Study of the energy performance of a retrofitting office

Paolo Valdiserri – CIRI Edilizia Costruzioni, Università di Bologna – paolo.valdiserri@unibo.it

Abstract

Building retrofitting is the most feasible and cost-effective method to improve building energy efficiency. To this aim, the building envelope should be equipped with new windows having low thermal transmission coefficients and/or with insulation material in the external partitions. This approach leads to considerable energy saving, but at the same time if the users do not properly ventilate the occupied spaces, it results in a worsening of indoor air quality.

The paper presents a comparative analysis of two different strategies to enhance the energy performance of an existing building. The first is to reduce the heat transfer by transmission (i.e. use of low-emissivity glass) and the second to decrease the heat transfer by ventilation (i.e. installation of a heat recovery). The study has been applied to an office block, located in the city of Bologna, Italy. Potential energy savings were calculated by dynamic simulation using Trnsys software. To this purpose, a reference office was selected and then the following cases were studied. The first one took into account the replacement of all the windows, the second one consisted in installing a total energy ventilation recovery system and the last one contemplated both the solutions. Finally, an evaluation of the simple payback time and the net present value was performed.

1. Introduction

Buildings consume around 40% of Europe's energy needs and account for 36% of EU CO_2 emissions. Member States of the European Union are required to implement energy efficiency measures for buildings under the Energy Performance of Building Directive. In order to reduce this consumption and pursue the goal imposed by the European Union, Italy issued several Legislative Decrees in particular no.192/2005, no.311/2006 and no.28/2011. The need to reduce energy consumption in buildings implies the use of considerable thermal insulation, but at the same time, in the absence of a suitable ventilation system, it could result in a worsening of indoor air quality. A healthy life imposes a good indoor air quality especially where people spend a considerable amount of time, so adequate air exchanges should be guaranteed to reduce indoor pollution. Due to the increase of insulation and the decrease of the thermal transmission coefficients, ventilation constitutes a growing part of the heating demand; between 20–50% for new and retrofitted buildings, depending on the building's insulation, compactness, air change rate, indoor heat sources, indoor set points and outdoor climate. Heat recovery (HRV) from exhaust air in buildings is considered an important strategy to reduce the heat transfer by ventilation and generate consequent energy savings. The principle is to recover heat from the exhaust air and to transfer it to the supply air through a heat exchanger. Primary energy savings of HRV can be highly significant, depending on the type of heat supply system, the airtightness of buildings, and the use of electricity to operate the HRV system.

In Italy, like several other European countries, the existing dwellings constructed before the application of energy saving regulations, represent the majority of the edifices. Therefore, building renovation becomes a key strategy to reduce energy consumption and costs.

In the present work, simulations of an existing office building (where some energy saving methods were applied) were performed.

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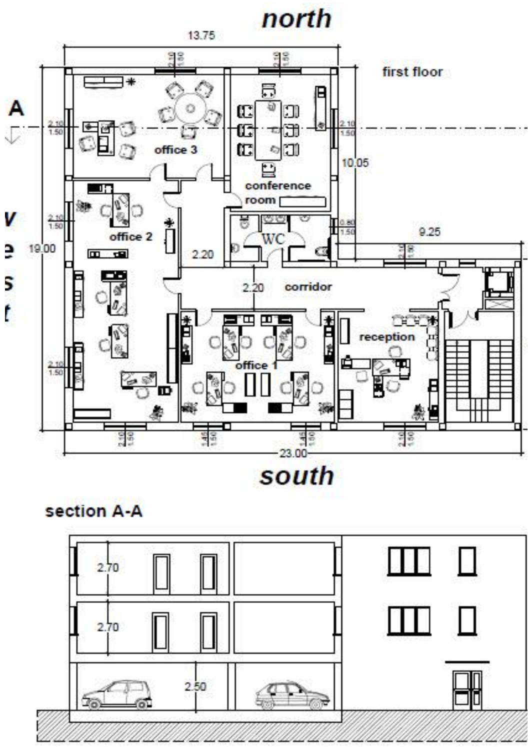


Figure 1 – Plant and section of the office block

The simulations were conducted using the Trnsys commercial code at the time step of 15 minutes. Trnsys is an extensible simulation environment for the transient simulation of energy systems including multizone buildings. It is used to validate new energy concepts, design and simulation of buildings and their equipment, including control strategies, occupant behaviour, and alternative energy systems (wind, solar, photovoltaic, hydrogen systems, etc.).

