Parametrical analysis for the evaluation of the technical and economic effectiveness of different refurbishment measures

Francesca Cappelletti – University IUAV of Venice, Venice, Italy
Paola Penna – Free University of Bozen/Bolzano, Bolzano, Italy
Piercarlo Romagnoni – University IUAV of Venice, Venice, Italy
Andrea Gasparella – Free University of Bozen/Bolzano, Bolzano, Italy

Abstract

One of the major aims in building energy refurbishment is to compare different solutions in order to achieve requirements of the law or improve the energy efficiency, but the priority of interventions and their effectiveness can be affected by the initial situation (weather conditions, geometry and shape of building, entity of transparent surfaces, and so on). In the present paper a reference building model has been simulated in order to calculate the primary energy need for heating and DHW production. The initial configuration of the building has been varied concerning the windows' size and orientation, the S/V ratio, the materials of the opaque envelope and the location. A total of 54 different reference buildings were obtained from the combination of the above alternatives. About 360 refurbishment packages have been analyzed for each reference building combining improvement measures on the opaque envelope and the transparent components, on the ventilation losses, and on the energy production system. The improvement packages have been analyzed from an economic and energetic perspective in order to draw up a priority list of investments and retrofit measurements.

1. Introduction

According to the International Energy Agency, the residential sector is mainly responsible for energy consumption (about 40% of the final energy demand). For that reason the Annex 56 activity has been recently approved with the purpose of analysing the potentiality of building renovation in energy saving.

In Italy two-thirds of the buildings were built before the adoption of the first energy legislations (Law no. 373 of 1976), and their energy performances are much lower than the law's prescriptions. For this reason energy retrofit actions present an huge potential in energy saving and they will represent the ever more predominant commitment of construction designers. To improve the energy behaviour of a building, a large number of interventions could be considered to achieve more energy-efficiency targets. The measures on the building envelope could reduce its global energy consumption significantly, by minimizing the thermal losses during the heating season and the solar gains through the windows during the cooling season. At the same time, the use of a more efficient system and RES-based solutions can lead to consistent energy savings. One of the major obstacles in building renovation is due to the financial aspect. For a single owner it is not clear how long it will take to get a return on the initial investment. Policy makers also aim to support the interventions which give the best energy advantages with the smallest need for economic incentives. Recently the European Commission has published the Commission Delegated Regulation EU 244/2012 (European Commission, 2012) which proposes a multi-objective methodology to find reasonable new energy requirements for buildings. In this methodology, called cost-optimal analysis, the aim is to identify the combination of strategies giving the best advantage in primary energy saving with the minimum life cycle cost, or Net Present Value (NPV). The optimal solution and the intermediate ones, as well as the optimal combination of retrofit measures, will depend on the characteristics of the starting reference case. Many approaches are described in the literature for comparing different retrofit measurements. In

some cases a great number of energy efficiency solutions is compared by means of simulation: this is the case of the analysis on the optimal thickness of insulation carried out for different buildings' characteristics, especially the glazing area and the glazing type (Kaynakli 2008, Kaynakli 2012, Özkan and Onan, 2011), and under different climatic conditions (Bolattürk 2008, Lollini *et al.* 2006). When a set of possibilities is composed in order to choose the best among them, some other methods have been investigated: some authors use the multi-criteria analysis (Alanne 2004, Ray 2004, Kaklauskas *et al.* 2005), others the multi-objective optimization (Asadi *et al.* 2012, Hamdy *et al.* 2012, Yang and Wang 2012, Zhu *et al.* 2012, Ihm and Krarti 2012) or the statistical sensitivity analysis (Heiselberg *et al.* 2009, Jaffal *et al.* 2009, Yildiz and Arsan 2011). Just a few authors have carried out a cost-benefit analysis (Hamdy *et al.* 2012, Ihm and Krarti 2012, Asadi *et al* 2012, Diakaki *et al.* 2010). Some of them analyze real cases studies (Jaggs and Palmer 2000, Alanne 2004, Kaklauskas *et al.* 2005, Asadi et al. 2012), some other uses many virtual models (Diakaki *et al.* 2010).

This paper analyzes a residential building model whose characteristics have been changed one at a time in order to obtain many reference models. The aim is to evaluate the contribution of each individual retrofit measure on a set of reference buildings, considering the energy needs and the corresponding cost impact, in order to list the measurement packages with reference to the Net Present Value, the energy performance and also the investment cost. The starting building models are obtained from an uninsulated single-storey module, by modifying the windows' size and orientation, the envelope materials and the ratio between the dispersing envelope and the conditioned volume. The analysis has been performed for three Italian localities situated in different climatic zones (Belluno, climatic zone F, Milan, climatic zone E and Pisa, climatic zone D) representative of the parts of Italy with relevant heating needs. Different retrofitting interventions such as the improvement of the thermal transmittance of the opaque and transparent envelope, the use of efficient energy conversion technologies and RES-based solutions, have been combined and each combination evaluated considering the energy needs and the total cost of the investment. The cost-optimal approach has been applied to all the cases and the Pareto front has been calculated for each reference building. Finally, the results have been elaborated to identify the combinations of the solutions which are the more cost and energy effective.

