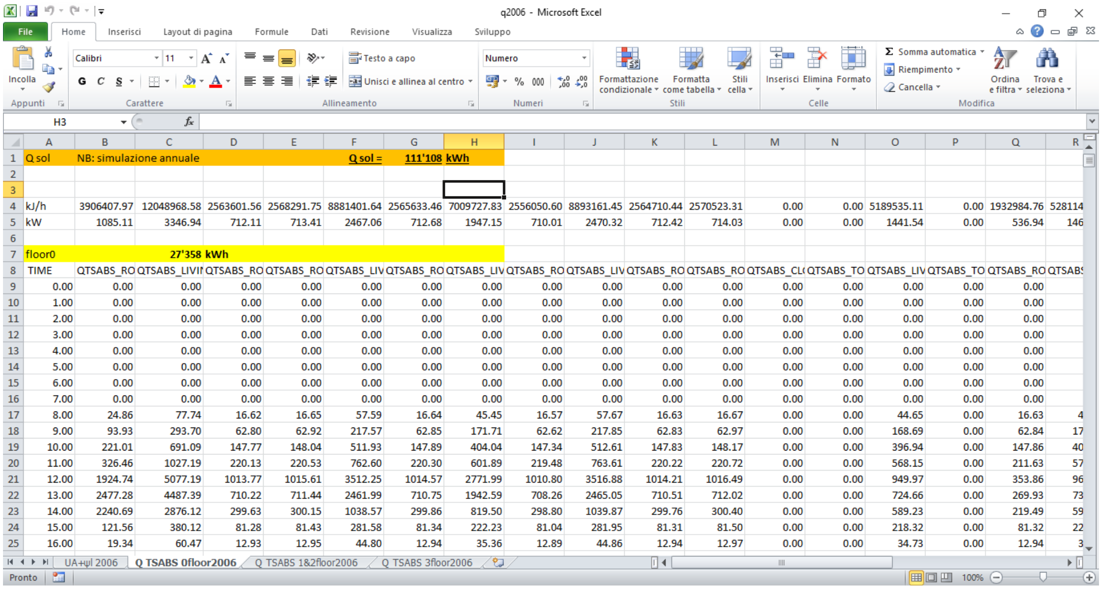
Possible Thermal Zones:
CORR_1
TOILET_1
WC_1
CLOSET_1
CORR_2
TOILET_2
WC_2
CLOSET_2
CORR_3

● zone outputs ○ group of zone outputs ○ surface outputs ○ balances

No	NType	Key	Additional Data
1	75	total	not available

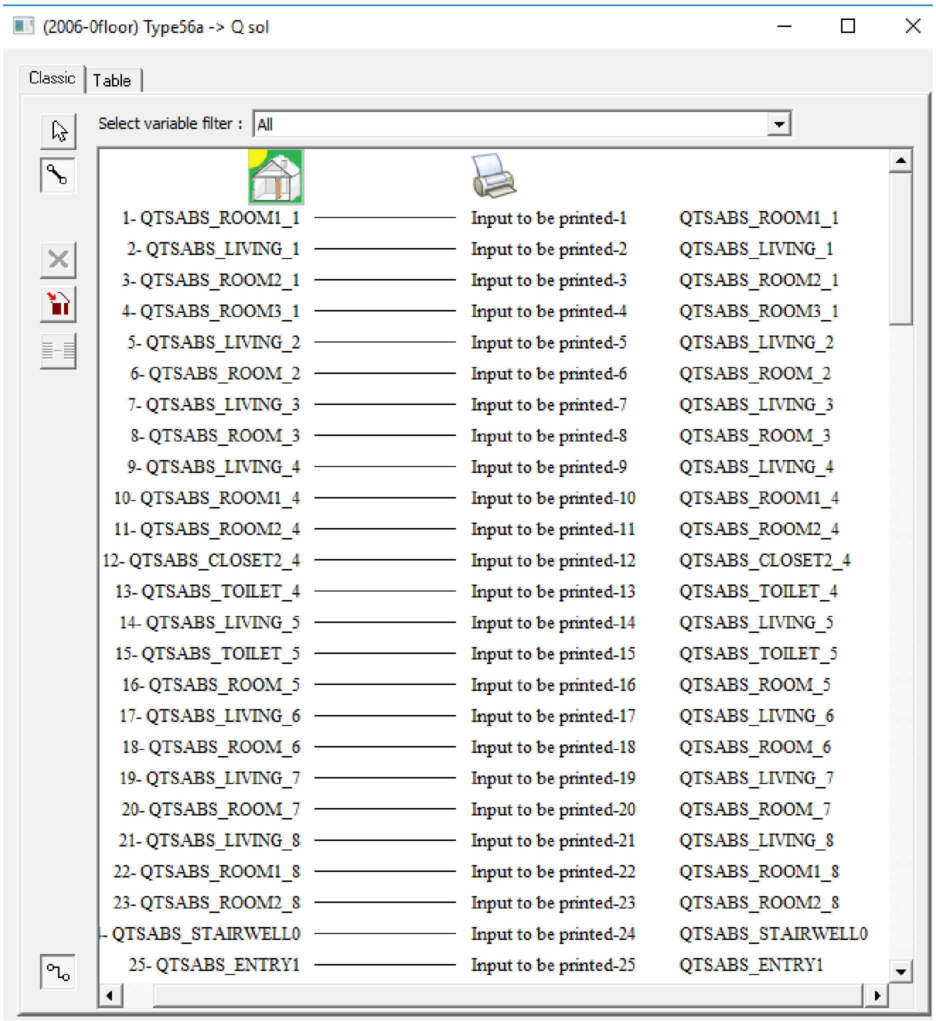
NType	Key	Description
62	PMV	predicted mean vote (PMV) value of zone
63	PPD	predicted percentage of dissatisfied persons (PPD) of zone
69	QTSGL	total solar absorption on all panes of all windows of zone
70	QTSISH	total solar absorption on all internal shading devices of a zor
71	QTSOFR	total solar absorption on outside frame of external windows c
72	QTSIFR	total solar absorption on all inside frame surface of zone
73	QTSOUT	total solar transmission to outside through external windows
74	QTSPAS	total solar radiation passing (trans+abs) the glass surface of
75	QTSABS	total solar radiation absorbed at all inside surfaces of zone
76	QTWG	total wallgains on inside surfaces of zone
77	QTSKY	total radiation losses to sky of outside surfaces of a zone
78	QRHEAT	radiative energy rate of sensible heating demand of zone

Figure 5.1 - TRNSYS possible outputs



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Q sol	NB: simulazione annuale				Q sol =	111'108	kWh										
2																		
3																		
4	kJ/h	3906407.97	12048968.58	2563601.56	2568291.75	8881401.64	2565633.46	7009727.83	2556050.60	8893161.45	2564710.44	2570523.31	0.00	0.00	5189535.11	0.00	1932984.76	528114
5	kW	1085.11	3346.94	712.11	713.41	2467.06	712.68	1947.15	710.01	2470.32	712.42	714.03	0.00	0.00	1441.54	0.00	536.94	146
6																		
7	floor0		27'358	kWh														
8	TIME	QTSABS_RO	QTSABS_LIVI	QTSABS_RO	QTSABS_RO	QTSABS_LIV	QTSABS_RO	QTSABS_LIV	QTSABS_RO	QTSABS_LIV	QTSABS_RO	QTSABS_RO	QTSABS_CL	QTSABS_TO	QTSABS_LIV	QTSABS_TO	QTSABS_RO	QTSABS
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
10	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
11	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
12	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
13	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
14	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
15	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
16	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
17	8.00	24.86	77.74	16.62	16.65	57.59	16.64	45.45	16.57	57.67	16.63	16.67	0.00	0.00	44.65	0.00	16.63	4
18	9.00	93.93	293.70	62.80	62.92	217.57	62.85	171.71	62.62	217.85	62.83	62.97	0.00	0.00	168.69	0.00	62.84	17
19	10.00	221.01	691.09	147.77	148.04	511.93	147.89	404.04	147.34	512.61	147.83	148.17	0.00	0.00	396.94	0.00	147.86	40
20	11.00	326.46	1027.19	220.13	220.53	762.60	220.30	601.89	219.48	763.61	220.22	220.72	0.00	0.00	568.15	0.00	211.63	57
21	12.00	1924.74	5077.19	1013.77	1015.61	3512.25	1014.57	2771.99	1010.80	3516.88	1014.21	1016.49	0.00	0.00	949.97	0.00	353.86	96
22	13.00	2477.28	4487.39	710.22	711.44	2461.99	710.75	1942.59	708.26	2465.05	710.51	712.02	0.00	0.00	724.66	0.00	269.93	73
23	14.00	2240.69	2876.12	299.63	300.15	1038.57	299.86	819.50	298.80	1039.87	299.76	300.40	0.00	0.00	589.23	0.00	219.49	59
24	15.00	121.56	380.12	81.28	81.43	281.58	81.34	222.23	81.04	281.95	81.31	81.50	0.00	0.00	218.32	0.00	81.32	22
25	16.00	19.34	60.47	12.93	12.95	44.80	12.94	35.36	12.89	44.86	12.94	12.97	0.00	0.00	34.73	0.00	12.94	3

Figure 5.2 - Direct solar gains (2006)



Select variable filter : All

1- QTSABS_ROOM1_1	Input to be printed-1	QTSABS_ROOM1_1
2- QTSABS_LIVING_1	Input to be printed-2	QTSABS_LIVING_1
3- QTSABS_ROOM2_1	Input to be printed-3	QTSABS_ROOM2_1
4- QTSABS_ROOM3_1	Input to be printed-4	QTSABS_ROOM3_1
5- QTSABS_LIVING_2	Input to be printed-5	QTSABS_LIVING_2
6- QTSABS_ROOM_2	Input to be printed-6	QTSABS_ROOM_2
7- QTSABS_LIVING_3	Input to be printed-7	QTSABS_LIVING_3
8- QTSABS_ROOM_3	Input to be printed-8	QTSABS_ROOM_3
9- QTSABS_LIVING_4	Input to be printed-9	QTSABS_LIVING_4
10- QTSABS_ROOM1_4	Input to be printed-10	QTSABS_ROOM1_4
11- QTSABS_ROOM2_4	Input to be printed-11	QTSABS_ROOM2_4
12- QTSABS_CLOSET2_4	Input to be printed-12	QTSABS_CLOSET2_4
13- QTSABS_TOILET_4	Input to be printed-13	QTSABS_TOILET_4
14- QTSABS_LIVING_5	Input to be printed-14	QTSABS_LIVING_5
15- QTSABS_TOILET_5	Input to be printed-15	QTSABS_TOILET_5
16- QTSABS_ROOM_5	Input to be printed-16	QTSABS_ROOM_5
17- QTSABS_LIVING_6	Input to be printed-17	QTSABS_LIVING_6
18- QTSABS_ROOM_6	Input to be printed-18	QTSABS_ROOM_6
19- QTSABS_LIVING_7	Input to be printed-19	QTSABS_LIVING_7
20- QTSABS_ROOM_7	Input to be printed-20	QTSABS_ROOM_7
21- QTSABS_LIVING_8	Input to be printed-21	QTSABS_LIVING_8
22- QTSABS_ROOM1_8	Input to be printed-22	QTSABS_ROOM1_8
23- QTSABS_ROOM2_8	Input to be printed-23	QTSABS_ROOM2_8
- QTSABS_STAIRWELL0	Input to be printed-24	QTSABS_STAIRWELL0
25- QTSABS_ENTRY1	Input to be printed-25	QTSABS_ENTRY1

Figure 5.3 - connection interface QTSABS

Direct solar gains of the whole building appears to be equal to $111'108\ kWh/y$ (Figure 5.2)

With those values, specific heat loss is equal to $q_m = 0.0894$, satisfying completely the requirement of $q_m \leq 0.222\ [W/m^3K]$.

The third requirement is again about the primary energy of the building.

$$E_p = 120 \times (A/V) + 74\ [kWh/m^2y]$$

The maximum specific heat loss must therefore be equal to

$$E_p = 120 \times (0.3570) + 74 = 116.84\ [kWh/m^2y]$$

To calculate the primary energy the same considerations already discussed in the chapter 4.3 are applied, but with the following differences:

About primary energy for heating:

- $q_{f,h}$ is a coefficient related to the typology of control in the heating system. For 2003 a value equal to 1.1 kWh/m^2y is considered, representative of "*Termosztatikus szelepek és mas ananyos szabalyozok 1K*" (thermostatic valves with hysteresis equal to 1K);
- $q_{f,v}$ is a coefficient related to the water temperature provided by the heating system. This value is expressed in function of the floor area of the building. For 2006 a value equal to 1.8 kWh/m^2y is considered, representative of water supply at 70°C, and its return to the boiler at 55°C, with a ΔT of 15°C.
- C_k is a coefficient relative to the typology of boiled used, and is equal to $1/\eta$. Also this value is expressed in function of net floor area of the building. For 2006 a value equal to 1.09 $[-]$ is considered, representative of a *low temperature boiler*.
- E_{FSz} represent the electrical consumption of the recirculation pumps. In 2006, for "*Allando fordulatu szivattyu 70/55°C*", that is a system with pump with constant speed and a ΔT of 15°C, the value of 0.24 kWh/m^2y is used.

About primary energy for domestic hot water:

$$E_{HMV} = \left(q_{HMV} + q_{HMV,v} + q_{HMV,t}\right) * \sum \left(C_k\ \alpha_k\ e_{HMV}\right) + \left(E_C + E_K\right) * e_v$$

$$E_{HMV} = \left(q_{HMV} + q_{HMV,v} + q_{HMV,t}\right) * \left[\left(C_k\ \alpha_k\ e_{HMV}\right)_{gas} + \left(C_k\ \alpha_k\ e_{HMV}\right)_{sol}\right] + \left(E_C + E_K\right) * e_v$$

- $q_{HMV,v}$ is representative of the heat losses during the distribuition. It's equal to 12% q_{HMV}.
- $q_{HMV,t}$ is representative of the heat losses on storage tanks. It's equal to 4% q_{HMV};
- C_k is a coefficient relative to the typology of boiled used, and is equal to $1/\eta$. This value is expressed in function of net floor area of the building. For 2006 a value equal to 1.12 $[-]$, is considered, representative of a boiler with 89% of efficiency.
- α_k is a coefficient representative of the percentage of heating provided by a single heat source.
  In this refurbishment is taken into account a surface of 60 mq of thermal collectors, that provide 52'767 kWh/year, which correspond to 23.74 kWh/m2y.
  $\alpha_{k,sol}$ is calculate as follow: $\alpha_{k,sol} = \frac{q_{sol,th}}{q_{HMV}} = \frac{23.74\ kWh/m^2y}{33.84\ kWh/m^2y} = 0.701$
  Consequently, $\alpha_{k,gas}$ is $\alpha_{k,gas} = \frac{q_{HMV} - q_{sol,th}}{q_{HMV}} = 0.299$.

- e_{HMW} is the primary energy transformation factor for heat source used. Its value is equal to 1 for the gas; 0 for the solar component.
- all the values not mentioned above don't present any difference within the ones already presented in chapter 4.3

About primary energy for cooling:

$$E_{hu} = \frac{Q_{hu} \times e_{hu}}{A_n}$$

where

- Q_h is the energy demand for cooling, equal to $56'994[kWh/m^2y]$;
- e_{hu} is the conversion factor from electric energy to cooling energy, and it's equal to $e_v/SEER$.
- $SEER$ is consider equal to 4.28.