2. Description of the building under investigation

The numerical model has been applied to an office building, located in Bologna (Italy). The construction, shown in Figure 1, is a three-storey building having heated offices on the first and second floor and parking lots on the ground floor (not heated). The floor surface of the two offices is 534 m^2; each floor is composed by one reception, three offices and a conference room. Table 1 illustrates the surface of each room and the acronyms used in the calculations.

Table 1 – surface of each room of the office and list of acronyms adopted in the simulations.

Room	Surface, [m^2]	Acronym
Reception	27.84	R1
Office 1	45.24	O1
Office 2	66.25	O2
Office 3	40.50	O3
Conference room	33.50	CR

Table 2 highlights the thermal characteristics of the building envelope (between the heated offices and the unheated spaces).

Table 2 - Values of thermal transmittance referred to the envelope elements.

Envelope element	Thermal transmittance U [W m^{-2} K^{-1}]
Outside walls	0.51
First floor / Roof	0.44 / 0.46
Internal ceiling	1.57
Windows	2.85

The heating system is supposed to operate 14 hours a day from 5 a.m. to 7 p.m from Monday to Friday. In this period, it is set to maintain the internal temperature of 20°C. The ventilation system is switched on from 7 a.m. to 7 p.m. every working day. In each floor, the fresh air enters the reception, the conference room and the three offices at the flow rate illustrated in Table 3 and extracted from the corridor. Whilst the ventilation is working, a humidification system operates to provide the relative humidity of 50% in the offices.
During the night and at the weekend, the heating system is able to provide the temperature of 16°C without any humidity control and with the ventilation system switched off.
Table 3 also includes the occupancy and the personal computers (PCs) connected in each office

during working hours (7 a.m. to 7 p.m. – Monday to Friday).

Table 3 – Ventilation flow rate, number of people and computers during working hours (7 a.m. to 7 p.m. – Monday to Friday).

Room	**Flow rate [$m^3\ h^{-1}$]**	**People and PCs**
Reception	150	3 - 1
Office 1	244	4 - 4
Office 2	358	4 - 4
Office 3	219	1 - 1
Conference room	192	2 - 0

In the present study, the performance of the reference case (Case 0) and of other three cases of retrofitting (Case 1, 2 and 3) are simulated and calculated.

Trnsys simulations were conducted with a time step of 15 minutes. The weather data (such as external temperature, solar radiation etc.) are derived from the Meteonorm database. The solar gains are calculated by the software Trnsys from the input of the Meteonorm file.

All the cases under investigation refer to the period when the heating system is switched on (winter period) that is for Bologna from October 15 to April 15.

3. Description of the simulated cases

3.1 Case 0

This is the reference case and represents the "pre-retrofitting" condition, characterized by the features illustrated in the previous paragraph. All the windows have a thermal transmittance of 2.85 Wm^2K^{-1}. The ventilation operates at the flow rate illustrated in table 3 with total external fresh air. The infiltration is set at the rate of 0.4 vol h^{-1}.

3.2 Case 1

Case 1 refers to the replacement of all the windows with new frames and low low-emissivity glass having a thermal transmittance of 1.6 Wm^2K^{-1}. The ventilation works at the same conditions as Case 0, but the infiltration is reduced to the rate of 0.2 vol h^{-1}.

3.3 Case 2

This is characterized by the introduction of a heat recovery ventilation system that can save energy from the ejected air, as depicted in Figure 2. The windows remain the same as Case 0.

The model employs a total energy recovery with an enthalpy wheel silica gel loaded, able to exchange both heat and humidity.

The sensible and latent effectiveness of the heat recovery system are defined as follows:

$$\varepsilon_S = \frac{T_S - T_O}{T_R - T_O} \qquad \varepsilon_L = \frac{X_S - X_O}{X_R - X_O}$$

where:

T_S and X_S are respectively the temperature and the humidity ratio of the supply air.

T_O and X_O represent the temperature and the humidity ratio of the external air (outdoor air).

T_R and X_R are respectively the temperature and the humidity ratio of the extracted air (return air).