2. Reference buildings and energy efficiency measures

2.1 The reference cases

The reference case is a module with a squared floor of 100 m^2 and 3 m of internal height. The vertical walls are oriented towards the cardinal orientations and the opaque envelope is a simplified structure composed of a single massive layer of clay with a thermal resistance equal to 0.8 m^2 K W^{-1}. For windows a single-pane glass and a standard timber frame have been considered. A standard boiler coupled with radiators with an on-off regulation system has been considered. The characteristics of the envelope and the heating system have been summarized in Table 1.

Three different ratios between the dispersing envelope and the conditioned volume have been considered:

- S/V = 0.97 (one wall adjacent to another conditioned zone, considered as adiabatic);
- S/V = 0.63 (one wall and the floor adjacent to another conditioned zone, as adiabatic);
- S/V = 0.30 (one wall, the floor and the ceiling adjacent to another conditioned zone, as adiabatic)

Two different windows to floor ratio have been analysed (14.4 % and 28.8 %) and three possible orientations for all the windows have been considered (East, South, North). The considered climates were Belluno (HDD_{20} = 3043 K d), Milan (HDD_{20} = 2404 K d) and Pisa (HDD_{20} = 1694 K d), in the three colder Italian climatic areas (F, E and D respectively in the Italian classification; Dfc, Cfa and Cfa according to the Köppen classification).

The effect of the thermal bridges has been

considered, with a fixed value of 0.15 W m^{-1} K^{-1} for the walls, ceiling and floor corners and of 0.2 W m^{-1} K^{-1} for the windows perimeter, for all the examined cases. The infiltration rates have been calculated according to EN 12207:1999 (CEN, 1999) and EN 15242:2007 (CEN, 2007). The reference air tightness n_{50} is 7 (h^{-1}) and the infiltration rates, for the different glazing sizes and S/V ratios, are reported in Table 2.

CHARACTERISTICS OF OPAQUE ENVELOPE		
Thickness d (m)		0.2
Conductivity λ (W m^{-1} K^{-1})		0.25
Thermal Resistance R (m^2 K W^{-1})		0.80
Areal heat capacity κ (kJ m^{-2} K^{-1})		150
Density ϱ (kg m^{-3})		893
Specific heat capacity c (J kg^{-1} K^{-1})		840
CHARACTERISTICS OF WINDOWS		
Glazing	Single-pane glass U_{gl} = 5.693 W m^{-2} K^{-1}	
Frame	Metal without thermal break U_f = 3.2 W m^{-2} K^{-1}	
Ratio A_{win}/A_{fl}	Size 1: 14.4%	
	Size 2: 28.8%	
Orientation	East (E) / South (S) / North (N)	
CHARACTERISTICS OF HEATING SYSTEM		
	Max	Min
Power (kW)	24.3	10.7
On cycle flue losses	8.6 %	8.6 %
Off cycle flue losses	0.1 %	-
Jacket losses	1.2 %	-

Table 1 – Characteristics of the reference cases

Ratio S/V	Size 1 (14.4%)	Size 2 (28.8%)
0.3	0.062	0.124
0.63	0.130	0.260
0.97	0.200	0.400

Table 2 – Infiltration Rate (ach h-1) values according to the different characteristics of the reference buildings

2.2 Energy Efficiency Measures (EEMs)

To improve the thermal performance of the envelope, the following EEMs have been considered (Table 4):

- Application of external insulation layer (EPS with conductivity λ=0.04 W m^{-1} K^{-1}, specific heat c=1470 J kg^{-1} K^{-1} and density ϱ=40 kg m^{-3}) with five different thicknesses: 0.05 m, 0.10 m, 0.15 m, 0.20 m, 0.25 m;
- Substitution of the existing with better performing windows: two double and two triple respectively with two different solar heat gain coefficients and an aluminium frame with thermal break;
- Replacement of the boiler with a modulating or a condensing boiler and climatic regulation;
- Introduction of flat-plate solar thermal collectors coupled with a water storage tank of 300 l for Domestic Hot Water (DHW);
- Introduction of a mechanical ventilation system with heat recovery.