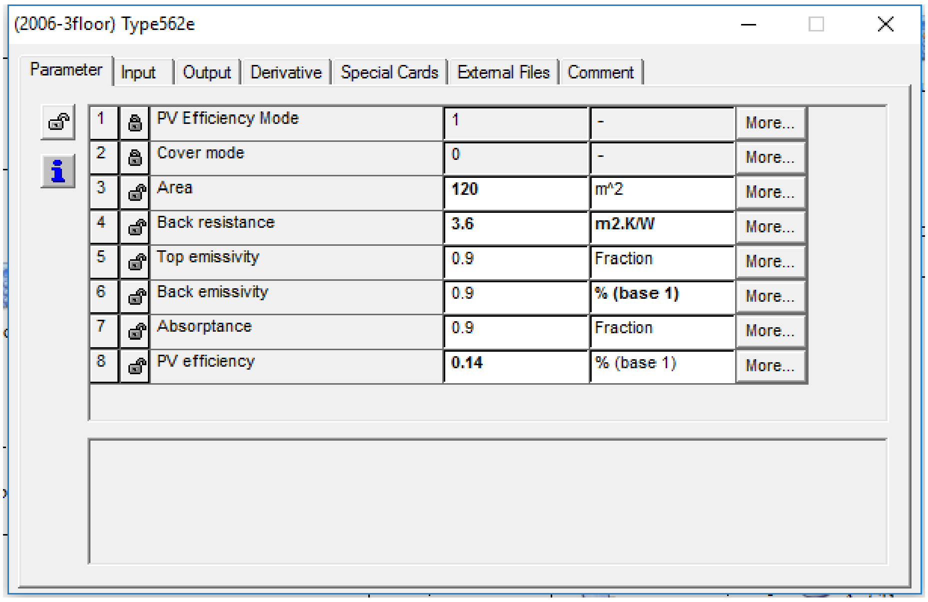
In Table 5.8, the results found with the first refurbishment in 2006.

Table 5.8 - Primary energy need of the building (2006)

	FLAT			**GARAGE**		
HEATING	E_f =	62.26	kWh/m^{2}y	E_f =	4.42	kWh/m^{2}y
DHW	E_{HMV} =	13.65	kWh/m^{2}y			
VENTILATION	E_{LT} =	11.98	kWh/m^{2}y	E_{LT} =	17.51	kWh/m^{2}y
COOLING	E_{hu} =	14.96	kWh/m^{2}y			
TOT 2006 =		**124.79**	**kWh/m^{2}y**			

Is possible to see how are still missing 7.95 kWh/m^2y to satisfy the third requirement about primary energy; it will be decided to add an area of photovoltaic collectors big enough to satisfy that request.

Type562e is used to model that component (Figure 5.4); is used a value of efficiency equal to 0.14, quite low, but that englobes also the efficiency of the inverter.



1	PV Efficiency Mode	1	-	More...
2	Cover mode	0	-	More...
3	Area	**120**	m^2	More...
4	Back resistance	**3.6**	**m2.K/W**	More...
5	Top emissivity	0.9	Fraction	More...
6	Back emissivity	0.9	**% (base 1)**	More...
7	Absorptance	0.9	Fraction	More...
8	PV efficiency	**0.14**	% (base 1)	More...

Figure 5.4 - Type562e, photovoltaic collectors

A surface of 45 m^2 of photovoltaic panels is necessary to cover the missing 7.95 kWh/m^2y, as they produce 7’507 kWh/y, that correspond to 18’767 kWh/y of primary energy.

Following, in Table 5.9, the CO_2 emission of the building with the current refurbishment in 2006

Table 5.9 - CO_2 emissions of the building (2006)

	FLAT			**GARAGE**		
HEATING	$F_{CO2,f}$ =	12.57	kg_{co2}/m^2y	$F_{CO2,f}$ =	0.83	kg_{co2}/m^2y
DHW	$F_{CO2,HMV}$ =	2.74	kg_{co2}/m^2y			
VENTILATION	$F_{CO2,LT}$ =	1.74	kg_{co2}/m^2y	$F_{CO2,LT}$ =	2.55	kg_{co2}/m^2y
COOLING	$F_{CO2,hu}$ =	2.18	kg_{co2}/m^2y			
TOT 2006 =		**22.65**	**kg_{co2}/m^2y**			

5.2 2006 Second version

Due to the big number of panels needed in this first refurbishment, it was decided to realize a second simulation, further improving the thickness of the insulation, with the aim to reducing the installation costs.

Are listed below in Table 5.10 the new wall layers, and in Table 5.11 the new values of thermal bridges. It was afterward made a new simulation with TRNSYS, only updating the layer's stratigraphy adding more insulation, and modifying the new value of thermal bridges.

Table 5.10 - Increase of the insulation thickness (2006v2)

SURFACE	U normative	Insulation	U actual
External walls	0.45 W/m^2K	14 cm EPS	0.25 W/m^2K
Roof	0.25 W/m^2K	24 cm ROCKWOOL	0.173 W/m^2K
Slab attic	0.3 W/m^2K	20 cm EPS	0.196 W/m^2K
Slab cellar	0.5 W/m^2K	12 cm EPS	0.312 W/m^2K
Walls on ground	0.45 W/m^2K	14 cm EPS	0.25 W/m^2K
Slab on ground	0.5 W/m^2K	12 cm EPS	0.312 W/m^2K

Table 5.11 - Values of thermal bridges (2006v2)

THERMAL BRIDGES 2006v2	
SOLAIO	0.067 W/mK
CORNER	0.133 W/mK
T30	0.078 W/mK
T10	0.030 W/mK
T10+PILLAR	0.037 W/mK
GIMKANA	0.043 W/mK
SLALOM+T10 --- NB: SX	-0.004 W/mK
SLALOM+T10 --- NB: DX	0.041 W/mK
SLALOM+T30 --- NB: SX	-0.021 W/mK
SLALOM+T30 --- NB: DX	0.044 W/mK
STAIRWELL --- NB: DX	0.120 W/mK
TERRACE	0.600 W/mK
ROOF CORNER	0.057 W/mK
ROOF T30	0.053 W/mK
ROOF T10	0.020 W/mK
ROOF-WALL JUNCTION	0.022 W/mK
ROOF 60	0.146 W/mK
ROOF 15	0.056 W/mK

In the following the results of the net energy requirement of the building heating are summarized.

In annex A.6 can be found the full results; here in Table 5.12 an extract:

Table 5.12 - Heating and cooling demand of the building (2006v2)

APARTMENTS	**2223** m^2	
heating	**102346.92**	*kWh/year*
	46.04	kWh/m^2y
cooling	**61120.36**	*kWh/year*
	27.49	kWh/m^2y
GARAGE	**617** m^2	
heating	**265.31**	*kWh/year*
	0.43	kWh/m^2y

The second requirement still requires a maximum specific heat loss rapported to the heated volume equal to

$$q_m = 0.38 \times A/V + 0.086 = 0.222 \; [W/m^3K]$$

- Transmission losses are now equal to $\Sigma(A \times U) + \Sigma(\mathrm{l} \times \psi) = 1693.35 \; \frac{W}{K}$;
- Direct solar gains of the whole building appears to be equal to $111'108 \; kWh/y$

With those values, specific heat loss is equal to $q_m = 0.0182$, satisfying completely the requirement of $q_m \leq 0.222 \; [W/m^3K]$.

Recalculation of the primary energy need with this second refurbishment was made.

About primary energy for domestic hot water, was still taken into account a surface of 60 mq of thermal collectors, that provide 52’767 kWh/year, which correspond to 23.74 kWh/m2y.

$\alpha_{k,sol}$ is calculate as follow: $\alpha_{k,sol} = \frac{q_{sol,th}}{q_{HMV}} = \frac{23.74 \; kWh/m^2y}{33.84 \; kWh/m^2y} = 0.701$

Consequently, $\alpha_{k,gas}$ is $\alpha_{k,gas} = \frac{q_{HMV} - q_{sol,th}}{q_{HMV}} = 0.299$

Table 5.13 - Primary energy need of the building (2006 v2)

	FLAT			GARAGE		
HEATING	E_f =	54.40	kWh/m^{2}y	E_f =	4.68	kWh/m^{2}y
DHW	E_{HMV} =	13.65	kWh/m^{2}y			
VENTILATION	E_{LT} =	11.98	kWh/m^{2}y	E_{LT} =	17.51	kWh/m^{2}y
COOLING	E_{hu} =	16.06	kWh/m^{2}y			
TOT 2006v2 =		**118.28**	**kWh/m^{2}y**			

From Table 5.13 is possible to see that 1.44 kWh/m^2y are still missing to satisfy the third requirement about primary energy; is decided to add an area of photovoltaic collectors big enough to satisfy that request.

A surface of only 10 m^2 of photovoltaic panels is necessary to cover the missing 1.44 kWh/m^2y, as they produce 1'668 kWh/y, that correspond to 4'170 kWh/y of primary energy.

Following in Table 5.14, the CO_2 emission of the building with the current refurbishment in 2006v2.0

Table 5.14 - CO_2 emissions of the building (2006v2)

	FLAT			GARAGE		
HEATING	$F_{CO2,f}$ =	10.98	kg$_{co2}$/m^{2}y	$F_{CO2,f}$ =	0.89	kg$_{co2}$/m^{2}y
DHW	$F_{CO2,HMV}$ =	2.74	kg$_{co2}$/m^{2}y			
VENTILATION	$F_{CO2,LT}$ =	1.74	kg$_{co2}$/m^{2}y	$F_{CO2,LT}$ =	2.55	kg$_{co2}$/m^{2}y
COOLING	$F_{CO2,hu}$ =	2.34	kg$_{co2}$/m^{2}y			
TOT 2006v2.0 =		**21.26**	**kg$_{co2}$/m^{2}y**			

5.3 Refurbishment according to the cost optimum requirements (2014)

Cost optimum requirements were elaborated and published in 2014, but they should be applied from 1st January 2015. Nearly zero requirements are valid from 1st January 2016.

As in the previous case, the satisfaction of this requirement, published in 2006, provide the fulfilment of 3 criteria.

1st level requirement: are defined the overall heat transfer coefficients:

- external walls: $U = 0.24\ W/m^2\,K$
- external roof: $U = 0.17\ W/m^2\,K$
- slab between heated space and attic: $U = 0.17\ W/m^2\,K$
- windows: $U = 1.15\ W/m^2\,K$
- attic windows (mounted inclined in the roof): $U = 1.25\ W/m^2\,K$
- slab above the cellar: $U = 0.30\ W/m^2\,K$
- walls in contact with ground: $U = 0.30\ W/m^2\,K$

2nd level requirement: specific heat loss (rapported to the heated volume). This is valuated in function of the ratio $\frac{\text{building envelope}}{\text{heated volume}}$

- $A/V < 0.3 \rightarrow q_m = 0.16\ [W/m^3K]$
- $0.3 \leq A/V \leq 1.3 \rightarrow q_m = 0.079 + 0.27 \times (A/V)\ [W/m^3K]$
- $A/V > 1.3 \rightarrow q_m = 0.43\ [W/m^3K]$

3rd level requirement is about total primary energy consumption. This is calculated again in function of the building envelope/heated volume ratio.

- $A/V < 0.3 \rightarrow E_p = 110\ [kWh/m^2a]$
- $0.3 \leq A/V \leq 1.3 \rightarrow E_p = 30 \times (A/V) + 101\ \ [kWh/m^2a]$
- $A/V > 1.3 \rightarrow E_p = 140\ [kWh/m^2a]$

To satisfy the first requirement, have been necessary to add or increase the thickness of the insulation layer of the external building elements until the requirements are fulfilled.

The solution reported in Table 5.15 is used:

Table 5.15 - Increase of the insulation thickness (2014)

SURFACE	U normative	Insulation	U actual
External walls	0.24 W/m^2K	20 cm EPS	0.184 W/m^2K
Roof	0.17 W/m^2K	30 cm ROCKWOOL	0.14 W/m^2K
Slab attic	0.17 W/m^2K	24 cm EPS	0.165 W/m^2K
Slab cellar	0.3 W/m^2K	16 cm EPS	0.241 W/m^2K
Walls on ground	0.3 W/m^2K	30 cm EPS	0.184 W/m^2K
Slab on ground	0.3 W/m^2K	16 cm EPS	0.241 W/m^2K

The value of thermal bridges are reported in Table 5.16.

Table 5.16 - Values of thermal bridges (2014)

THERMAL BRIDGES 2014	
SOLAIO	0.048 W/mK
CORNER	0.113 W/mK
T30	0.058 W/mK
T10	0.022 W/mK
T10+PILLAR	0.026 W/mK
GIMKANA	0.013 W/mK
SLALOM+T10 --- NB: SX	0.021 W/mK
SLALOM+T10 --- NB: DX	0.028 W/mK
SLALOM+T30 --- NB: SX	0.016 W/mK
SLALOM+T30 --- NB: DX	0.034 W/mK
STAIRWELL --- NB: DX	0.106 W/mK
TERRACE	0.207 W/mK
ROOF CORNER	0.058 W/mK
ROOF T30	0.043 W/mK
ROOF T10	0.016 W/mK
ROOF-WALL JUNCTION	0.024 W/mK
ROOF 60	0.112 W/mK
ROOF 15	0.044 W/mK

A new simulation with TRNSYS was made, modifying the following changes:

- the layer's stratigraphy was updated, adding more insulation when required, as shown in Table 5.15
- The thermal bridge values was updated with the values shown in Table 5.16
- The efficiency of the heat recuperator in garage is increased to a value equal to 80%

In the following are summarized the results of the net energy requirement of the building heating.

In annex A.7 can be found the full results; here in Table 5.17 an extract:

Table 5.17 - Heating and cooling demand of the building (2014)

APARTMENTS	**2223** m^2	
heating	**76626.81**	*kWh/year*
	34.47	kWh/m^2y
cooling	**70512.85**	*kWh/year*
	31.71	kWh/m^2y
GARAGE	**617** m^2	
heating	**43.19**	*kWh/year*
	0.07	kWh/m^2y

The second requirement request now a maximum specific heat loss rapported to the heated volume equal to

$$q_m = 0.27 \times (0.3570) + 0.079 = 0.175\ [W/m^3K]$$

Recalculating the transmission losses with the new value of transmittance and thermal bridges, the result is:

$$\Sigma(A \times U) + \Sigma(\mathrm{l} \times \psi) = 746.24\ \frac{W}{K}$$

With those values, specific heat loss is even negative equal to $q_m = -0.096$, satisfying completely the requirement of $q_m \leq 0.175\ [W/m^3K]$.

The third requirement is again about the primary energy of the building.

$$E_p = 30 \times (A/V) + 101\ [kWh/m^2y]$$

The maximum specific heat loss must therefore be equal to

$$E_p = 30 \times (0.3570) + 101 = 111.71\ [kWh/m^2y]$$

To calculate primary energy the same considerations already discussed in the previous chapter can be applied, with the following differences:

About primary energy for heating:

- $q_{f,h}$ is a coefficient related to the typology of control in the heating system. For 2014 a value equal to 0.7 kWh/m^2y is considered, representative of "*Elektronikus szabalyozo*" (electronic regulation).
- $q_{f,v}$ is a coefficient related to the water temperature provided by the heating system. This value is expressed in function of the floor area of the building. For 2014 a value equal to 1.2 kWh/m^2y is considered, representative of water supply at 55°C, and its return to the boiler at 45°C, with a ΔT of 10°C.
- C_k is a coefficient relative to the typology of boiled used, and is equal to $1/\eta$. Also this value is expressed in function of net floor area of the building. For 2014 a value equal to $1.02\ [-]$ is considered, representative of a *condensation boiler*.
- E_{FSz} represent the electrical consumption of the recirculation pumps. In 2014, for "*Allando fordulatu szivattyu 555/45°C*", that is a system with pump with constant speed and a ΔT of 10°C, the value of 0.33 kWh/m^2y is used.