The heat recovery efficiency values adopted in the simulations derived from the Jeong and Mumma correlation. The authors developed effectiveness correlations as a function of inlet air temperature, relative humidity, and face velocity. In the simulation, the heat recovery is designed to work with a time variable effectiveness and a face velocity of 3 m s^{-1}. The ventilation system extracts air from the two corridors, with the flow rate of 1163 $m^3\ h^{-1}$ for each floor. The fresh air enters the two receptions, the two conference rooms and the six offices at the flow rate illustrated in Table 3. The air leaves the heat recovery at the temperature T_S and at the humidity ratio X_S which are a time dependent values.

The electric power needed for the heat recovery at the design condition is of 500 W.

Finally, it is important to highlight that 0.4 air changes per hour for infiltration are considered.

3.4 Case 3

Case 3 contemplates both the replacement of the windows (described in Case1) and the introduction of the total energy recovery (described in Case 2). This case considers a rate of 0.2 vol h^{-1} for infiltration.

4. Simulation results

4.1 Case 0

The energy need for heating and humidification in the winter period is shown in Table 4:

Table 4 – Case 0: Energy need for heating and humidification

	Energy need [kWh] for	
Month	**Heating**	**Humidification**
October	1395	78
November	6022	716
December	9668	1482
January	11330	2002
February	8003	1419
March	4419	997
April	669	42
TOTAL	**41505**	**6736**

The amount of energy need requested for ventilation and infiltration is equal to 14674 kWh and 9718 kWh, respectively. Given an energy efficiency of 85% for the heating and humidification system, the primary energy for heating and humidification is 48830 kWh and 7925 kWh, respectively.

4.2 Case 1

The energy need for heating and humidification in the winter period can be seen in Table 5.
Since the new windows are placed, the infiltration is reduced and the energy need for infiltration becomes 4933 kWh. Considering energy efficiency of 85% for the heating and humidification system, the primary energy for heating and humidification is 40280 kWh and 6930 kWh respectively.

Table 5 – Case 1: Energy need for heating and humidification

	Energy need [kWh] for	
Month	**Heating**	**Humidification**
October	1112	62
November	4966	619
December	7986	1301
January	9423	1767
February	6599	1245
March	3613	862
April	539	34
TOTAL	**34238**	**5891**

4.3 Case 2

Table 6 shows the energy need for heating and humidification in the winter period:

Table 6 – Case 2: Energy need for heating and humidification

	Energy need [kWh] for	
Month	**Heating**	**Humidification**
October	813	17
November	4147	114
December	7007	265
January	8135	389
February	5734	258
March	2920	162
April	440	8
TOTAL	**29196**	**1213**

The energy need for ventilation is equal to 2185 kWh. Considering energy efficiency of 85% for the heating and humidification system, the primary energy for heating and humidification is 34348 kWh and 1428 kWh respectively. In this case, the electric energy need for heat recovery accounts for an additional 786 kWh. Considering a conversion coefficient of 0.46, the primary energy for the ventilation recovery system is 1709 kWh.

4.4 Case 3

The energy need for heating and humidification in the winter period for case 3 is highlighted in Table 7:

Table 7 – Case 3: Energy need for heating and humidification

	Energy need [kWh] for	
Month	**Heating**	**Humidification**
October	542	10
November	3090	60
December	5324	137
January	6229	190
February	4330	133
March	2120	89
April	320	6
TOTAL	**21954**	**626**

Considering energy efficiency of 85% for the heating and humidification system, the primary energy for heating and humidification is 25828 kWh and 736 kWh respectively. The primary energy for the recovery system is 1709 kWh.

4.5 Comparison between the different solutions

Table 8 shows the primary energy demands for the different cases analysed. The primary energy include the energy for heating, humidification and the operation of the total recovery.

Table 8 – Primary energy for heating, humidification and recovery electricity for the four different cases.

	Primary energy [kWh]			
Month	**Case 0**	**Case 1**	**Case 2**	**Case 3**
October	1733	1382	1146	819
November	7926	6571	5300	3993
December	13118	10926	8829	6699
January	15684	13165	10329	7852
February	11084	9227	7310	5510
March	6372	5265	3914	2885
April	837	675	657	514
TOTAL	**56754**	**47210**	**37485**	**28273**

A mere comparison of the primary energy request among the simulated cases shows that case 3 (where the combination of window replacement and the total energy recovery introduction) is the most efficient. The primary energy saved in the different scenarios is:

- Scenario 1 (Case 1 versus Case 0): 9544 kWh;
- Scenario 2 (Case 2 versus Case 0): 19270 kWh;
- Scenario 3 (Case 3 versus Case 0): 28481 kWh;
- Scenario 4 (Case 3 versus Case 1): 18937 kWh.