Although the replacement of the boiler is considered, the substitution of the emission system (kind and nominal capacity, in particular) is not planned. The air tightness of the building is assumed to improve with the substitution of the windows: in this case the infiltration rates become half of the values in Table 2. The reference for the prices of the different EEMs (Table 4) is the Regional Price List, RPL, of Lazio which has been chosen as a benchmark because it represents a possible reference for North and Central Italy.

3. The COST-EFFECTIVE analysis

The Primary Energy demand for space and DHW Heating (EPH) was calculated, according to the monthly quasi-steady-state method of UNI/TS 11300:2008, the Italian specification for the application of EN ISO 13790:2008. This allowed for the calculation of a consistent number of cases over a short time. The cost-effective analysis was carried out for each reference building according to the methodology proposed by the EU 244/2012. The Net Present Value (NPV) was evaluated for a calculation period of 30 years, considering the initial Investment Cost (IC), the annual running costs (composed by the Energy Cost and Maintenance Cost), the replacement cost (due to the periodic substitution of building elements) and

the residual value for the equipment with longer lifetimes.

The investment and operative costs and economic parameters are reported in Tables 3 and 4. The lifespan of the building elements and the maintenance costs refer to the values suggested by the EN 15459:2009 (CEN, 2009). A cost of 1000 euros has been considered for the replacement of a standard boiler. Each one of the 360 interventions per reference case has been evaluated in terms of NPV and EPH. The Pareto front (the configurations with the best NPV for a given EPH) has been isolated (Figure 1). In order to check the accuracy of the results, the Pareto front points of three reference cases with smaller windows oriented towards the east (S/V=0.3 Pisa, S/V=0.63 Milano, S/V=0.97 Belluno) were calculated by dynamic simulations with TRNSYS v.17.1 (SEL, 2012) showing good agreement (Figure 2). The interventions for the Pareto front points, ranked by decreasing energy demand, have been listed for the different starting buildings (tables 7a to 7c), just for the cases with small windows because of space reasons. From the tables, it can be noticed that the cost of the investment is continuously increasing.

The optimal combination (in bold) and so the investment costs, depends largely on the locality and just in some cases on the S/V ratio, on the windows' orientation and size. In some cases the investment cost of the optimum is similar, but the EPH reached is different: for example in Belluno the optimal EEMs are the same for east as for south orientation but the EPH demand reached is lower for south orientation as can be seen in Table 5.

In particular, in Milan the optimal intervention set remains the same in all the considered cases with the application of 15 cm of insulation, the substitution of the existing windows with DH window and the replacement of the standard boiler with a condensing one. The situation in Belluno does not present a single trend. What the common feature is for this location is that the solar collectors are never considered in the optimal configuration, nor the mechanical ventilation. In general for east and south orientation the cost-optimal combination is 15 cm of insulation, DH windows and condensing boiler, except for the case with S/V ratio of 0.97 where TH glazing is needed.

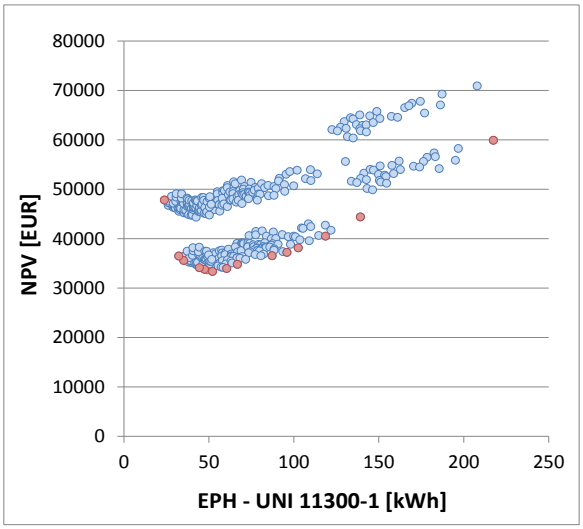

Fig. 1 – NPV and EPH [kWh year-1 m-2] for the case of Milan, Ratio S/V=0.63, windows East exposed with smaller dimension.

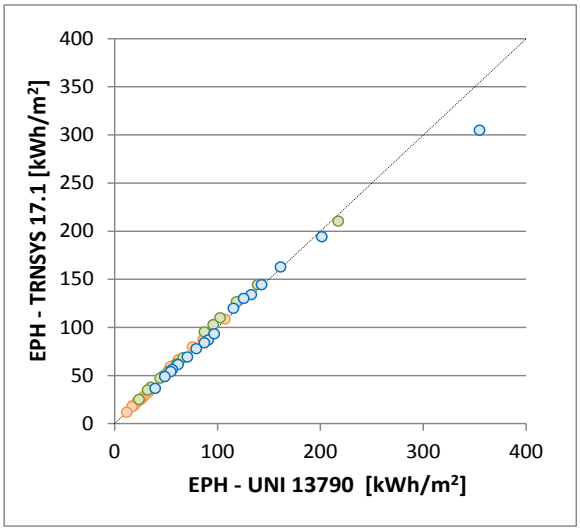

Fig. 2 – Comparison between the Primary Energy Demand for Heating and DHW (EPH) calculated according to EN 13790 and with Trnsys17.1

For Pisa the optimal combination of EEMs depends on the windows' size and orientation. In particular, for east and south orientations the optimal solution of EEMs requires the introduction of the solar collectors, while for north orientation the boiler replacement with a condensing one becomes a preferable solution. Considering the insulation, 10 or 15 cm are needed depending on the size of windows and on their orientation. Regarding the type of glazing the DH is needed for all the orientation except for south.