About primary energy for domestic hot water:

$$E_{HMV} = \left(q_{HMV} + q_{HMV,v} + q_{HMV,t}\right) * \sum (\, C_k\, \alpha_k\, e_{HMV}) \; + (E_C + E_K) * e_v$$

$$\begin{aligned} E_{HMV} = {} & \left(q_{HMV} + q_{HMV,v} + q_{HMV,t}\right) * \left[(\, C_k\, \alpha_k\, e_{HMV})_{gas} + (\, C_k\, \alpha_k\, e_{HMV})_{sol}\right] \\ & + (E_C + E_K) * e_v \end{aligned}$$

- C_k is a coefficient relative to the typology of boiled used, and is equal to $1/\eta$. This value is expressed in function of net floor area of the building. For 2014 a value equal to $1.09\ [-]$ is considerd, representative of a condensation boiler with 92% of efficiency.
- α_k is a coefficient representative of the percentage of heating provided by a single heat source.

  In this refurbishment a surface of 40 mq of thermal collectors is taken into account, that provide 35'178 kWh/year, which correspond to 15.82 kWh/m2y.

  $\alpha_{k,sol}$ is calculate as follow: $\alpha_{k,sol} = \frac{q_{sol,th}}{q_{HMV}} = \frac{15.82\ kWh/m^2y}{33.84\ kWh/m^2y} = 0.468$

  Consequently, $\alpha_{k,gas}$ is $\alpha_{k,gas} = \frac{q_{HMV} - q_{sol,th}}{q_{HMV}} = 0.532.$

About primary energy for cooling, an EER value equal to 4.8 is considered.

About ventilation, pressure losses have increased to 1100 Pa because we're considering a more performant heat recovery system.

All the values not mentioned above don't present any difference within the ones already presented.

Following, in Table 5.18, the results found with the refurbishment in 2014.

Table 5.18 - Primary energy need of the building (2014)

	FLAT			**GARAGE**		
HEATING	E_f =	38.37	kWh/m^{2}y	E_f =	3.28	kWh/m^{2}y
DHW	E_{HMV} =	23.30	kWh/m^{2}y			
VENTILATION	E_{LT} =	11.98	kWh/m^{2}y	E_{LT} =	20.28	kWh/m^{2}y
COOLING	E_{hu} =	16.52	kWh/m^{2}y			
TOT 2014 =		**113.73**	**kWh/m^{2}y**			

Can be seem that a little more than 2 kWh/m^2y are still missing, to satisfy the third requirement about primary energy; is decided to add an area of photovoltaic collectors big enough to satisfy that request.

A surface of $15\ m^2$ of photovoltaic panels is necessary, as they produce $2'502\ kWh/y$, that correspond to $6'256\ kWh/y$ of primary energy.

About CO_2 emission in 2014:

Table 5.19 - CO_2 emissions of the building (2014)

	FLAT			**GARAGE**		
HEATING	$F_{CO2,f}$ =	7.71	kg$_{co2}$/m^{2}y	$F_{CO2,f}$ =	0.59	kg$_{co2}$/m^{2}y
DHW	$F_{CO2,HMV}$ =	4.70	kg$_{co2}$/m^{2}y			
VENTILATION	$F_{CO2,LT}$ =	1.74	kg$_{co2}$/m^{2}y	$F_{CO2,LT}$ =	2.96	kg$_{co2}$/m^{2}y
COOLING	$F_{CO2,hu}$ =	2.41	kg$_{co2}$/m^{2}y			
TOT 2014 =		**20.13**	**kg$_{co2}$/m^{2}y**			

5.4 Refurbishment according to the nZEB requirements (2016)

Here the **nearly zero energy building** requirements:

1st level requirement, about overall heat transfer coefficients is equal to the cost optimum requirement:

- external walls: $U = 0.24\ W/m^2\,K$
- external roof: $U = 0.17\ W/m^2\,K$
- slab between heated space and attic: $U = 0.17\ W/m^2\,K$
- windows: $U = 1.15\ W/m^2\,K$
- attic windows (mounted inclined in the roof): $U = 1.25\ W/m^2\,K$
- slab above the cellar: $U = 0.30\ W/m^2\,K$
- walls in contact with ground: $U = 0.30\ W/m^2\,K$

2nd level requirement: specific heat loss (rapported to the heated volume).

- $A/V < 0.3 \rightarrow q_m = 0.12\ [W/m^3K]$
- $0.3 \leq A/V \leq 1.3 \rightarrow q_m = 0.05143 + 0.2296 \times (A/V)\ [W/m^3K]$
- $A/V > 1.3 \rightarrow q_m = 0.28\ [W/m^3K]$

3rd level requirement is about total primary energy consumption. With nZEB requirement is no more function of the building envelope/heated volume ratio: the total primary energy consumption must be lower to $100\,kWh/m^2a$; 25% of primary energy (without contribution of RES) at least must be assured from renewable energy sources:

- $E_p < 100\ [kWh/m^2a]$
- $RES \geq 0.25 \times E_{p,no\ RES}$

Since the first requirement is equal to the cost optimum in 2014, the same building of 2014 is considered, only paying attention to satisfy second and third requirement.

Second requirement want a specific heat loss $q_m \leq 0.133\ [W/m^3K]$; our value is –as in 2014– equal to -0.096.

To calculate primary energy the same considerations already discussed in the previous chapter will be applied, with the following differences:

About primary energy for heating:

- $q_{f,h}$ coefficient related to the typology of control in the heating system, is value equal to $0.4\ kWh/m^2y$, representative of "*Elektronikus szabalyozo optimalizalasi funkcioval*"

In this refurbishment a surface of 60 mq of thermal collectors is taken into account, that provide 52'767 kWh/year, which correspond to 23.74 kWh/m2y.
$\alpha_{k,sol}$ is calculate as follow: $\alpha_{k,sol} = \frac{q_{sol,th}}{q_{HMV}} = \frac{23.74\ kWh/m^2y}{33.84\ kWh/m^2y} = 0.701$
Consequently, $\alpha_{k,gas}$ is $\alpha_{k,gas} = \frac{q_{HMV}-q_{sol,th}}{q_{HMV}} = 0.299$.

About primary energy for cooling an EER value equal to 5 is considered.

All the values not mentioned above don't present any difference within the ones already presented.

Following, in Table 5.20, the results found with the refurbishment in 2016.

Table 5.20 - Primary energy need of the building (2016)

	FLAT			**GARAGE**		
HEATING	E_f =	38.07	kWh/m^{2}y	E_f =	2.97	kWh/m^{2}y
DHW	E_{HMV} =	13.30	kWh/m^{2}y			
VENTILATION	E_{LT} =	11.98	kWh/m^{2}y	E_{LT} =	20.28	kWh/m^{2}y
COOLING	E_{hu} =	15.86	kWh/m^{2}y			
TOT 2016 =		**102.45**	**kWh/m^{2}y**			

Still 2.45 kWh/m^2y are missing to satisfy the third requirement about primary energy; is decided to add an area of photovoltaic collectors big enough to satisfy that request.

With $50\, m^2$ of photovoltaic panels 8'341 kWh/y are produced, that correspond to 20'852 kWh/y of primary energy, equal to 9.38 kWh/m^2y. Requirement about primary energy needed lower than 100 kWh/m^2y is therefore satisfied.

The 25% of the primary energy need of the building without any presence of renewable energy sources is 33.11 kWh/m^2y, because the primary energy need of the building without any renewable source is 132.47 kWh/m^2y.

Summing up the primary energy provided by thermal collectors for DHW and primary energy provided by photovoltaic panels, are obtained $23.74\ \frac{kWh}{m^2y} + 3.75\ \frac{kWh}{m^2y} \times e_v$, that reaches exactly the second target.

About CO$_2$ emission in 2016:

Table 5.21 - CO$_2$ emissions of the building (2016)

	FLAT			**GARAGE**		
HEATING	$F_{CO2,f}$ =	7.65	kg$_{co2}$/m^{2}y	$F_{CO2,f}$ =	0.53	kg$_{co2}$/m^{2}y
DHW	$F_{CO2,HMV}$ =	2.66	kg$_{co2}$/m^{2}y			
VENTILATION	$F_{CO2,LT}$ =	1.74	kg$_{co2}$/m^{2}y	$F_{CO2,LT}$ =	2.96	kg$_{co2}$/m^{2}y
COOLING	$F_{CO2,hu}$ =	2.31	kg$_{co2}$/m^{2}y			
TOT 2016 =		**17.88**	**kg$_{co2}$/m^{2}y**			

6 Cost analysis

6.1 Replacing windows

It has been obtained a catalogue of windows from the impresario *Ajto-Ablak*, which provides a large number of models of windows [21].

For each type of windows it has been chosen a model with better thermal properties, as a following thermal refurbishment is developed.

At the price of the single window is then necessary to add 700 HUF each (~2.30 euro) as labour work. With a total of 164 windows, the cost for the work of substitution is 114’800 HUF (~383 euro).

Following, in Table 6.1, the resume about windows replacement.

Table 6.1 - Cost for windows replacement

Type	*Dimensions*		*N°*	*Price/each*				**Price tot windows**			
				2006	*2006v2*	*2014*	*nZEB*	2006	2006 v2.2	2014	nZEB
A	150	150	8	***43'742***	***64'035***	***74'078***	***74'078***	349'936	512'280	592'624	592'624
B	90	150	64	***23'606***	***34'318***	***40'039***	***40'039***	1'510'784	2'196'352	2'562'496	2'562'496
C	120	150	36	***28'157***	***40'849***	***47'658***	***47'658***	1'013'652	1'470'564	1'715'688	1'715'688
D	150	240	26	***61'080***	***88'183***	***102'881***	***102'881***	1'588'080	2'292'758	2'674'906	2'674'906
E	90	240	3	***37'946***	***54'315***	***63'368***	***63'368***	113'838	162'945	190'104	190'104
F	120	140	8	***28'157***	***40'849***	***40'039***	***40'039***	225'256	326'792	320'312	320'312
G	78	140	9	***23'606***	***34'318***	***40'039***	***40'039***	212'454	308'862	360'351	360'351
H	120	240	2	***56'232***	***81'416***	***94'772***	***94'772***	112'464	162'832	189'544	189'544
I	90	9900	8	***22'002***	***36'039***	***42'047***	***42'047***	176'016	288'312	336'376	336'376
Total number of windows			164	Total windows price				**5'302'480**	**7'721'697**	**8'942'401**	**8'942'401**
Work price for sobstitution			114’800	**TOTAL PRICE NEW WINDOWS**				5'417'280	7'836'497	9'057'201	9'057'201
Prezzo totale nuovi infissi (euro)								~18’058	~26’122	~30’191	~30’191

Áron Ház Kft

AJTÓ-ABLAK
szakkereskedés
info@aronhaz.hu
www.aronhaz.hu

6.2 Insulation material for the retrofit of the envelope

About insulation, it has been necessary to split material's cost from installation cost.

It was supposed that it was necessary to change the old insulation material, where already present. So for the cost analysis was not considered the pre-existing thickness of insulation.

The following interventions realized:

- Insulation of facades of the building (external walls);
- Installation of metallic frames on which place the ESP panels, both on the perimeter of the windows (Figure 6.2), both at the base and the top of the facades (Figure 6.3);
- Insulation of attic with rockwool (roof) (Figure 6.4);
- Insulation of the slab between cellar and ground floor (Figure 6.5);
- Insulation of the slab between third floor and attic (Figure 6.6);
- Insulation walls of the garage;
- Scaffolds assembling.

Area of facades is calculate as follow in Table 6.2:

Table 6.2 - Area of the facades of the building

Area of facedes					
Orientation	0 floor	1 floor	2 floor	3 floor	TOT
S	124.14	124.14	124.14	97.98	*470.39*
E	53.68	53.68	53.68	65.42	*226.46*
N	119.87	119.87	119.87	91.98	*451.57*
W	51.85	51.85	51.85	63.59	*219.14*
	349.53	*349.53*	*349.53*	*318.97*	**1367.56**
Area sup totale (with windows) = 1367.56 m^2 Area muri da isolare tot = 891.05 m^2 Perimetro spallette tot =1267.0 m					

Where area of windows and perimeter of the frame is calculate as follow in Table 6.3:

Table 6.3 - Area and perimeter of the window frame

FINESTRE											
	Caratteristiche finestre				Numero finestre					Area finestre	Perimetro spallette
	Dimensioni [cm]		Area [m2]	Perimetro [m]	TOT	*0floor*	*1 floor*	*2 floor*	*3 floor*	[m^2]	[m]
A	150	150	2.25	6	8	*2*	*2*	*2*	*2*	18	48
B	90	150	1.35	4.8	64	*18*	*18*	*18*	*10*	86.4	307.2
C	120	150	1.8	5.4	36	*9*	*11*	*11*	*5*	64.8	194.4
D	150	240	3.6	7.8	26	*7*	*7*	*7*	*5*	93.6	202.8
E	90	240	2.16	6.6	3	*1*	*1*	*1*	*0*	6.48	19.8
F	120	140	1.68	5.2	8	*0*	*0*	*0*	*8*	13.44	41.6
G	78	140	1.09	4.4	9	*0*	*0*	*0*	*9*	9.828	39.24
H	120	240	2.88	7.2	2	*2*	*0*	*0*	*0*	5.76	14.4
I	**90**	**9900**	**89.1**	**199.8**	2	*	*	*	*	178.2	399.6
						39	*39*	*39*	*39*	*476.5*	*1267.0*

Length of metallic frames is calculate as follow in Table 6.4:

Table 6.4 - Top and bottom perimeter of the building

Metalic frame [base+top]	
Orientation	Lenght
South	40.7
East	17.6
North	39.3
West	17
	114.6
h =	12

6.3 DHW energy demand and cost

The size of the heat generator must be chosen related to the maximum heat power needed for each refurbishment.

Not knowing the typology of system for building heating and domestic hot water generation, is supposed a central heating system, that provide both heating and DHW.

In residential buildings the daily water consumption of occupants (per person) can be calculated as:

$$V_l = a \times f \times \frac{1}{1000} \ [m^3/d]$$

where:

- a is the specific water quantity consumption $[liter/person]$. In Hungary is about $100 \ l/person$;
- f is the number of persons in the building (depending on the net floor area of the dwelling can be counted $2-3$ or $4 \, persons/dwelling$). In Hungary the average is $2.4 \, persons/dwelling.$

The DHW demand of the building is considered 40% from the total water consumption of the building (only the water consumption of occupants is taken into account).

$$V_m = 0.4 \times V_l \ [m^3/d]$$

The volume of DHW storage tank will be:

$$V_b = 34.7 \times Z \times V_m \ [liter]$$

Z is the correction factor (depending on the number of persons in the building):

n° pensons in building	50	100	250	500	1000	2500	5000	7500	10000	15000	25000	50000	Felette
Z	10	9	7.5	6.5	5.5	4.5	3.5	3	2.9	2.8	2.5	2.3	2

The peak load for DHW preparation is:

$$Q_m = 0.4 \times V_m \times (t_m - t_h) \ [kW]$$

where:

- t_m is the temperature of hot water (is considered equal to 60°C);
- t_h is the temperature of cold water (is considered to be 10° C).

Case study: 32 dwellings (~80 persons).

$$V_l = 80 \times 100 \times \frac{1}{1000} = 8\ m^3/d$$

$$V_m = 0.4 \times V_l = 0.4 \times 8 = 3.2\ m^3/d$$

$$V_b = 34.7 \times Z \times V_m = 34.7 \times 9.5 \times 3.2 = 1054.88\ liter$$

$$Q_m = 0.4 \times V_m \times (t_m - t_h)\ = 0.4 \times 3.2 \times (60 - 10) = 64\ kW$$

The power of the boiler should be calculated considering both the pick power demand for the preparation of DHW and the heating demand of the building.
However, since the pick power of the heat demand is calculated to -15°C daily mean temperature (extremely rare), designers can choose a boiler which power is higher than the heat loss of the building, but lower than the sum of heat loss and DHW output.
The DHW tank is heated up usually within 2 hours; during this period of time the indoor air temperatures will not decrease too much if the heating of the building operates at a partial capacity.