The latter scenario was included to evaluate the advantages of the heat recovery installation following the windows replacement.

5. Economic issues

The two retrofitting solutions presented in this study aim at decreasing energy demand and improving energy performance of the office block. Nevertheless, the application of energy saving measures usually needs to be evaluated in relation to economic assessments.

Simple Payback Time (SPBT) and Net Present Value (NPV) are used as financial parameters for evaluating the economic feasibility of the different approach.

$$SPBT = \frac{I_0}{S} \qquad NPV = -I_0 + \sum_{n=1}^{LS} \frac{S_n - C_n}{(1+r)^n}$$

where:
- I_0 is the initial investment cost of the project,
- S is the energy saving evaluated at year *0*,
- S_n is the energy saving for year n,
- C_n is the maintenance cost for year n,
- n is the time period,
- LS is the lifespan,
- r is the cost of capital.

The economic analysis was carried out for the retrofitting cases in the four different scenarios and was based on the technical-economic situation in Italy in 2014.
The following data have been used for the evaluation:
- cost of the energy: natural gas: 0.10 €/kWh, electricity: 0.18 €/kWh,
- cost for replacement windows: 21 000 €,
- cost for installing the heat recovery system: 14 000 €.

The yearly cost for heating, humidification and electricity for heat recovery are reported below:
Case 0: €5,675
Case 1: €4,721
Case 2: €3,885
Case 3: €2,964

In Table 9 the initial investment, the energy saving obtained during the first year since the retrofitting, and the SPT are reported.

Table 9 – Initial investment, energy saving during the first year and Simple Payback Time for the four different scenarios.

	Sc. 1	Sc. 2	Sc. 3	Sc. 4
Investment (€)	21000	14000	35000	14000
Energy saving (€)	954	1790	2711	1757
SPBT (years)	22.0	7.8	12.9	8.0

NPV is calculated for each scenario considering different increments of the cost of energy (2%, 4% or 6%). In the present evaluation, we considered a lifespan of 30 years for windows, and of 15 years for the heat recovery system.
According to the Italian regulation on energy saving, it is possible to claim a tax refund of 65% of the cost of the investment over 10 years. NPV was reported either without tax refund claim (i.e. NPV(0)) or considering a 65% tax refund over 10 years (i.e. NPV(65)).
NPV calculated for the different scenarios are reported in Tables 10-13.

Table 10 – Net Present Value calculated for Scenario 1 (Case 1 vs Case 0) at different increment of the cost of energy (i) considering or not the tax refund of 65% - lifespan 30 years.

Scenario 1	i = 2%	i = 4%	i =6%
NPV (0)	481	7620	17974
NPV (65)	11553	18691	29045

In the evaluation of NPV, the maintenance cost of the heat recovery system (1% per year, revaluated at 2% of inflation) was taken into account.
In the case of Scenario 2 (Table 11), the value of NPV was reported at two time points: i) 15 years (the lifespan of the recovery system), and ii) 30 years. In the case of the latter time points it is necessary to add the cost of the heat recovery replacement and extraordinary maintenance works on the entire system, for a total amount of €9,421 (to be paid 15 years after the retrofitting).

Table 11 – Net Present Value calculated for Scenario 2 (Case 2 vs Case 0) at different increment of the cost of energy (i) considering or not the tax refund of 65%, after 15 years and after 30 years.

Scenario 2	i = 2%	i = 4%	i =6%
NPV (0) – 15ys	7299	11081	15607
NPV (65) – 15ys	14680	18462	22988
NPV (0) – 30 ys	17985	31378	50806
NPV (65) – 30 ys	25366	38759	58187

In the case of Scenario 3 and 4 (Table 12-13) the evaluation of NPV was done only for time point 30 years, considering the replacement of the heat recovery and other extraordinary maintenance works after 15 years.

Table 12 – Net Present Value calculated for Scenario 3 (Case 3 vs Case 0) at different increment of the cost of energy (i) considering or not the tax refund of 65% - lifespan 30 years.