Opaque Envelope: insulation layer thermal characteristic						**Cost (EUR m^{-2})**
thickness x* (cm)	5	10	15	20	25	IC_{VW} = 1.6 x* + 38.53
U (W m^{-2} K^{-1})	0.45	0.29	0.21	0.17	0.14	IC_{HW} = 1.88 x* + 8.19
Windows			U_{gl} - U_f (W m^{-2} K^{-1})		SHGC	**Cost (EUR m^{-2})**
DH – Double, high SHGC (4/9/4, krypton, low-e)			1.140 – 1.2		0.608	IC_{DH} = 404.33
DL – Double, low SHGC (6/16/6, krypton, low-e)			1.099 – 1.2		0.352	IC_{DL} = 439.06
TH – Triple, high SHGC (6/12/6/12/6 krypton, low-e)			0.613 – 1.2		0.575	IC_{TH} = 477.65
TL – Triple, low SHGC (6/14/4/14/6 argon, low-e)			0.602 – 1.2		0.343	IC_{TL} = 454.49

Heating System: Boiler					
	Power max/min (kW)	On cycle flue losses	Off cycle flue losses	Jacket losses	**Cost (EUR)**
Modulating MDL	26.7/11.7	6%	0.1%	1.2%	IC_{MDL}= 1500
Condensing CND	24.3/8.4	2.1/0.3%	0.1%	0.3%	IC_{CND} = 2000

Thermal Solar System (SS)					
Absorber area (m^2)	Orientation	Slope	Heat loss coefficients a_1 / a_2 (W m^{-2} K^{-2})	Zero-loss efficiency	**Cost (EUR)** including tank
4.66	South	30°	4.16 / 0.0073	84 %	IC_{SS} = 2500

Mechanical ventilation system (MVS)		
Ventilation Rate (m^3 h^{-1})	Power (W)	**Cost (EUR)**
150	59.7	IC_{MV} = 6000

Table 3 – Energy Efficiency Measures and the related Investment Costs without VAT.

Fuel Cost [1]	85 EUR cent Sm^{-3}
Fuel Lower Heating Value [2]	32.724 MJ Sm^{-3}
Electricity Cost [1]	6.94 EUR cent MJ$_{el}^{-3}$
Increase Fuel price [3]	2.8%
Increase Electricity price [3]	1.71%
VAT	10%
Real Interest Rate	3%

[1] Autorità per l´Energia Elettrica e il Gas, 2011, *Relazione annuale sullo stato dei servizi e sull'attività svolta,* Milan, Italy
[2] Ministry of Economic Development, 2011, *Bilancio Energetico Nazionale 2010*, Rome.
[3] EU Enery Trends to 2030, update 2009. European Union 2010.

Table 4 – Costs and Parameters for the economic analysis

	S/V	North	East	South
Belluno	0.3	52	45	34
	0.63	65	59	47
	0.97	72	71	59
Milan	0.3	49	41	31
	0.63	61	52	41
	0.97	75	65	54
Pisa	0.3	33	26	41
	0.63	47	35	56
	0.97	49	58	61

Table 5 – Primary Energy demand for Heating and DHW for cost-optimal cases (small windows)in kWh/m2

In this case the replacement of the windows is not needed to achieve the cost-optimal level.

4. Conclusions

In this paper a cost-optimal analysis has been carried out on a set of reference residential building models in order to define a list of prior retrofit interventions. The primary energy demand for heating and DHW and the Net Present Value have been calculated for different localities. For each reference case it was possible to identify the cost-optimal solution and the configurations with the best *NPV* for a given *EPH* which lay on the Pareto front. The investment cost, always increasing with decreasing *EPH* demand, for the optimal combination of EEMs depends on the locality. In some climates (e.g. Milan) the starting case configuration (S/V ratio, windows size and orientation) does not influence the optimal combination of EEMs. This methodology can give a contribution in guiding the choices of interventions for the existing buildings' refurbishment.