For example: if the heat demand is 150 kW and the DHW output is 60 kW, than the designers may choose a boiler with 180 kW capacity (or two 90-90 kW).

Prices have been found in the site efficaceclima.it [22]; are then reported in Table 6.5.

Table 6.5 - Cost of the boiler

	2003	**2006**	**2006 v2.2**	**2014**	**nZEB**
$P_{max,heat}$ [kW]	240	*187*	*182*	166	166
$P_{max,DHW}$ [kW]	64	64	64	64	64
P_{TOT} [kW]	304	251	246	230	230
Size		116 + 116	116 + 116	200	200
P tot		232	232	200	200
price/generator		11'029	11'030	16306	16306
p total [euro]		22'058	22'060	16'306	16'306
Price [huf]		**6'617'400**	**6'618'000**	**4'891'800**	**4'891'800**

6.4 CHILLER cost

It is supposed that the summer conditioning is provided by a centralized air conditioning system with fan coil in the apartments.

The size of the chiller must be chosen related to the maximum heat power needed for each refurbishment.

Table 6.6 - Chiller power and price

	2003	**2006**	**2006 v2.2**	**2014**	**nZEB**
$P_{max,cooling}$ [kW]	62.88	70.96	70.71	69.59	69.59
Model	-	Daikin EWAQ-G-SS	Daikin EWAQ-G-SS	Daikin EWAQ-DAYNN-80	Carrier 30WG-070
Max power [kW]	-	74.7	74.7	81.0	73.8
price [euro]	-	15'557	15'557	16'854	20'545
Price [huf]	**-**	**4'667'100**	**4'667'100**	**5'056'200**	**6'163'500**

6.5 Installation of renewable sources

Prices of both thermal [23] and photovoltaic systems [24] are drawn from the Hungarian supplier Naplopo (Figure 6.1)

Figure 6.1 - Homepage of the considered supplier

For all the four refurbishment have been opted for the basic system, with the pick power of

- 8 kW in 2006 (first version),
- 2 kW in 2006 (second version),
- 2.5 kW in 2014,
- 10 kW in 2016.

In Table 6.7 are reported the cost for both thermal and solar collectors

Table 6.7 - Cost of thermal and photovoltaic collectors (from naplopo.hu)

	2006	2006 v2.2	2014	nZEB
THERMAL COLLECTORS				
Model	30 panels 60 m^2	30 panels 60 m^2	20 panels 40 m^2	30 panels 60 m^2
Price [Huf]	10'073'765	10'073'765	7'377'926	10'073'765
Prezzo [Euro]	**33'579**	**33'579**	**24'593**	**33'579**
PHOTOVOLTAIC				
Model	basic 8kw	basic 2 kw	basic 2.5 kw	basic 10 kw
Price [Huf]	2'823'153	838'371	988'790	3'337'617
Prezzo [Euro]	**9'411**	**2'795**	**3'296**	**11'125**

As shown in Table 6.8, the total cost of refurbishment is

- **49'744'073** HUF in 2006,
- **52'325'461** HUF in 2006 (second version),
- **57'031'491** HUF in 2014,
- **63'183'457** HUF in 2016

Table 6.8 - Total cost of refurbishment

MATERIAL'S PRICES			WORK PRICES	TOTAL PRICE	Dimensione caratteristica	2006	2006 v2.2	2014	nZEB
WALLS -windows (EPS)	8 cm	2450 HUF/m^2	2800 HUF/m^2	**5250 HUF/m^2**	891 m^2	*4'677'997*			
	14 cm	3325 HUF/m^2	2800 HUF/m^2	**6125 HUF/m^2**			*5'457'663*		
	20 cm	4350 HUF/m^2	2800 HUF/m^2	**7150 HUF/m^2**				*6'370'986*	*6'370'986*
Plastering covering walls		1150 HUF/m^2		**1150 HUF/m^2**	891 m^2	*1'024'704*	*1'024'704*	*1'024'704*	*1'024'704*
Plastering covering windows		900 HUF/m		**900 HUF/m**	1267 m	*1'140'336*	*1'140'336*	*1'140'336*	*1'140'336*
CORNER PROTECTION	vertical+windows	139 HUF/m	750 HUF/m	**889 HUF/m**	1411 m	*1'254'415*	*1'254'415*	*1'254'415*	*1'254'415*
	base+top	260 HUF/m	750 HUF/m	**1010 HUF/m**	229 m	*231'492*	*231'492*	*231'492*	*231'492*
Impalcature			950 HUF/m^2	**950 HUF/m^2**	1368 m^2	*1'299'177*	*1'299'177*	*1'299'177*	*1'299'177*
ROOF (mineral wool)	18 cm	2786 HUF/m^2	3500 HUF/m^2	**6286 HUF/m^2**	567 m^2	*3'561'879*			
	24 cm	3481 HUF/m^2	3500 HUF/m^2	**6981 HUF/m^2**			*3'955'692*		
	30 cm	4176 HUF/m^2	3500 HUF/m^2	**7676 HUF/m^2**				*4'349'504*	*4'349'504*
SLAB CELLAR	8 cm	2450 HUF/m^2	2800 HUF/m^2	**5250 HUF/m^2**	640 m^2	*3'360'000*			
	12 cm	3030 HUF/m^2	2800 HUF/m^2	**5830 HUF/m^2**			*3'731'200*		
	16 cm	3800 HUF/m^2	2800 HUF/m^2	**6600 HUF/m^2**				*4'224'000*	*4'224'000*
SLAB ATTIC	14 cm	3325 HUF/m^2	2800 HUF/m^2	**6125 HUF/m^2**	587 m^2	*3'595'375*			
	20 cm	4350 HUF/m^2	2800 HUF/m^2	**7150 HUF/m^2**			*4'197'050*		
	24 cm	5280 HUF/m^2	2800 HUF/m^2	**8080 HUF/m^2**				*4'742'960*	*4'742'960*
WALLS GARAGE	12 cm	3030 HUF/m^2	2800 HUF/m^2	**5830 HUF/m^2**	285 m^2			*798'000*	*798'000*
FLOOR GARAGE	16 cm	3800 HUF/m^2	2800 HUF/m^2	**6600 HUF/m^2**	640 m^2			*4'224'000*	*4'224'000*
THERMAL COLLECTORS						*10'073'765*	*10'073'765*	*7'377'926*	*10'073'765*
PHOTOVOLTAIC						*2'823'153*	*838'371*	*988'790*	*3'337'617*
Caldaia						*6'617'400*	*6'618'000*	*4'891'800*	*4'891'800*
CHILLER						*4'667'100*	*4'667'100*	*5'056'200*	*6'163'500*
Changing windows			700 HUF/n°	**700 HUF/n°**	164	*114'800*	*114'800*	*114'800*	*114'800*
Windows						*5'302'480*	*7'721'697*	*8'942'401*	*8'942'401*

Some pictures are following reported, with the aim to facilitate the understanding of the different cost components presented in Table 6.8.

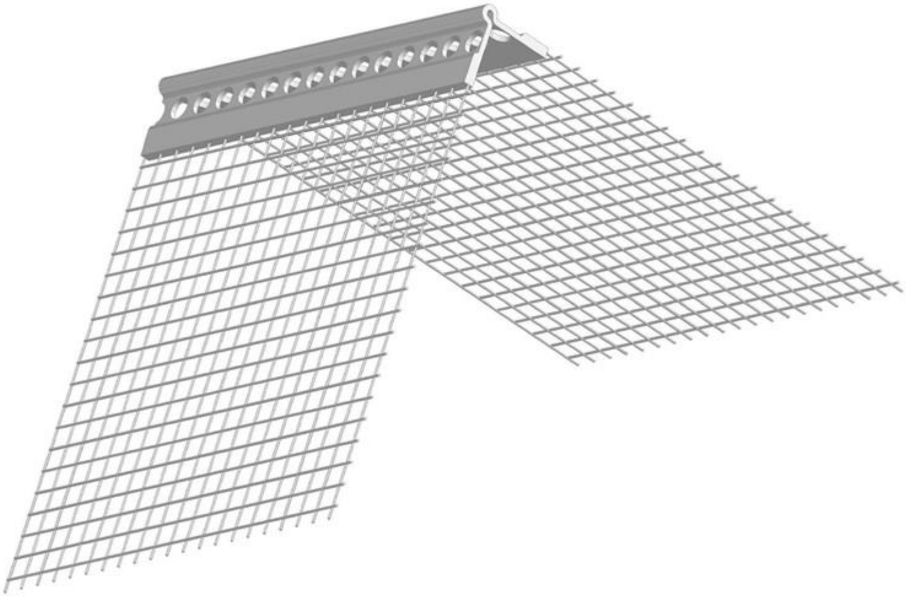


Figure 6.2 - Metallic vertical corners protection

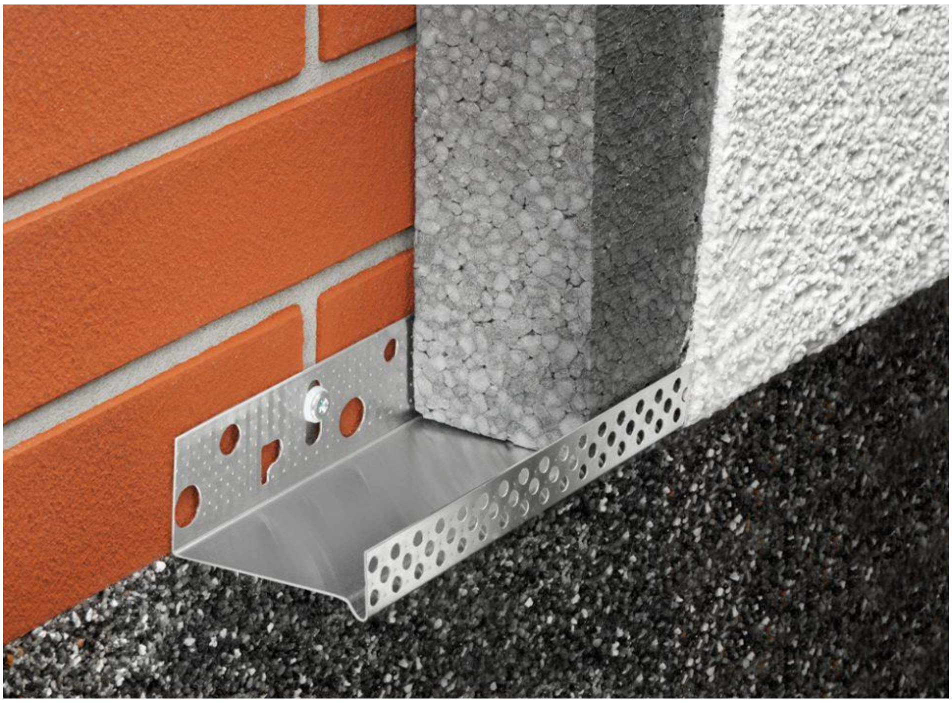


Figure 6.3 - Metallic base and top protection for the insulation

Figure 6.4 - Roof insulation

Figure 6.5 - Cellar slab insulation

Figure 6.6 - Attic slab insulation

6.6 Cost comparison

Supposing a cost of electrical energy equal to $51\ Ft/kWh_{el}$, and a price of natural gas equal to $130\ Ft/m^3$ $(= 13.56\ Ft/kWh_{th})$, are obtained the savings in the different refurbishments that have been analysed. Results are reported in Table 6.9

Table 6.9 - Cost analysis (HUF)

	2003	2006	2006 v2.0	2014	2016
Investment	-	49'744'073 Ft	57'031'491 Ft	52'325'461 Ft	63'183'457 Ft
Saving	-	3'714'647 Ft/y	4'043'306 Ft/y	3'899'604 Ft/y	4'386'529 Ft/y
Payback	**-**	**13.4 y**	**13.4 y**	**14.1 y**	**14.4 y**

For a better clarity of exposure, data reported in Table 6.9 are also reported in Euro in Table 6.10. Full calculations can be found in Table 6.11.

Cost of electrical energy is $0.167\ €/kWh_{el}$; price for natural gas is $0.427\ €/m^3$ $(= 0.044\ €/kWh_{th}$

Table 6.10 - Cost analysis (€)

	2003	2006	2006 v2.0	2014	2016
Investment	-	165'814 €	190'105 €	174'418 €	210'612 €
Saving	-	12'382 €/y	13'478 €/y	12'999 €/y	14'622 €/y
Payback	**-**	**13.4 y**	**13.4 y**	**14.1 y**	**14.4 y**

It should be known that the refurbishment based on the 2006 requirements can be done only until 31th December 2017, if no support is required from the state. Between 1st January 2018 and 31th December 2020, the cost optimum requirements should be taken into account (without support from the state). After 1st January 2021 only nZEB requirements are permitted -without support from the state-.

Nowadays, if the building owner applies for money to obtain support from the state for the refurbishments, the requirement of 2014 must be fulfilled. If the refurbishment will be done after 2018, the requirement of nZEB must be fulfilled. However, in these cases the investment cost is lower (max. 50% support can be obtained, also if is very rare). So, the requirements are more strict, but (in a lucky case) the investment cost might be lower (decreased with the support).

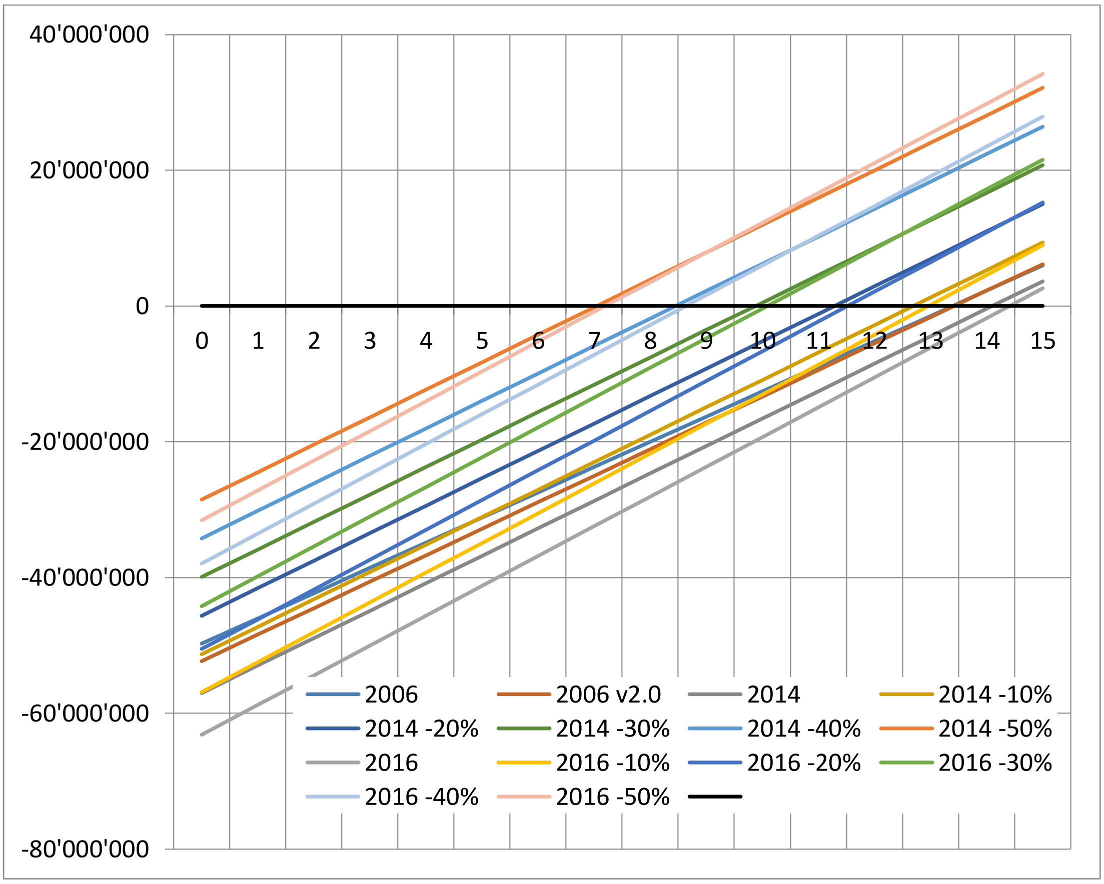
After 31st December 2020 other support conditions has to be considered. For a refurbishment which fulfils only the 2006th requirements no support is given.