5. Nomenclature

Symbols

A	area	(m^2)
HDD_{20}	heating degree days	(K d)
IC	investment cost	(Eur m^{-2})
NPV	Net Present Value	(Eur)
EPH	Primary Energy for Heating	(kWh/m^2)
SHGC	solar heat gain coefficient	(-)
S	dispersing envelope surface	(m^2)
U	thermal transmittance	(W m^{-2} K^{-1})
V	conditioned volume of building	(m^3)
VAT	Value Added Tax	(%)

Greek symbols

α	solar absorptance	(-)
λ	thermal conductivity	(W m^{-1} K^{-1})

Subscripts

f	frame	H	horizontal
fl	floor	**W**	wall
gl	glazings	win	window
V	vertical		

References

Alanne, K. 2004. Selection of renovation actions using multi-criteria knapsack model, Automation in construction, 13, 377–391.

Asadi, E., Gameiro, M., Henggeler, C., & Dias, L. 2012. A multi-objective optimization model for building retrofit strategies using TRNSYS simulations, GenOpt and MATLAB. Building and Environment, 56, 370–378.

Asadi, E., Gameiro, M., Henggeler, C., & Dias, L. 2012. Multi-objective optimization for building retrofit strategies : A model and an application. Energy & Buildings, 44, 81–87.

Bolattürk A., 2008. Optimization insulation thickness for building walls with respect to cooling and heating degree-hours in the warmest zone of the Turkey, Building Environment, vol. 43.

Diakaki, C., Grigoroudis, E., Kabelis, N., Kolokotsa, D., Kalaitzakis, K., & Stavrakakis, G. 2010. A multi-objective decision model for the improvement of energy efficiency in buildings. Energy, 35(12).

European Commission, 2012. Commission Delegated Regulation EU 244/2012, Official Journal of European Union, L81/18, 20/03/2012.

Hamdy, M., Hasan, A., & Siren, K. 2011. Applying a multi-objective optimization approach for Design of low-emission cost-effective dwellings. Building and Environment, 46(1), 109–123.

Heiselberg P., Brohus H., Hesselholt H., Rasmussen H., Seinre E., Thomas S. 2009, Application of sensitivity analysis in design of sustainable buildings, Renewable Energy, vol. 34, p. 2030-2036.

Ihm, P., & Krarti, M. 2012. Design optimization of energy efficient residential buildings in Tunisia. Building and Environment, 58, 81–90.

Jaffal, I., Inard, C., & Ghiaus, C. 2009. Fast method to predict building heating demand based on the design of experiments, 41, 669–677.

Jaggs, M., & Palmer, J. 2000. Energy performance indoor environmental quality retrofit — a European diagnosis and decision making method for building refurbishment, 97–101.

Kaynakli O., 2008. A study on residential heating energy requirement and optimum insulation thickness, Renewable Energy, vol. 33.

Kaynakli O., 2012. A review of the economical and optimum thermal insulation thickness for building applications, Renewable and Sustainable Energy Review, vol. 16.

Kaklauskas, A., Zavadskas, E. K., & Raslanas, S. 2005. Multivariant design and multiple criteria analysis of building refurbishments, 37.

Lollini R., Barozzi B., Fasano G., Meroni I., Zinzi M., 2006. Optimization of opaque components of the building envelope. Energy, economic and environmental issues, Building Environment, vol. 41, p. 1001-1013.

Özkan D.B., Onan C., 2011. Optimization of insulation thickness for different glazing areas in buildings for various climatic regions in Turkey, Applied Energy, vol. 88, p. 1331-1342.

Rey, E. 2004. Office building retrofitting strategies: multicriteria approach of an architectural and technical issue, 36, 367–372.

Solar Energy Laboratory, 2012. TRNSYS 17.1 Documentation, Madison, Wisconsin.

Yang, R., & Wang, L. 2012. Multi-objective optimization for decision-making of energy and comfort management in building automation and control. Sustainable Cities and Society, 2(1).

Yıldız, Y., & Durmus, Z. 2011. Identification of the building parameters that influence heating and cooling energy loads for apartment buildings in hot-humid climates, 36, 4287–4296.

Zhu, J., Chew, D. A. S., Lv, S., & Wu, W. 2012. Optimization method for building envelope design to minimize carbon emissions of building operational energy consumption using orthogonal experimental design (OED). Habitat International, 1–7.

INSULATION		GLAZING SYSTEM		BOILER		Domestic Hot Water		VENTILATION	
INS		GL		BOI		DHW		V	
0	No insulation	0	Single pane	0	Standard	0	Standard boiler	0	Natural
1	5 cm	1	Double H	1	Modulating	1	Solar system	1	Mechanical
2	10 cm	2	Double L	2	Condensing				
3	15 cm	3	Triple H						
4	20 cm	4	Triple L						
5	25 cm								

Table 6 – Reading code for tables 7

S/V = 0.3

N

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
2	0	0	0	0	4917
3	0	0	0	0	5582
2	0	1	0	0	6758
2	0	2	0	0	7500
3	0	2	0	0	8165
4	0	2	0	0	8830
2	1	0	0	0	11322
3	1	0	0	0	11987
4	1	0	0	0	12652
2	1	1	0	0	13163
2	1	2	0	0	13904
3	1	2	0	0	14569
4	**1**	**2**	**0**	**0**	**15235**
4	3	2	0	0	16396
5	3	2	0	0	17061
5	3	2	1	0	20768
5	3	2	1	1	29662

E/W

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
2	0	0	0	0	4917
3	0	0	0	0	5582
2	0	1	0	0	6758
3	0	1	0	0	7424
2	0	2	0	0	7500
3	0	2	0	0	8165
4	0	2	0	0	8830
2	1	0	0	0	11322
3	1	0	0	0	11987
2	1	1	0	0	13163
3	1	1	0	0	13828
2	1	2	0	0	13904
3	**1**	**2**	**0**	**0**	**14569**
4	3	2	0	0	16396
5	3	2	0	0	17061
5	3	2	1	0	20768
5	3	2	1	1	29662

S

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
2	0	0	0	0	4917
3	0	0	0	0	5582
2	0	1	0	0	6758
3	0	1	0	0	7424
2	0	2	0	0	7500
3	0	2	0	0	8165
4	0	2	0	0	8830
2	1	0	0	0	11322
3	1	0	0	0	11987
2	1	1	0	0	13163
3	1	1	0	0	13828
2	1	2	0	0	13904
3	**1**	**2**	**0**	**0**	**14569**
4	1	2	0	0	15235
4	3	2	0	0	16396
5	3	2	0	0	17061
4	3	2	1	0	20102
5	3	2	1	0	20768
5	3	2	1	1	29662

S/V = 0.63

N

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	1	0	0	11427
3	0	2	0	0	12168
2	1	0	0	0	14291
3	1	0	0	0	15990
2	1	1	0	0	16132
2	1	2	0	0	16873
2	3	2	0	0	18034
3	1	2	0	0	18572
3	**3**	**2**	**0**	**0**	**19734**
4	3	2	0	0	21433
5	3	2	0	0	23132
4	3	2	1	0	25139
5	3	2	1	0	26838
5	4	2	1	1	35366

E/W

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	1	0	0	11427
3	0	2	0	0	12168
2	1	0	0	0	14291
3	1	0	0	0	15990
2	1	1	0	0	16132
2	1	2	0	0	16873
3	**1**	**2**	**0**	**0**	**18572**
4	1	2	0	0	20272
4	3	2	0	0	21433
5	3	2	0	0	23132
4	3	2	1	0	25139
5	3	2	1	0	26838
5	3	2	1	1	35733

S

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
3	0	0	0	0	9585
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	1	0	0	11427
3	0	2	0	0	12168
3	1	0	0	0	15990
2	1	1	0	0	16132
2	1	2	0	0	16873
3	**1**	**2**	**0**	**0**	**18572**
4	1	2	0	0	20272
4	3	2	0	0	21433
5	1	2	0	0	21971
5	3	2	0	0	23132
4	3	2	1	0	25139
5	3	2	1	0	26838
5	3	2	1	1	35733

S/V = 0.97

N

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	1	0	0	15429
3	0	2	0	0	16171
4	0	2	0	0	18904
2	1	2	0	0	19842
2	3	1	0	0	20262
2	4	2	0	0	20637
2	3	2	0	0	21003
3	3	1	0	0	22995
3	4	2	0	0	23370
3	3	2	0	0	23737
4	**3**	**2**	**0**	**0**	**26470**
5	3	2	0	0	29203
5	3	2	1	0	32909
5	4	2	1	1	41437

E/W

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	1	0	0	15429
3	0	2	0	0	16171
2	1	2	0	0	19842
2	3	1	0	0	20262
2	3	2	0	0	21003
3	3	1	0	0	22995
3	**3**	**2**	**0**	**0**	**23737**
4	3	2	0	0	26470
5	3	2	0	0	29203
4	3	2	1	0	30176
5	3	2	1	0	32909
5	3	2	1	1	41804

S

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	1	0	0	15429
3	0	2	0	0	16171
2	3	1	0	0	20262
2	3	2	0	0	21003
3	3	1	0	0	22995
3	**3**	**2**	**0**	**0**	**23737**
4	3	2	0	0	26470
5	3	2	0	0	29203
4	3	2	1	0	30176
5	3	2	1	0	32909
5	3	2	1	1	41804

Tables 7a-7b-7c - Measures Packages ordered by Energy Demand for Heating and DHW from the higher till the lower. 7a- Belluno - Cases with small windows(S1).