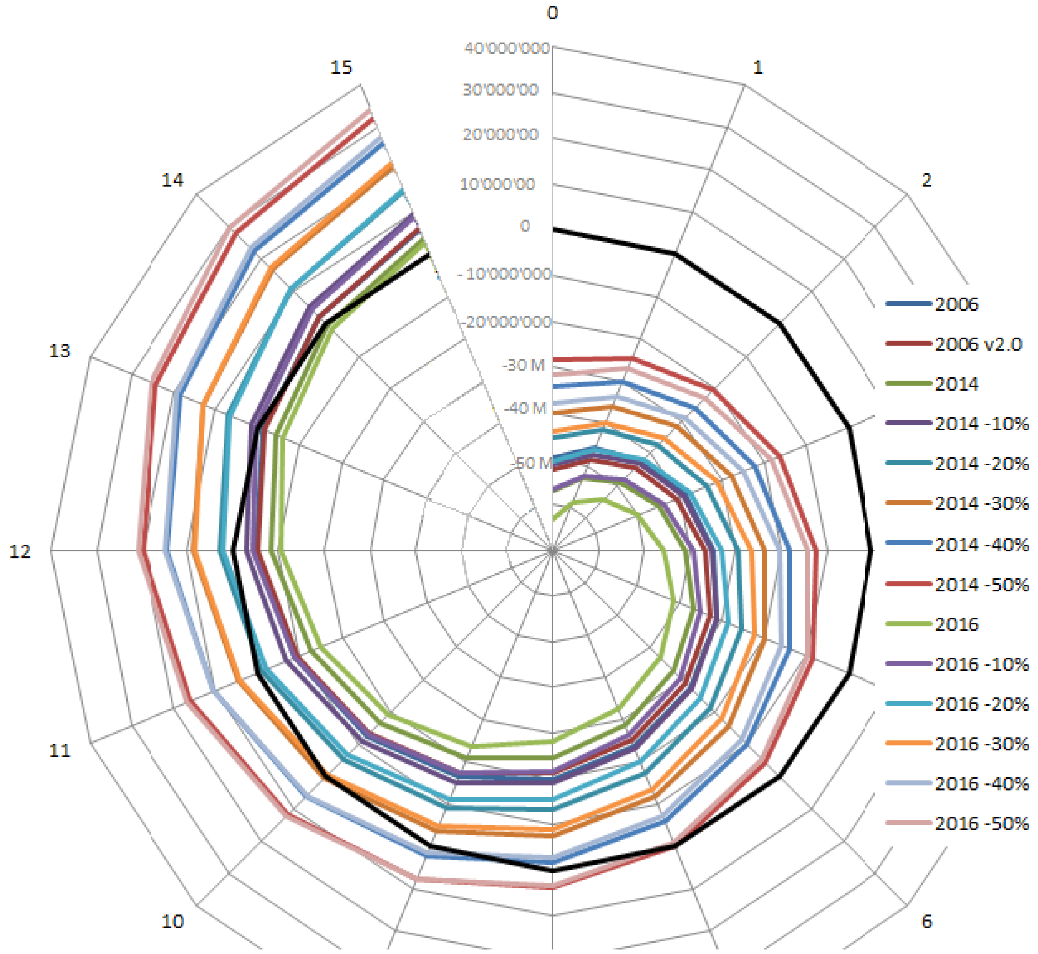
For this reason it is decided to calculate the payback time of 2014 and nZEB cases for 10%, 20%, 30%, 40% and 50% support from the government (decrease of the investment costs).

Table 6.11 - Complete cost analysis

	2003				2006				2006 v2.0				2014				2016			
	Apartments		Garage		Apartments		Garage		Apartments		Garage		Apartments		Garage		Apartments		Garage	
	2223.04	mq	617.1	mq	2223.04	mq	617.1	mq	2223.04	mq	617.1	mq	2223.04	mq	617.1	mq	2223.04	mq	617.1	mq
	Thermal	Electrical	Therm.	Electric.	Therm.	Electric.	Therm.	Electric.	Therm.	Electric.	Therm.	Electric.	Therm.	Electric.	Therm.	Electric.	Therm.	Electric.	Therm.	Electric.
Heating	155.56	0.46	6.93	0.46	61.21	0.42	3.37	0.42	53.35	0.42	3.63	0.42	37.10	0.51	2.01	0.51	36.79	0.51	1.70	0.51
DHW	49.46	0.209			13.13	0.209			13.13	0.209			22.78	0.209			12.78	0.209		
Ventilation		4.79		7.01		4.79		7.01		4.79		7.01		4.79		8.11		4.79		8.11
Cooling		3.70				5.98				6.42				6.61				6.34		
[kWh/m^{2}y]	205.02	9.16	6.93	7.47	74.33	11.41	3.37	7.43	66.47	11.84	3.63	7.43	59.88	12.12	2.01	8.62	49.57	11.85	1.70	8.62
kWh/y	**455'773**	**20'361**	**4'279**	**4'607**	**165'249**	**25'355**	**2'082**	**4'582**	**147'776**	**26'330**	**2'240**	**4'582**	**133'107**	**26'940**	**1'238**	**5'320**	**110'187**	**26'353**	**1'049**	**5'320**
	460'052		24'968		167'331		29'937		150'016		30'912		134'344		32'260		111'236		31'673	
	kWh/y th		kWh/y el		kWh/y th		kWh/y el		kWh/y th		kWh/y el		kWh/y th		kWh/y el		kWh/y th		kWh/y el	
ΔkWh/y	0		0		292'721		-4'969		310'036		-5'945		325'707		-7'292		348'816		-6'705	
Ft/y	0		0		3'968'059		-253'412		4'202'778		-303'174		4'415'221		-371'916		4'728'477		-341'948	
Investimento	-	Ft			49'744'073	Ft			52'325'461	Ft			57'031'491	Ft			63'183'457	Ft		
Saving	-	Ft/y			3'714'647	Ft/y			3'899'604	Ft/y			4'043'306	Ft/y			4'386'529	Ft/y		
Payback	**-**				**12.1**	**years**			**12.2**	**years**			**12.9**	**years**			**13.0**	**years**		

Printing the incoming cash flow in a period of 15 years, the following results are obtained:




0
1
2
6
10
11
12
13
14
15
40'000'000
30'000'00
20'000'00
10'000'00
0
- 10'000'000
-20'000'000
-30 M
-40 M
-50 M
2006
2006 v2.0
2014
2014 -10%
2014 -20%
2014 -30%
2014 -40%
2014 -50%
2016
2016 -10%
2016 -20%
2016 -30%
2016 -40%
2016 -50%

7 Conclusions

In Hungary, the main motivation for renovation of residential buildings is to improve the poor conditions of the existent building stock. Economic incentives are an important assistance tool to promote renovation project, since the payback time of investment of deep building retrofit is generally longer than 10-15 years.

This master thesis carried out a comparison analysis on different refurbishment solutions of the same case study, evaluating common retrofit activities, energy savings and costs of the renovation process. The salient points are listed below and are intended to be used as reference for future renovations.

First of all, every renovation solution accounted in the analysis focused on improving the thermal insulation of the building opaque structures: new insulation materials with lower U-value were installed, in building with pre-existing thermal insulation, as well as in not insulated building. The results are an increasing of the thermal performance and, meanwhile, a reduction of the energy losses..

The second step is the replacement of pre-existent thermal and cooling equipment: the installation of systems with higher efficiency can guarantee the same thermal (or cooling) output with a smaller amount of primary energy, improving the building's energy footprint.

As third step, renewable energy systems, especially solar thermal energy equipments for heating and hot water supply have been accounted be to reduce even more the primary energy needs. Renewable energy application can reduce traditional fossil fuel use, with positive impacts on environment from the point of view of CO_2 emissions.

As a general rule, by increasing the insulation of a building, transmission heat losses during winter will be reduced; on the other hand, solar gains will increase, requiring an higher utilization of cooling systems during summer periods. A solution to this aspect could be the utilization of shading devices, to reduce summer solar gains; however, it has been chosen to not to consider this aspect in the present work.

Finally, due to the high exchange air rate, the building's energy demands could be further reduced by installing a double flow-controlled ventilation system with heat recovery. These kind of ventilation systems, by exchanging heat between the external renewal air and the exhausted air extracted from the indoor environments, can supply heated or cooled fresh air rather than just deliver air from outdoor to indoor. Since the fresh air is at a comfortable temperature, the energy consumption for heating/cooling can be considerably reduced.

This aspect has not been taken into account because it would require a complete redesign of ventilation system: pre-existing suction ducts could be recovered, but it would have been necessary to install exnovo air inlet ducts.

This operation would undoubtedly have led to great reductions from the heating point of view of the building, but it would have caused the resident a negligible discomfort, as he would have been required to leave the building for the time needed to complete the work.

It has been rather opted for non-destructive renovation actions on the interior of buildings, as all the upgrades analysed in the present work are related to the external surface of the building, or common spaces such as the garage or the attic.
The only action that concerns the interior of the apartments is the replacement of the windows, but with a resident's discomfort significantly lower than what other approaches would have led to.

By presenting recent practice into sustainable renovation of residential buildings, the aim of the work is to state that living comfort, energy saving and environmental protection are not in contradiction, but on the contrary the compromise and the interaction between these aspects is the best way to increase living comfort, and finally secure the future. The environmental impact of life cycle extension in most cases is lower respect to demolition and new construction.

The conclusions of the study are not conclusive and can be deepened by following the guidelines outlined above. The debate about the environmental impact of interventions in the existing housing stock is not finished yet.

Today, the long necessary lifespan of the existing stock combined with rising energy prices and environmental measures could boost innovations and improvements in the field of sustainable renovation. Hopefully this work can contribute a little to the research in this field focus on sustainable renovation and provide knowledge and experience for similar projects in the future.

Bibliography

[1] «European Environment Agency, Annual European Union greenhouse gas-inventory 1990-2010 and inventory report. 2».

[2] «Direttiva Europea 2002/91/CE [1] del 16 dicembre 2002 sul rendimento energetico nell’edilizia]».

[3] «Direttiva Europea 2010/31/UE del 19 maggio 2010 sulla prestazione energetica nell’edilizia».

[4] «Prestazione energetica nell'edilizia,» europa.eu.

[5] UN 1998, «http://unfccc.int/resource/docs/cop3/07a01.pdf,» [Online].

[6] EU 2009, «http://ecologic.eu/11045,» [Online].

[7] EU 2011, «https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/roadmap_fact_sheet_en.pdf,» [Online].

[8] EU, 2010, «https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings,» [Online].

[9] «http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV:en0021,» [Online].

[10] «7/2006 (V.24) TNM rendelet».

[11] «20/2014. (III. 7.) BM rendelet az épületek energetikai jellemzőinek meghatározásáról szóló 7/2006. (V. 24.) TNM rendelet módosításáról».

[12] «39/2015. (IX. 14.) MvM rendelet az épületek energetikai jellemzőinek meghatározásáról szóló 7/2006. (V. 24.) TNM rendelet módosításáról».

[13] «https://www.google.it/maps/@47.5191538,19.1163048,190a,20y,88.06h,45.02t/data=!3m1!1e3?hl=it],» [Online].

[14] energyplus, «https://energyplus.net/weather,» [Online].

[15] «http://sel.me.wisc.edu/trnsys/weather/tmy2data.htm,» [Online].

[16] rehva.eu, «http://www.rehva.eu/publications-and-resources/rehva-journal/2012/012012/ventilation-rates-and-iaq-in-national-regulations.html,» [Online].

[17] rehva.eu, «http://www.rehva.eu/fileadmin/hvac-dictio/01-2012/ventilation-rates-and-iaq-in-national-regulations_rj1201.pdf,» [Online].

[18] vdi.de, «https://www.vdi.de/technik/fachthemen/bauen-und-gebaeudetechnik/fachbereiche/technische-

gebaeudeausruestung/richtlinienarbeit/vdi-2053/,» [Online].

[19] «http://www.engineeringtoolbox.com/garage-ventilation-d_1017.html,» [Online].

[20] emi.hu, «https://www.emi.hu/EMI/web.nsf/ Pub/TRTM4A/$FILE/ZBR-EH-09_co2_megtakaritas_szamitas.pdf,» [Online].

[21] «www.aronhaz.hu,» [Online].

[22] efficaceclima.it, «http://www.efficaceclima.it/caldaie_basamento_vaillant_condensazione/index.htm,» [Online].

[23] naplopo.hu, «http://www.naplopo.hu/rendszerek/napkollektoros-rendszerek/uszodak-stranfuerdok/multipuffer-pool-xl-rendszerek,» [Online].

[24] naplopo.hu, «http://naplopo.hu/rendszerek/napelemes-rendszerek,» [Online].

[25] «7/2006. (V. 24.) TNM rendelet».

Annexes

The annexes present information that integrates the discussion of the dissertation and helps to understand how the results have been obtained. They present the detailed characterization of the neighborhood and the drawings of the building stocks and typification proposed. Furthermore they present the excel tables with the results of the simulations and the quantification of savings due to the refurbishment.

A.1 nZEB DIRECTIVE 2010/31/EU

Buildings account for 40 % of total primary energy consumption and 36% of CO_2 emission in EU [1]. The sector is expanding, so the related energy consumption is bound to increase. The reduction of energy consumption and the use of energy from renewable sources in the buildings sector therefore constitute important measures needed to reduce the EU energy dependency and GHG emission [8]. Without exploiting the huge saving potential of the building stock, the EU will miss its reduction targets.

Aware of the great influence of building sector the Directive 2010/31/EU [8], the European reference directive on the energy performance of buildings (EPBD recast), promotes the improvement of the energy performance of buildings within the EU, and introduces a new standard for building, the Nearly Zero Energy Building.

NZEB is therefore introduced as instrument to guarantee the achievement of the strict target of reducing GHG emission to which EU has been bound since its commitments with the Kyoto protocol.

The task expected from the implementation of NZEB is that the reduced energy consumption and increased use of energy from renewable sources advocated would help the EU to honor both its long term commitment to maintain the global temperature rise below 2 °C, and to reduce overall GHG emission by at least 20 % below 1990 levels by 2020 [8].

NZEB is defined as a building that has a very high energy performance, which nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy produced on-site or nearby.

The two main focus of NZEB standard are:
- The performance of the building, and
- The cost-optimality of its implementation.

Concerning the performances, the NZEB targets to “very low amount of energy” required to keep the internal comfort condition, thus addressing to the implementation of passive strategies.

NZEB differs from the voluntary standards for highly energy efficient buildings, as passive house, since it is not restricted to reach low consumption. In addition to achieving low consumption it suggests in fact that a “significant extent of energy by renewable sources produced on-site or nearby” should cover the need of the buildings, in order to reduce emission through cleaner sources. It advocates the production on-site or nearby with the purpose of reducing the dependence from the grid.