S/V = 0.3

N

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
2	0	0	0	0	4917
3	0	0	0	0	5582
2	0	1	0	0	6758
2	0	2	0	0	7500
3	0	2	0	0	8165
2	1	0	0	0	11322
3	1	0	0	0	11987
2	1	1	0	0	13163
3	1	1	0	0	13828
2	1	2	0	0	13904
3	**1**	**2**	**0**	**0**	**14569**
4	1	2	0	0	15235
4	3	2	0	0	16396
4	3	0	1	0	17520
5	3	0	1	0	18185
4	3	2	1	0	20102
5	3	2	1	0	20768
5	3	2	1	1	29662

E/W

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
2	0	0	0	0	4917
3	0	0	0	0	5582
2	0	1	0	0	6758
2	0	2	0	0	7500
3	0	2	0	0	8165
2	1	0	0	0	11322
3	1	0	0	0	11987
2	1	1	0	0	13163
2	1	2	0	0	13904
3	**1**	**2**	**0**	**0**	**14569**
4	3	0	1	0	17520
5	3	0	1	0	18185
4	3	2	1	0	20102
5	3	2	1	0	20768
5	3	2	1	1	29662

S

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
2	0	0	0	0	4917
3	0	0	0	0	5582
2	0	1	0	0	6758
2	0	2	0	0	7500
3	0	2	0	0	8165
2	1	1	0	0	13163
2	1	2	0	0	13904
3	**1**	**2**	**0**	**0**	**14569**
3	1	0	1	0	15693
4	1	0	1	0	16358
5	1	0	1	0	17024
4	3	0	1	0	17520
5	3	0	1	0	18185
3	1	2	1	0	18276
4	1	2	1	0	18941
5	1	2	1	0	19606
4	3	2	1	0	20102
5	3	2	1	0	20768
4	3	2	1	1	28997
5	3	2	1	1	29662

S/V = 0.63

N

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	2	0	0	12168
2	1	0	0	0	14291
2	1	1	0	0	16132
2	1	2	0	0	16873
3	**1**	**2**	**0**	**0**	**18572**
3	3	2	0	0	19734
4	3	2	0	0	21433
4	3	2	1	0	25139
5	3	2	1	0	26838
5	3	2	1	1	35733

E/W

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	2	0	0	12168
2	1	1	0	0	16132
2	1	2	0	0	16873
3	**1**	**2**	**0**	**0**	**18572**
4	1	2	0	0	20272
4	3	2	0	0	21433
4	3	2	1	0	25139
5	3	2	1	0	26838
5	3	2	1	1	35733

S

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	1	0	0	11427
3	0	2	0	0	12168
2	1	1	0	0	16132
2	1	2	0	0	16873
3	**1**	**2**	**0**	**0**	**18572**
4	1	0	1	0	21395
4	3	0	1	0	22557
4	1	2	1	0	23978
4	3	2	1	0	25139
5	1	2	1	0	25677
5	3	2	1	0	26838
4	3	2	1	1	34034
5	3	2	1	1	35733

S/V = 0.97

N

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	1	0	0	15429
3	0	2	0	0	16171
2	1	1	0	0	19101
2	1	2	0	0	19842
3	1	1	0	0	21834
3	**1**	**2**	**0**	**0**	**22575**
3	3	2	0	0	23737
4	3	2	0	0	26470
4	3	2	1	0	30176
5	3	2	1	0	32909
5	3	2	1	1	41804

E/W

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	1	0	0	15429
3	0	2	0	0	16171
2	1	1	0	0	19101
2	1	2	0	0	19842
3	1	1	0	0	21834
3	**1**	**2**	**0**	**0**	**22575**
4	1	2	0	0	25309
4	3	2	0	0	26470
4	3	2	1	0	30176
5	3	2	1	0	32909
5	3	2	1	1	41804

S

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	1	0	0	15429
3	0	2	0	0	16171
2	1	1	0	0	19101
2	1	2	0	0	19842
3	**1**	**2**	**0**	**0**	**22575**
4	1	2	0	0	25309
4	3	2	0	0	26470
4	1	2	1	0	29015
4	3	2	1	0	30176
5	1	2	1	0	31748
5	3	2	1	0	32909
5	3	2	1	1	41804

7b – Milano - Cases with small windows(S1).

S/V = 0.3

N

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
0	0	1	0	0	2224
0	0	2	0	0	2965
2	0	0	0	0	4917
2	0	1	0	0	6758
2	0	2	0	0	7500
3	0	2	0	0	8165
2	1	1	0	0	13163
2	1	2	0	0	13904
3	1	2	0	0	14569
3	**1**	**0**	**1**	**0**	**15693**
4	1	0	1	0	16358
4	3	0	1	0	17520
5	3	0	1	0	18185
4	3	2	1	0	20102
5	3	2	1	0	20768
5	3	2	1	1	29662

E/W

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
0	0	1	0	0	2224
0	0	2	0	0	2965
2	0	0	0	0	4917
2	0	1	0	0	6758
2	0	2	0	0	7500
3	0	2	0	0	8165
2	1	2	0	0	13904
2	1	0	1	0	15028
3	**1**	**0**	**1**	**0**	**15693**
4	1	0	1	0	16358
4	3	0	1	0	17520
4	1	2	1	0	18941
4	3	2	1	0	20102
5	3	2	1	0	20768
5	3	2	1	1	29662

S

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
0	0	1	0	0	2224
0	0	2	0	0	2965
2	0	1	0	0	6758
2	0	2	0	0	7500
3	**0**	**2**	**0**	**0**	**8165**
3	0	0	1	0	9289
4	0	0	1	0	9954
2	1	0	1	0	15028
3	1	0	1	0	15693
4	1	0	1	0	16358
3	3	0	1	0	16855
5	1	0	1	0	17024
3	1	1	1	0	17534
3	1	2	1	0	18276
4	1	2	1	0	18941
3	3	2	1	0	19437
5	1	2	1	0	19606
4	3	2	1	0	20102
5	3	2	1	0	20768
3	1	2	1	1	27170
4	1	2	1	1	27836
3	3	2	1	1	28332
5	1	2	1	1	28501
4	3	2	1	1	28997
5	3	2	1	1	29662

S/V = 0.63

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	2	0	0	12168
2	1	1	0	0	16132
2	1	2	0	0	16873
3	**1**	**2**	**0**	**0**	**18572**
3	1	0	1	0	19696
3	3	0	1	0	20857
4	1	0	1	0	21395
4	3	0	1	0	22557
3	3	2	1	0	23440
4	3	2	1	0	25139
5	3	2	1	0	26838
5	3	2	1	1	35733

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	0	2	0	0	10469
3	0	2	0	0	12168
2	1	2	0	0	16873
3	1	2	0	0	18572
3	**1**	**0**	**1**	**0**	**19696**
4	1	0	1	0	21395
4	3	0	1	0	22557
4	1	2	1	0	23978
4	3	2	1	0	25139
5	3	2	1	0	26838
4	3	2	1	1	34034
5	3	2	1	1	35733

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	6187
2	0	0	0	0	7886
2	0	1	0	0	9727
2	**0**	**2**	**0**	**0**	**10469**
3	0	2	0	0	12168
3	0	0	1	0	13291
2	1	0	1	0	17997
3	1	0	1	0	19696
3	3	0	1	0	20857
4	1	0	1	0	21395
3	1	2	1	0	22279
4	1	1	1	0	23237
3	3	2	1	0	23440
4	1	2	1	0	23978
4	3	2	1	0	25139
5	1	2	1	0	25677
5	3	2	1	0	26838
4	1	2	1	1	32872
4	3	2	1	1	34034
5	1	2	1	1	34572
5	3	2	1	1	35733

S/V = 0.97

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	2	0	0	16171
2	1	1	0	0	19101
2	1	2	0	0	19842
3	**1**	**2**	**0**	**0**	**22575**
3	3	2	0	0	23737
3	3	0	1	0	24860
4	3	0	1	0	27594
3	3	2	1	0	27443
4	3	2	1	0	30176
5	3	2	1	0	32909
5	3	2	1	1	41804

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	0	2	0	0	16171
2	1	2	0	0	19842
3	**1**	**2**	**0**	**0**	**22575**
3	1	0	1	0	23699
3	3	0	1	0	24860
4	1	0	1	0	26432
3	1	2	1	0	26281
4	3	0	1	0	27594
4	1	2	1	0	29015
4	3	2	1	0	30176
5	1	2	1	0	31748
5	3	2	1	0	32909
5	3	2	1	1	41804

INS	GL	BOI	DHW	MV	I
0	0	0	0	0	382
1	0	0	0	0	8122
2	0	0	0	0	10855
2	0	1	0	0	12696
2	0	2	0	0	13437
3	**0**	**2**	**0**	**0**	**16171**
3	1	0	1	0	23699
3	3	0	1	0	24860
4	1	0	1	0	26432
4	3	0	1	0	27594
4	1	1	1	0	28273
4	1	2	1	0	29015
4	3	2	1	0	30176
5	1	2	1	0	31748
5	3	2	1	0	32909
4	3	2	1	1	39071
5	1	2	1	1	40643
5	3	2	1	1	41804

7c - Pisa – Cases with small windows(S1)