The NZEB introduces a change of paradigm, building is not seen anymore only on the side of the energy demand, but it also contributes to the supply of energy. The requirements are not fixed anymore in term of consumption, but in term on energy balance. What interests is not the energy consumption itself, but the balance between energy consumed and produced. What has to be guaranteed is not that the buildings consumes less than a maximum consumption allowed, but that the balance between energy consumed and energy produced on-site never exceed the limit sets for NZEB standard.

A.2 Calculation of ACH

	zona	superficie m^2	vol tot m^3	infiltrazioni vol/h	ventilazione vol/h	h/gg	%	vol/h only vent	ACH [vol/h]	ACH [m^3 /h]
apt 9	toilet	6.8	18.9	0	5	2.5	0.104	0.521	0.521	9.86
	wc	1.7	4.6	0	5	2.5	0.104	0.521	0.521	2.41
	kitchen	27.5	76.9	0.5	3	3	0.125	0.688	1.188	91.33
	corr	14.0	39.2	0	3	2.5	0.104	0.313	0.313	12.26
	room1	14.6	40.8	0.5	0	0	0	0	0.5	20.38
	room2	10.6	29.6	0.5	0	0	0	0	0.5	14.80
	room3	13.6	38.2	0.5	0	0	0	0	0.5	19.08
	closet	1.5	4.1	0	0	0	0	0	0	0.00
	VOL tot =	252.3	m^3					ACH =	170.13	[m^3/h]
	S tot =	90.1	m^2						0.674	[1/h]
apt 10	toilet	4.3	12.0	0	5	2.5	0.104	0.521	0.521	6.26
	wc	1.6	4.4	0	5	2.5	0.104	0.521	0.521	2.28
	kitchen	24.3	67.9	0.5	3	3	0.125	0.825	1.325	89.97
	corr	6.8	19.0	0	4	2.5	0.104	0.450	0.450	8.53
	room1	11.7	32.8	0.5	0	0	0	0	0.5	16.38
	room2	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	room3	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	closet	1.9	5.4	0	0	0	0	0	0	0.00
	VOL tot =	141.4	m^3					ACH =	123.41	[m^3/h]
	S tot =	50.5	m^2						0.873	[1/h]
apt 11	toilet	6.3	17.8	0	5	2.5	0.104	0.521	0.521	9.25
	wc	1.4	4.0	0	5	2.5	0.104	0.521	0.521	2.09
	kitchen	25.0	70.0	0.5	3	3	0.125	1.053	1.553	108.70
	corr	6.0	16.7	0	6.51	2.5	0.104	0.678	0.678	11.33
	room1	11.2	31.3	0.5	0	0	0	0	0.5	15.65
	room2	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	room3	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	closet	1.8	5.0	0	0	0	0	0	0	0.00
	VOL tot =	144.8	m^3					ACH =	147.02	[m^3/h]
	S tot =	51.7	m^2						1.015	[1/h]
apt 12	toilet	7.4	20.6	0	5	2.5	0.104	0.521	0.521	10.75
	wc	1.2	3.2	0	5	2.5	0.104	0.521	0.521	1.68
	kitchen	30.0	83.9	0.5	3	3	0.125	0.716	1.216	102.01
	corr	13.0	36.4	0	3.27	2.5	0.104	0.341	0.341	12.43
	room1	10.9	30.4	0.5	0	0	0	0	0.5	15.20
	room2	14.0	39.3	0.5	0	0	0	0	0.5	19.66
	room3	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	closet	3.5	9.8	0	0	0	0	0	0	0.00
	VOL tot =	223.7	m^3					ACH =	161.72	[m^3/h]
	S tot =	79.9	m^2						0.723	[1/h]
apt 13	toilet	6.4	18.0	0	5	2.5	0.104	0.521	0.521	9.39
	wc	1.2	3.2	0	5	2.5	0.104	0.521	0.521	1.68
	kitchen	23.0	64.3	0.5	3	3	0.125	0.751	1.251	80.37
	corr	10.5	29.5	0	3.61	2.5	0.104	0.376	0.376	11.07
	room1	10.4	29.1	0.5	0	0	0	0	0.5	14.56
	room2	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	room3	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	closet	2.4	6.8	0	0	0	0	0	0	0.00
	VOL tot =	150.9	m^3					ACH =	117.07	[m^3/h]
	S tot =	53.9	m^2						0.776	[1/h]

	zona	superficie m^2	vol tot m^3	infiltrazioni vol/h	ventilazione vol/h	h/gg	%	vol/h only vent	ACH [vol/h]	ACH [m^3 /h]
apt 14	toilet	4.0	11.2	0	5	2.5	0.104	0.521	0.521	5.83
	wc	1.2	3.2	0	5	2.5	0.104	0.521	0.521	1.69
	kitchen	25.4	71.2	0.5	3	3	0.125	0.938	1.438	102.42
	corr	4.8	13.4	0	5.41	2.5	0.104	0.563	0.563	7.53
	room1	8.0	22.4	0.5	0	0	0	0	0.5	11.20
	room2	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	room3	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	closet	0.0	0.0	0	0	0	0	0	0	0.00
	VOL tot =	121.4	m^3					ACH =	128.67	[m^3/h]
	S tot =	43.4	m^2						1.060	[1/h]
apt 15	toilet	7.1	19.9	0	5	2.5	0.104	0.521	0.521	10.35
	wc	1.1	3.1	0	5	2.5	0.104	0.521	0.521	1.63
	kitchen	27.5	77.0	0.5	3	3	0.125	0.785	1.285	98.89
	corr	10.5	29.3	0	3.93	2.5	0.104	0.410	0.410	11.99
	room1	10.1	28.3	0.5	0	0	0	0	0.5	14.14
	room2	10.1	28.3	0.5	0	0	0	0	0.5	14.14
	room3	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	closet	2.4	6.8	0	0	0	0	0	0	0.00
	VOL tot =	192.6	m^3					ACH =	151.14	[m^3/h]
	S tot =	68.8	m^2						0.785	[1/h]
apt 16	toilet	6.8	19.1	0	5	2.5	0.104	0.521	0.521	9.96
	wc	1.4	3.9	0	5	2.5	0.104	0.521	0.521	2.04
	kitchen	25.8	72.3	0.5	3	3	0.125	0.682	1.182	85.42
	corr	14.0	39.1	0	2.95	2.5	0.104	0.307	0.307	12.00
	room1	12.5	35.0	0.5	0	0	0	0	0.5	17.50
	room2	8.7	24.4	0.5	0	0	0	0	0.5	12.18
	room3	0.0	0.0	0.5	0	0	0	0	0.5	0.00
	closet	2.1	5.9	0	0	0	0	0	0	0.00
	VOL tot =	199.7	m^3					ACH =	139.11	[m^3/h]
	S tot =	71.3	m^2						0.697	[1/h]

A.3 Maximum heating power (2003)

	ZONE	m^2	Qmax	Qmax*						
apt 1	LIVING_1	27.5	6.2	224.6						
	ROOM1_1	14.6	1.1	77.8						
	ROOM2_1	10.6	0.8	78.3						
	ROOM3_1	13.6	0.9	65.1						
	CORR_1	14.0	0.0	0.0						
	TOILET_1	6.8	0.4	63.4						
	WC_1	1.7	0.1	78.8						
	CLOSET_1	1.5	0.0	15.1	**TOT 1**	**9.6**	**kW**	Q* apart	106.5	W/m^2
apt 2	LIVING_2	24.3	4.8	197.6						
	ROOM_2	11.7	0.8	66.9						
	CORR_2	6.8	0.0	0.0						
	TOILET_2	4.3	0.3	69.2						
	WC_2	1.6	0.2	102.2						
	CLOSET_2	1.9	0.0	12.6	**TOT 2**	**6.1**	**kW**	Q* apart	119.9	W/m^2
apt 3	LIVING_3	25.0	4.5	180.4						
	ROOM_3	11.2	0.6	50.0						
	CORR_3	6.0	0.0	0.0						
	TOILET_3	6.3	0.3	47.9	**TOT 3**	**5.4**	**kW**	Q* apart	110.8	W/m^2
apt 4	LIVING_4	30.0	5.7	190.7						
	ROOM1_4	10.9	0.7	64.8						
	ROOM2_4	14.0	1.7	122.3						
	CORR_4	13.0	0.0	0.0						
	TOILET_4	2.2	0.8	379.4						
	WC_4	3.2	0.1	35.2						
	CLOSET1_4	2.2	0.0	1.1						
	CLOSET2_4	3.2	0.2	68.9	**TOT 4**	**9.3**	**kW**	Q* apart	118.3	W/m^2
apt 5	LIVING_5	23.0	5.2	226.2						
	ROOM_5	10.4	0.7	67.5						
	CORR_5	10.5	0.0	0.0						
	TOILET_5	6.4	0.7	113.7						
	WC_5	1.2	0.1	70.3						
	CLOSET_5	2.4	0.0	9.7	**TOT 5**	**6.7**	**kW**	Q* apart	124.9	W/m^2
apt 6	LIVING_6	25.4	4.8	187.4						
	ROOM_6	8.0	0.8	97.1						
	CORR_6	4.8	0.0	0.0						
	TOILET_6	4.0	0.3	69.4						
	WC_6	1.2	0.1	91.7	**TOT 6**	**5.9**	**kW**		136.7	W/m^2
apt 7	LIVING_7	27.5	5.5	201.6						
	ROOM_7	12.9	0.9	68.3						
	CORR_7	10.5	0.0	0.0						
	TOILET_7	7.1	0.3	45.9						
	WC_7	1.1	0.1	98.2						
	CLOSET_7	4.8	0.1	19.3	**TOT 7**	**7.0**	**kW**	Q* apart	108.9	W/m^2
apt 8	LIVING_8	25.8	6.1	235.6						
	ROOM1_8	12.5	0.7	57.5						
	ROOM2_8	8.7	0.6	70.3						
	CORR_8	14.0	0.0	0.0						
	TOILET_8	6.8	0.4	60.8						
	WC_8	1.4	0.1	94.9						
	CLOSET_8	2.1	0.0	0.0	**TOT 8**	**8.0**	**kW**	Q* apart	111.6	W/m^2
common spaces	CORRIDOR0	30.4	0.0	0.0						
	STAIRWELL0	18.0	0.9	52.5						
	ENTRY1	10.9	0.1	12.5						
	ENTRY2	5.6	0.4	67.4						
	GARAGE	617.1	13.2	21.4	**TOT common**	**14.6**	**kW**	Q* apart	21.5	W/m^2
					TOT 1 floor	**72.5**	**kW**			

	ZONE	m^2	Qmax	_Qmax*_						
apt 9	LIVING_9	27.5	5.3	_193.2_						
	ROOM1_9	14.6	0.9	_58.6_						
	ROOM2_9	10.6	0.6	_58.8_						
	ROOM3_9	13.6	0.6	_45.6_						
	CORR_9	14.0	0.0	_0.0_						
	TOILET_9	6.8	0.7	_103.6_						
	WC_9	1.7	0.2	_148.0_						
	CLOSET_9	1.5	0.0	_0.0_	**TOT 9**	**8.3**	**kW**	_Q* apart_	_92.6_	_W/m^2_
apt 10	LIVING_10	24.3	4.4	_181.9_						
	ROOM_10	11.7	0.5	_45.7_						
	CORR_10	6.8	0.0	_0.0_						
	TOILET_10	4.3	0.6	_133.7_						
	WC_10	1.6	0.3	_163.2_						
	CLOSET_10	1.9	0.0	_0.0_	**TOT 10**	**5.8**	**kW**	_Q* apart_	_114.3_	_W/m^2_
apt 11	LIVING_11	25.0	4.6	_183.7_						
	ROOM_11	11.2	0.5	_40.7_						
	CORR_11	6.0	0.0	_0.0_						
	TOILET_11	6.3	0.7	_111.8_						
	WC_11	1.4	0.3	_193.5_						
	CLOSET_11	1.8	0.0	_0.0_	**TOT 11**	**6.0**	**kW**	_Q* apart_	_116.7_	_W/m^2_
apt 12	LIVING_12	30.0	5.3	_175.7_						
	ROOM1_12	10.9	0.5	_47.5_						
	ROOM2_12	14.0	1.5	_108.5_						
	CORR_12	13.0	0.0	_0.0_						
	TOILET_12	7.4	1.0	_140.7_						
	WC_12	1.2	0.3	_242.8_						
	CLOSET1_12	2.2	0.0	_0.0_						
	CLOSET2_12	3.2	0.2	_55.6_	**TOT 12**	**8.8**	**kW**	_Q* apart_	_107.7_	_W/m^2_
apt 13	LIVING_13	23.0	4.9	_212.8_						
	ROOM_13	10.4	0.5	_44.9_						
	CORR_13	10.5	0.0	_0.0_						
	TOILET_13	6.4	0.7	_111.4_						
	WC_13	1.2	0.1	_130.2_						
	CLOSET_13	2.4	0.0	_0.6_	**TOT 13**	**6.2**	**kW**	_Q* apart_	_115.4_	_W/m^2_
apt 14	LIVING_14	25.4	4.3	_171.0_						
	ROOM_14	8.0	0.6	_79.5_						
	CORR_14	4.8	0.0	_0.0_						
	TOILET_14	4.0	0.4	_108.7_						
	WC_14	1.2	0.2	_154.3_	**TOT 14**	**5.6**	**kW**	_Q* apart_	_129.1_	_W/m^2_
apt 15	LIVING_15	27.5	5.1	_185.2_						
	ROOM1_15	10.1	0.5	_48.6_						
	ROOM2_15	10.1	0.8	_79.6_						
	CORR_15	10.5	0.0	_0.0_						
	TOILET_15	7.1	0.7	_93.5_						
	WC_15	1.1	0.2	_194.7_						
	CLOSET_15	2.4	0.0	_3.9_	**TOT 15**	**7.3**	**kW**	_Q* apart_	_105.8_	_W/m^2_
apt 16	LIVING_16	25.8	5.7	_220.3_						
	ROOM1_16	12.5	0.5	_40.2_						
	ROOM2_16	8.7	0.5	_55.8_						
	CORR_16	14.0	0.0	_0.0_						
	TOILET_16	6.8	0.7	_107.1_						
	WC_16	1.4	0.3	_194.3_						
	CLOSET_16	2.1	0.0	_0.0_	**TOT 16**	**7.7**	**kW**	_Q* apart_	_107.7_	_W/m^2_
common spaces	CORRIDOR1	30.4	0.0	_0.0_						
	STAIRWELL1	18.0	0.6	_32.6_	**TOT COM1**	**0.6**	**kW**	_Q* apart_	_12.1_	_W/m^2_
					TOT 2 floor	**56.3**	**kW**			

	ZONE	m^2	Qmax	*Qmax**						
apt 25	LIVING_25	27.5	5.6	*202.8*						
	ROOM1_25	14.6	1.1	*73.1*						
	ROOM2_25	10.6	0.8	*78.6*						
	ROOM3_25	13.6	0.8	*62.2*						
	CORR_25	14.0	0.0	*0.0*						
	TOILET_25	6.8	0.8	*113.7*						
	WC_25	1.7	0.3	*167.5*						
	CLOSET_25	1.5	0.0	*11.2*	**TOT 25**	**9.4**	kW	*Q* apart*	*104.0*	*W/m^2*
apt 26	LIVING_26	24.3	4.6	*191.2*						
	ROOM_26	11.7	0.6	*52.8*						
	CORR_26	6.8	0.0	*0.0*						
	TOILET_26	4.3	0.7	*156.7*						
	WC_26	1.6	0.3	*191.9*						
	CLOSET_26	1.9	0.0	*10.8*	**TOT 26**	**6.2**	kW	*Q* apart*	*123.7*	*W/m^2*
apt 27	LIVING_27	25.0	4.9	*197.8*						
	ROOM_27	11.2	0.5	*44.6*						
	CORR_27	6.0	0.0	*0.0*						
	TOILET_27	6.3	0.8	*133.4*						
	WC_27	1.4	0.3	*224.9*						
	CLOSET_27	1.8	0.0	*7.4*	**TOT 27**	**6.6**	kW	*Q* apart*	*128.1*	*W/m^2*
apt 28	LIVING_28	30.0	5.8	*192.6*						
	ROOM1_28	10.9	0.6	*53.7*						
	ROOM2_28	14.0	1.5	*105.4*						
	CORR_28	13.0	0.0	*0.0*						
	TOILET_28	7.4	1.1	*152.9*						
	WC_28	1.2	0.3	*257.6*						
	CLOSET1_28	2.2	0.0	*4.6*						
	CLOSET2_28	3.2	0.2	*65.7*	**TOT 28**	**9.5**	kW	*Q* apart*	*116.0*	*W/m^2*
apt 29	LIVING_29	23.0	4.6	*200.6*						
	ROOM_29	10.4	0.5	*52.2*						
	CORR_29	10.5	0.0	*0.0*						
	TOILET_29	6.4	0.8	*118.2*						
	WC_29	1.2	0.2	*139.8*						
	CLOSET_29	2.4	0.0	*0.0*	**TOT 29**	**6.1**	kW	*Q* apart*	*112.6*	*W/m^2*
apt 30	LIVING_30	25.4	4.8	*188.8*						
	ROOM_30	8.0	0.8	*94.0*						
	CORR_30	4.8	0.0	*0.0*						
	TOILET_30	4.0	0.5	*131.9*						
	WC_30	1.2	0.2	*183.5*	**TOT 30**	**6.3**	kW	*Q* apart*	*145.2*	*W/m^2*
apt 31	LIVING_31	27.5	5.6	*204.5*						
	ROOM1_31	10.1	0.6	*63.0*						
	ROOM2_31	10.1	0.9	*91.7*						
	CORR_31	10.5	0.0	*0.0*						
	TOILET_31	7.1	0.8	*109.7*						
	WC_31	1.1	0.2	*221.9*						
	CLOSET_31	2.4	0.1	*37.6*	**TOT 31**	**8.3**	kW	*Q* apart*	*120.7*	*W/m^2*
apt 32	LIVING_32	25.8	5.4	*210.4*						
	ROOM1_32	12.5	0.6	*45.2*						
	ROOM2_32	8.7	0.6	*65.6*						
	CORR_32	14.0	0.0	*0.0*						
	TOILET_32	6.8	0.8	*123.1*						
	WC_32	1.4	0.3	*225.2*						
	CLOSET_32	2.1	0.0	*0.0*	**TOT 32**	**7.7**	kW	*Q* apart*	*108.3*	*W/m^2*
common spaces	CORRIDOR3	30.4	0.0	*0.0*						
	STAIRWELL3	18.0	0.7	*38.6*	**TOT COM3**	**0.7**	kW	*Q* apart*	*14.4*	*W/m^2*
					TOT 4 floor	**54.5**	kW			

A.4 Heating and cooling demand of the building (2003)

[kWh/y]	ZONE	Q heating	Q cooling
apt 1	LIVING_1	9529.8	225.3
	ROOM1_1	1715.6	62.7
	ROOM2_1	1263.7	53.1
	ROOM3_1	1420.5	32.1
	CORR_1	5.0	0.0
	TOILET_1	1272.8	0.0
	WC_1	369.8	0.0
	CLOSET_1	15.4	0.0
apt 2	LIVING_2	6645.8	140.3
	ROOM_2	1203.9	26.0
	CORR_2	0.2	0.6
	TOILET_2	693.9	0.1
	WC_2	534.6	0.0
	CLOSET_2	3.4	0.0
apt 3	LIVING_3	6062.1	112.0
	ROOM_3	667.2	50.1
	CORR_3	3.1	0.6
	TOILET_3	650.4	1.5
apt 4	LIVING_4	7858.6	109.9
	ROOM1_4	922.0	39.9
	ROOM2_4	3582.7	46.7
	CORR_4	3.5	0.0
	TOILET_4	2285.2	0.4
	WC_4	352.5	0.0
	CLOSET1_4	0.0	0.0
	CLOSET2_4	343.8	1.0
apt 5	LIVING_5	8315.8	80.3
	ROOM_5	861.0	22.5
	CORR_5	1.8	0.0
	TOILET_5	1900.2	1.6
	WC_5	219.9	0.0
	CLOSET_5	2.4	0.0
apt 6	LIVING_6	6743.4	52.5
	ROOM_6	1216.1	45.8
	CORR_6	0.2	5.0
	TOILET_6	720.7	0.1
	WC_6	284.6	0.1
apt 7	LIVING_7	8478.6	74.4
	ROOM_7	1532.9	16.1
	CORR_7	0.4	0.0
	TOILET_7	846.9	0.0
	WC_7	374.5	0.0
	CLOSET_7	141.8	0.0
apt 8	LIVING_8	9940.2	189.4
	ROOM1_8	922.5	17.5
	ROOM2_8	802.9	36.2
	CORR_8	2.5	0.0
	TOILET_8	1134.6	0.0
	WC_8	389.2	0.0
	CLOSET_8	0.0	0.0
common spaces	CORRIDOR0	0.0	0.0
	STAIRWELL0	638.6	0.0
	ENTRY1	6.4	0.0
	ENTRY2	520.4	0.0
	GARAGE	109.6	0.0

[kWh/y]	ZONE	Q heating	Q cooling
apt 9	LIVING_9	6139.0	624.4
	ROOM1_9	897.1	247.2
	ROOM2_9	638.0	198.4
	ROOM3_9	587.4	200.6
	CORR_9	0.0	138.0
	TOILET_9	337.6	66.1
	WC_9	49.2	37.1
	CLOSET_9	0.0	9.9
apt 10	LIVING_10	4554.9	478.8
	ROOM_10	376.4	213.1
	CORR_10	0.0	166.4
	TOILET_10	41.8	116.5
	WC_10	74.6	45.2
	CLOSET_10	0.0	15.6
apt 11	LIVING_11	4600.6	543.1
	ROOM_11	272.3	188.3
	CORR_11	0.0	161.5
	TOILET_11	32.8	118.2
	WC_11	63.7	45.1
	CLOSET_11	0.0	15.6
apt 12	LIVING_12	5423.0	437.8
	ROOM1_12	383.0	164.5
	ROOM2_12	2807.9	135.4
	CORR_12	0.0	105.0
	TOILET_12	1319.2	28.1
	WC_12	44.9	16.1
	CLOSET1_12	0.0	18.2
	CLOSET2_12	198.8	10.6
apt 13	LIVING_13	6490.2	245.2
	ROOM_13	238.7	140.1
	CORR_13	0.0	81.4
	TOILET_13	1092.3	36.4
	WC_13	16.4	15.6
	CLOSET_13	0.0	17.2
apt 14	LIVING_14	4389.8	307.2
	ROOM_14	715.1	180.9
	CORR_14	0.0	150.2
	TOILET_14	102.4	147.7
	WC_14	43.8	38.5
apt 15	LIVING_15	5894.0	356.4
	ROOM1_15	425.0	133.3
	ROOM2_15	1262.7	153.3
	CORR_15	0.0	125.0
	TOILET_15	101.6	112.3
	WC_15	38.1	40.6
	CLOSET_15	0.0	55.6
apt 16	LIVING_16	7689.2	489.2
	ROOM1_16	316.8	126.8
	ROOM2_16	428.6	128.9
	CORR_16	0.0	113.3
	TOILET_16	91.7	105.9
	WC_16	28.6	41.9
	CLOSET_16	0.0	10.1
common spaces	CORRIDOR1	0.0	0.0
	STAIRWELL1	79.5	0.0

[kWh/y]	ZONE	Q heating	Q cooling
apt 25	LIVING_25	7730.1	517.1
	ROOM1_25	1227.5	240.9
	ROOM2_25	1022.5	182.2
	ROOM3_25	958.3	198.7
	CORR_25	0.0	121.3
	TOILET_25	902.8	58.2
	WC_25	240.8	26.9
	CLOSET_25	0.8	9.9
apt 26	LIVING_26	5580.4	447.4
	ROOM_26	536.3	243.2
	CORR_26	0.0	132.7
	TOILET_26	452.1	87.2
	WC_26	284.0	29.6
	CLOSET_26	0.0	16.0
apt 27	LIVING_27	6022.2	514.6
	ROOM_27	320.7	220.5
	CORR_27	0.0	126.1
	TOILET_27	611.4	89.9
	WC_27	264.8	30.0
	CLOSET_27	0.0	15.4
apt 28	LIVING_28	6987.9	420.0
	ROOM1_28	514.6	203.9
	ROOM2_28	2617.0	171.1
	CORR_28	0.0	116.3
	TOILET_28	1897.0	42.1
	WC_28	228.2	16.3
	CLOSET1_28	0.0	14.8
	CLOSET2_28	262.0	14.1
apt 29	LIVING_29	6437.2	241.0
	ROOM_29	391.3	155.3
	CORR_29	0.0	89.7
	TOILET_29	1476.8	45.8
	WC_29	136.6	15.5
	CLOSET_29	0.0	18.0
apt 30	LIVING_30	5850.6	292.0
	ROOM_30	924.3	170.3
	CORR_30	0.0	124.4
	TOILET_30	458.6	97.6
	WC_30	190.3	28.5
apt 31	LIVING_31	7537.2	360.2
	ROOM1_31	657.3	138.0
	ROOM2_31	1465.6	150.2
	CORR_31	0.0	116.9
	TOILET_31	739.1	76.1
	WC_31	221.6	27.1
	CLOSET_31	1.1	34.0
apt 32	LIVING_32	7877.8	447.7
	ROOM1_32	450.6	140.2
	ROOM2_32	562.8	127.8
	CORR_32	0.0	114.6
	TOILET_32	723.8	72.3
	WC_32	248.6	27.7
	CLOSET_32	0.0	10.4
common spaces	CORRIDOR3	0.0	0.0
	STAIRWELL3	126.3	0.0

A.5 Heating and cooling demand of the building (2006)

[kWh/y]	ZONE	Q heating	Q cooling
apt 1	LIVING_1	4487.99	927.51
	ROOM1_1	252.25	391.91
	ROOM2_1	190.69	304.83
	ROOM3_1	254.04	284.23
	CORR_1	1.60	109.76
	TOILET_1	488.56	49.30
	WC_1	119.16	30.15
	CLOSET_1	0.41	9.22
apt 2	LIVING_2	3386.27	719.36
	ROOM_2	185.60	249.54
	CORR_2	0.18	154.90
	TOILET_2	174.08	104.72
	WC_2	215.89	24.88
	CLOSET_2	0.57	11.60
apt 3	LIVING_3	2999.66	667.80
	ROOM_3	42.66	308.01
	CORR_3	0.93	121.02
	TOILET_3	168.99	106.58
apt 4	LIVING_4	4098.33	635.47
	ROOM1_4	94.42	272.97
	ROOM2_4	905.13	186.35
	CORR_4	0.89	105.83
	TOILET_4	626.65	15.35
	WC_4	105.85	15.97
	CLOSET1_4	0.01	20.69
	CLOSET2_4	0.50	4.41
apt 5	LIVING_5	3697.65	378.32
	ROOM_5	27.35	220.39
	CORR_5	0.79	75.83
	TOILET_5	434.68	36.85
	WC_5	52.04	17.17
	CLOSET_5	0.05	13.70
apt 6	LIVING_6	3646.85	413.02
	ROOM_6	170.47	279.45
	CORR_6	0.13	168.18
	TOILET_6	244.97	117.75
	WC_6	88.29	34.71
apt 7	LIVING_7	4437.48	522.00
	ROOM_7	330.17	184.02
	CORR_7	0.36	125.14
	TOILET_7	260.59	66.67
	WC_7	141.17	30.95
	CLOSET_7	4.02	62.94
apt 8	LIVING_8	4592.64	818.85
	ROOM1_8	48.22	186.57
	ROOM2_8	64.31	191.43
	CORR_8	1.01	101.06
	TOILET_8	348.70	57.51
	WC_8	116.55	27.26
	CLOSET_8	0.03	4.37
common spaces	CORRIDOR0	0.00	0.00
	STAIRWELL0	20.97	0.00
	ENTRY1	0.14	0.00
	ENTRY2	109.89	0.00
	GARAGE	120.85	0.00

[kWh/y]	ZONE	Q heating	Q cooling
apt 9	LIVING_9	3273.41	1261.05
	ROOM1_9	64.61	547.04
	ROOM2_9	45.41	419.49
	ROOM3_9	51.31	421.55
	CORR_9	0.00	293.22
	TOILET_9	146.05	131.18
	WC_9	13.03	66.63
	CLOSET_9	0.00	21.96
apt 10	LIVING_10	2443.98	937.45
	ROOM_10	7.57	437.07
	CORR_10	0.00	298.11
	TOILET_10	6.57	208.10
	WC_10	22.00	75.08
	CLOSET_10	0.00	33.63
apt 11	LIVING_11	2361.05	1062.68
	ROOM_11	5.28	378.50
	CORR_11	0.00	277.24
	TOILET_11	8.73	220.18
	WC_11	16.86	74.97
	CLOSET_11	0.00	33.53
apt 12	LIVING_12	3149.21	879.38
	ROOM1_12	14.05	380.40
	ROOM2_12	570.47	272.10
	CORR_12	0.00	266.63
	TOILET_12	254.54	54.76
	WC_12	6.75	36.35
	CLOSET1_12	0.00	37.30
	CLOSET2_12	0.00	9.97
apt 13	LIVING_13	2939.56	508.31
	ROOM_13	1.41	320.50
	CORR_13	0.00	194.45
	TOILET_13	152.15	80.26
	WC_13	2.26	35.21
	CLOSET_13	0.00	42.57
apt 14	LIVING_14	2608.94	595.16
	ROOM_14	33.72	411.54
	CORR_14	0.00	299.82
	TOILET_14	22.70	261.95
	WC_14	8.64	70.62
apt 15	LIVING_15	3339.84	721.11
	ROOM1_15	13.94	294.21
	ROOM2_15	242.73	374.84
	CORR_15	0.00	274.73
	TOILET_15	27.62	188.09
	WC_15	9.63	66.72
	CLOSET_15	0.01	111.96
apt 16	LIVING_16	3667.06	1027.81
	ROOM1_16	4.11	281.26
	ROOM2_16	7.47	269.44
	CORR_16	0.00	258.80
	TOILET_16	22.67	177.59
	WC_16	5.78	71.43
	CLOSET_16	0.00	19.57
common spaces	CORRIDOR1	0.00	0.00
	STAIRWELL1	1.05	0.00

[kWh/y]	ZONE	Q heating	Q cooling
apt 25	LIVING_25	3596.97	1006.18
	ROOM1_25	147.30	495.82
	ROOM2_25	142.00	362.93
	ROOM3_25	147.81	395.80
	CORR_25	0.00	231.99
	TOILET_25	309.66	107.31
	WC_25	57.58	55.36
	CLOSET_25	0.05	19.05
apt 26	LIVING_26	2774.17	908.10
	ROOM_26	30.41	474.66
	CORR_26	0.00	264.65
	TOILET_26	60.51	180.63
	WC_26	74.48	61.67
	CLOSET_26	0.03	30.82
apt 27	LIVING_27	2754.13	1026.66
	ROOM_27	6.83	437.96
	CORR_27	0.00	244.05
	TOILET_27	77.42	187.73
	WC_27	61.66	61.98
	CLOSET_27	0.01	30.76
apt 28	LIVING_28	3513.53	847.35
	ROOM1_28	20.93	421.66
	ROOM2_28	634.84	329.53
	CORR_28	0.00	247.57
	TOILET_28	422.66	51.98
	WC_28	46.58	31.44
	CLOSET1_28	0.03	31.92
	CLOSET2_28	0.03	11.34
apt 29	LIVING_29	2764.69	425.46
	ROOM_29	6.26	316.21
	CORR_29	0.00	171.69
	TOILET_29	260.37	70.35
	WC_29	16.73	29.87
	CLOSET_29	0.01	38.70
apt 30	LIVING_30	3072.78	567.77
	ROOM_30	88.45	389.44
	CORR_30	0.00	267.04
	TOILET_30	106.12	220.07
	WC_30	40.20	60.40
apt 31	LIVING_31	3813.76	696.95
	ROOM1_31	48.32	283.52
	ROOM2_31	371.19	353.83
	CORR_31	0.00	246.71
	TOILET_31	171.16	146.90
	WC_31	53.70	54.35
	CLOSET_31	0.77	89.05
apt 32	LIVING_32	3540.55	851.36
	ROOM1_32	13.79	272.28
	ROOM2_32	24.66	247.32
	CORR_32	0.00	223.43
	TOILET_32	153.53	137.57
	WC_32	49.28	56.40
	CLOSET_32	0.00	17.22
common spaces	CORRIDOR3	0.00	0.00
	STAIRWELL3	3.68	0.00

A.6 Heating and cooling demand of the building (2006v2)

[kWh/y]	ZONE	Q heating	Q cooling
apt 1	LIVING_1	3902.33	1040.12
	ROOM1_1	141.54	453.93
	ROOM2_1	104.96	350.79
	ROOM3_1	153.74	333.43
	CORR_1	1.55	162.08
	TOILET_1	375.81	72.86
	WC_1	85.59	39.84
	CLOSET_1	0.38	13.25
apt 2	LIVING_2	2994.10	803.37
	ROOM_2	101.56	294.08
	CORR_2	0.17	195.23
	TOILET_2	110.91	132.01
	WC_2	167.79	35.28
	CLOSET_2	0.54	18.42
apt 3	LIVING_3	2625.65	751.08
	ROOM_3	15.67	349.93
	CORR_3	0.90	154.91
	TOILET_3	108.30	131.06
apt 4	LIVING_4	3644.40	722.53
	ROOM1_4	40.23	321.14
	ROOM2_4	592.27	233.99
	CORR_4	0.87	159.46
	TOILET_4	396.79	31.69
	WC_4	71.29	23.96
	CLOSET1_4	0.01	29.18
	CLOSET2_4	0.20	6.68
apt 5	LIVING_5	3108.44	447.71
	ROOM_5	10.85	262.82
	CORR_5	0.78	116.55
	TOILET_5	255.84	57.27
	WC_5	29.52	24.32
	CLOSET_5	0.04	21.60
apt 6	LIVING_6	3226.57	476.49
	ROOM_6	82.57	327.61
	CORR_6	0.13	203.24
	TOILET_6	177.34	149.07
	WC_6	61.85	44.03
apt 7	LIVING_7	3936.89	596.54
	ROOM_7	216.01	228.64
	CORR_7	0.35	165.23
	TOILET_7	180.68	90.43
	WC_7	104.13	40.10
	CLOSET_7	3.51	92.33
apt 8	LIVING_8	3961.79	919.73
	ROOM1_8	17.33	223.70
	ROOM2_8	22.41	225.21
	CORR_8	0.98	150.26
	TOILET_8	241.02	86.40
	WC_8	79.28	37.94
	CLOSET_8	0.03	8.03
common spaces	CORRIDOR0	0.00	0.00
	STAIRWELL0	13.40	0.00
	ENTRY1	0.13	0.00
	ENTRY2	59.55	0.00
	GARAGE	265.61	0.00

[kWh/y]	ZONE	Q heating	Q cooling
apt 9	LIVING_9	3022.90	1295.33
	ROOM1_9	26.18	571.00
	ROOM2_9	19.19	437.74
	ROOM3_9	24.88	437.38
	CORR_9	0.00	305.48
	TOILET_9	123.01	137.54
	WC_9	9.75	68.66
	CLOSET_9	0.00	23.18
apt 10	LIVING_10	2252.08	962.41
	ROOM_10	4.45	452.53
	CORR_10	0.00	308.15
	TOILET_10	6.36	215.09
	WC_10	16.06	77.78
	CLOSET_10	0.00	35.16
apt 11	LIVING_11	2175.44	1088.39
	ROOM_11	3.49	390.91
	CORR_11	0.00	286.53
	TOILET_11	8.55	227.14
	WC_11	12.00	77.65
	CLOSET_11	0.00	34.99
apt 12	LIVING_12	2932.59	906.01
	ROOM1_12	6.19	401.29
	ROOM2_12	354.85	304.28
	CORR_12	0.00	289.14
	TOILET_12	132.74	72.71
	WC_12	4.51	40.94
	CLOSET1_12	0.00	39.56
	CLOSET2_12	0.00	12.66
apt 13	LIVING_13	2547.63	543.72
	ROOM_13	0.24	336.56
	CORR_13	0.00	211.87
	TOILET_13	68.79	95.42
	WC_13	2.18	39.78
	CLOSET_13	0.00	44.45
apt 14	LIVING_14	2425.97	611.86
	ROOM_14	11.70	436.50
	CORR_14	0.00	313.20
	TOILET_14	16.63	273.16
	WC_14	5.82	73.23
apt 15	LIVING_15	3090.29	743.25
	ROOM1_15	6.80	308.10
	ROOM2_15	156.99	401.36
	CORR_15	0.00	290.02
	TOILET_15	21.35	195.24
	WC_15	7.30	69.25
	CLOSET_15	0.01	116.50
apt 16	LIVING_16	3272.35	1072.86
	ROOM1_16	2.15	294.16
	ROOM2_16	2.86	284.19
	CORR_16	0.00	272.36
	TOILET_16	17.62	183.74
	WC_16	5.08	74.05
	CLOSET_16	0.00	20.47
common spaces	CORRIDOR1	0.00	0.00
	STAIRWELL1	0.67	0.00

[kWh/y]	ZONE	Q heating	Q cooling
apt 25	LIVING_25	3143.75	1053.00
	ROOM1_25	69.20	524.31
	ROOM2_25	73.48	386.02
	ROOM3_25	82.99	415.61
	CORR_25	0.00	250.52
	TOILET_25	237.66	117.05
	WC_25	41.77	60.27
	CLOSET_25	0.04	20.48
apt 26	LIVING_26	2488.52	942.30
	ROOM_26	12.01	490.90
	CORR_26	0.00	282.14
	TOILET_26	34.90	193.35
	WC_26	54.26	66.98
	CLOSET_26	0.03	33.08
apt 27	LIVING_27	2449.07	1061.52
	ROOM_27	4.39	453.37
	CORR_27	0.00	260.03
	TOILET_27	43.51	201.84
	WC_27	42.88	67.20
	CLOSET_27	0.01	32.87
apt 28	LIVING_28	3168.20	883.84
	ROOM1_28	8.31	445.79
	ROOM2_28	398.04	361.20
	CORR_28	0.00	268.91
	TOILET_28	255.67	67.33
	WC_28	29.54	35.53
	CLOSET1_28	0.03	34.54
	CLOSET2_28	0.03	13.91
apt 29	LIVING_29	2319.05	455.02
	ROOM_29	3.12	331.89
	CORR_29	0.00	186.31
	TOILET_29	136.63	84.33
	WC_29	7.76	34.16
	CLOSET_29	0.01	41.14
apt 30	LIVING_30	2768.86	590.82
	ROOM_30	32.13	416.78
	CORR_30	0.00	286.96
	TOILET_30	74.70	237.07
	WC_30	27.37	65.34
apt 31	LIVING_31	3423.95	723.81
	ROOM1_31	19.27	298.69
	ROOM2_31	250.83	381.71
	CORR_31	0.00	262.90
	TOILET_31	120.14	162.67
	WC_31	38.42	59.42
	CLOSET_31	0.76	98.48
apt 32	LIVING_32	3050.51	893.94
	ROOM1_32	6.98	283.75
	ROOM2_32	6.80	264.16
	CORR_32	0.00	238.42
	TOILET_32	104.64	152.55
	WC_32	32.38	62.43
	CLOSET_32	0.00	18.18
common spaces	CORRIDOR3	0.00	0.00
	STAIRWELL3	3.00	0.00

A.7 Heating and cooling demand of the building (2014)

[kWh/y]	ZONE	Q heating	Q cooling
apt 1	LIVING_1	2707.99	1302.31
	ROOM1_1	12.43	592.14
	ROOM2_1	10.36	457.85
	ROOM3_1	17.71	450.23
	CORR_1	1.51	220.52
	TOILET_1	223.03	98.50
	WC_1	48.44	51.77
	CLOSET_1	0.35	18.67
apt 2	LIVING_2	2051.09	1016.92
	ROOM_2	14.14	388.97
	CORR_2	0.17	250.51
	TOILET_2	56.22	170.21
	WC_2	106.00	45.62
	CLOSET_2	0.53	26.14
apt 3	LIVING_3	1752.93	956.71
	ROOM_3	4.68	442.18
	CORR_3	0.88	195.10
	TOILET_3	54.06	167.36
apt 4	LIVING_4	2526.73	942.24
	ROOM1_4	5.64	428.24
	ROOM2_4	220.00	327.41
	CORR_4	0.85	220.66
	TOILET_4	246.10	49.40
	WC_4	38.41	30.61
	CLOSET1_4	0.01	39.70
	CLOSET2_4	0.17	9.85
apt 5	LIVING_5	2100.49	589.22
	ROOM_5	3.52	350.03
	CORR_5	0.77	160.77
	TOILET_5	141.14	82.46
	WC_5	11.55	30.67
	CLOSET_5	0.03	31.75
apt 6	LIVING_6	2205.16	639.28
	ROOM_6	9.24	434.13
	CORR_6	0.12	265.28
	TOILET_6	98.20	197.91
	WC_6	33.37	58.00
apt 7	LIVING_7	2751.17	774.74
	ROOM_7	39.40	324.07
	CORR_7	0.34	220.44
	TOILET_7	101.29	120.15
	WC_7	61.31	53.07
	CLOSET_7	3.19	130.75
apt 8	LIVING_8	2698.70	1141.19
	ROOM1_8	4.60	311.72
	ROOM2_8	3.05	308.85
	CORR_8	0.96	211.46
	TOILET_8	129.78	116.66
	WC_8	41.81	50.26
	CLOSET_8	0.03	12.59
common spaces	CORRIDOR0	0.00	0.00
	STAIRWELL0	4.89	0.00
	ENTRY1	0.12	0.00
	ENTRY2	17.47	0.00
	GARAGE	40.80	0.00

[kWh/y]	ZONE	Q heating	Q cooling
apt 9	LIVING_9	2638.63	1381.47
	ROOM1_9	8.36	608.84
	ROOM2_9	6.77	465.58
	ROOM3_9	10.60	463.17
	CORR_9	0.00	326.18
	TOILET_9	95.35	145.44
	WC_9	6.05	72.74
	CLOSET_9	0.00	24.94
apt 10	LIVING_10	1973.38	1020.54
	ROOM_10	2.38	478.04
	CORR_10	0.00	327.26
	TOILET_10	6.05	229.48
	WC_10	10.40	82.23
	CLOSET_10	0.00	37.42
apt 11	LIVING_11	1892.60	1153.47
	ROOM_11	1.92	412.22
	CORR_11	0.00	304.07
	TOILET_11	8.26	241.86
	WC_11	7.85	82.07
	CLOSET_11	0.00	37.25
apt 12	LIVING_12	2586.00	967.07
	ROOM1_12	2.32	434.48
	ROOM2_12	221.09	336.07
	CORR_12	0.00	318.07
	TOILET_12	74.92	88.97
	WC_12	3.87	44.38
	CLOSET1_12	0.00	42.80
	CLOSET2_12	0.00	15.60
apt 13	LIVING_13	2125.81	598.07
	ROOM_13	0.11	363.41
	CORR_13	0.00	237.30
	TOILET_13	27.59	111.96
	WC_13	2.11	42.78
	CLOSET_13	0.00	48.60
apt 14	LIVING_14	2140.43	655.58
	ROOM_14	5.04	473.61
	CORR_14	0.00	335.30
	TOILET_14	11.60	293.19
	WC_14	3.62	78.16
apt 15	LIVING_15	2686.39	800.56
	ROOM1_15	3.60	331.27
	ROOM2_15	96.04	436.16
	CORR_15	0.00	316.34
	TOILET_15	16.24	206.00
	WC_15	5.47	73.78
	CLOSET_15	0.01	123.40
apt 16	LIVING_16	2760.99	1167.06
	ROOM1_16	0.70	316.85
	ROOM2_16	1.28	307.95
	CORR_16	0.00	300.08
	TOILET_16	14.10	194.09
	WC_16	4.74	78.20
	CLOSET_16	0.00	22.69
common spaces	CORRIDOR1	0.00	0.00
	STAIRWELL1	0.29	0.00

[kWh/y]	ZONE	Q heating	Q cooling
apt 25	LIVING_25	2174.03	1256.22
	ROOM1_25	4.81	648.32
	ROOM2_25	4.85	480.03
	ROOM3_25	6.47	523.95
	CORR_25	0.00	295.85
	TOILET_25	139.77	139.11
	WC_25	23.32	68.94
	CLOSET_25	0.04	25.14
apt 26	LIVING_26	1746.52	1118.77
	ROOM_26	2.90	587.09
	CORR_26	0.00	320.24
	TOILET_26	16.67	218.44
	WC_26	26.10	76.66
	CLOSET_26	0.03	39.32
apt 27	LIVING_27	1724.25	1244.55
	ROOM_27	0.93	543.69
	CORR_27	0.00	295.34
	TOILET_27	22.53	231.12
	WC_27	19.27	76.91
	CLOSET_27	0.01	38.68
apt 28	LIVING_28	2307.64	1074.55
	ROOM1_28	1.49	543.15
	ROOM2_28	128.98	455.39
	CORR_28	0.00	319.45
	TOILET_28	151.89	80.12
	WC_28	16.07	42.25
	CLOSET1_28	0.03	40.87
	CLOSET2_28	0.02	17.33
apt 29	LIVING_29	1599.14	569.85
	ROOM_29	0.30	410.54
	CORR_29	0.00	225.80
	TOILET_29	71.73	101.14
	WC_29	4.18	40.71
	CLOSET_29	0.01	47.92
apt 30	LIVING_30	1978.33	733.17
	ROOM_30	3.91	520.04
	CORR_30	0.00	339.05
	TOILET_30	38.23	274.88
	WC_30	13.98	76.12
apt 31	LIVING_31	2539.70	869.43
	ROOM1_31	2.56	375.24
	ROOM2_31	58.50	492.93
	CORR_31	0.00	316.87
	TOILET_31	71.84	185.99
	WC_31	22.19	67.18
	CLOSET_31	0.75	117.77
apt 32	LIVING_32	2099.19	1070.49
	ROOM1_32	1.20	357.97
	ROOM2_32	0.97	340.51
	CORR_32	0.00	285.46
	TOILET_32	55.37	175.50
	WC_32	16.87	72.28
	CLOSET_32	0.00	21.05
common spaces	CORRIDOR3	0.00	0.00
	STAIRWELL3	0.33	0.00