Scenario 3	**i = 2%**	**i = 4%**	**i =6%**
NPV (0)	17724	38008	67433
NPV (65)	36176	56460	85885

Table 13 – Net Present Value calculated for Scenario 4 (Case 4 vs Case 1) at different increment of the cost of energy (i) considering or not the tax refund of 65% - lifespan 30 years.

Scenario 4	**i = 2%**	**i = 4%**	**i =6%**
NPV (0)	17242	30388	49458
NPV (65)	24623	37769	56839

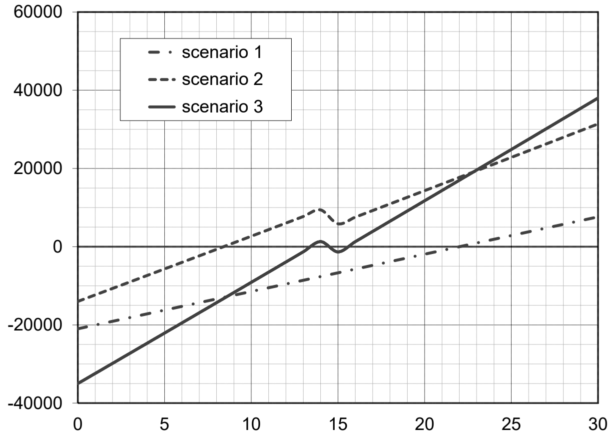
6. Discussion

The conducted analysis highlighted that replacing windows (Scenario 1) does not produce a significant energy saving. Moreover, the SPBT is 22 years, a very long period of time compared to a 30-year lifespan. Conversely, the installation of a heat recovery system seems a valid alternative for saving energy, with an SPBT of 7.8 and 8 years, for Scenario 2 and Scenario 4 respectively. These observations are supported by the values of NPV shown in tables 10-13.

Fig. 3 and Fig. 4 represent the variation of Net Present Value during the 30 years for the different scenarios analysed with or without the tax refund. Here, NPV was calculated using an increment of the cost of energy of 4% per year. The curve of NPV for Scenario 4 was similar to the one of Scenario 2, and it not shown.

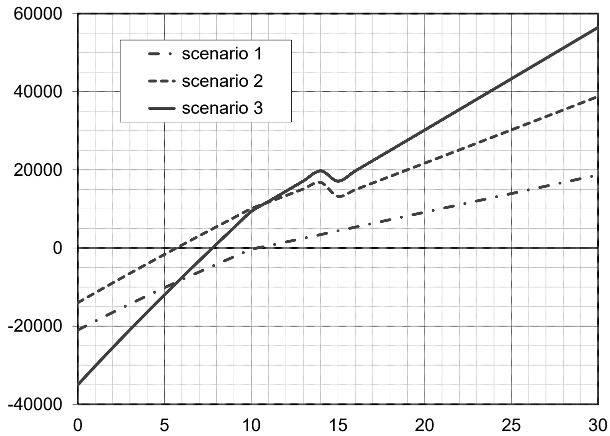
Figure 3 shows that the retrofitting solution with the highest NPV is the one which includes both windows replacement and the setting of a heat recovery system (Scenario 3). However, this solution is the one which requires a major investment. After 30 years, the difference of NPV between Scenario 3 and Scenario 2 is less than €7,000. For this reason it appears that the installation of the heat recovery system alone (Scenario 2) is better than the combination of the two investments (Scenario 3).

Figure 3 – Cash flows considering an increment of 4% in the cost of energy, without tax refund for Scenario 1, 2 and 3



The deflection of the curves of Scenario 2 and 3 at the end of year 14 is due the cost of the replacement of the heat recovery and extraordinary maintenance at year 15.

Figure 4 – Cash flows considering an increment of 4% in the cost of energy, and 65% of tax refund in 10 years for Scenario 1, 2 and 3



In Figure 4, the change of the slope at year ten is due to the end of the period of the tax refund.
As shown previously without tax refund (Figure 3), also Figure 4 illustrates that the highest value of NPV is obtained with Scenario 3. In this case, at the end of the 10 years of tax refund the NPV values are roughly the same for Scenario 2 and Scenario 3. After 30 years the NPV difference between the two scenarios is about €17,700. For these two reasons, in the case of the tax refund, Scenario 3 is to be preferred.

7. Conclusion

In the present work, a dynamic simulation of an existing office building, located in Bologna, Italy was performed, where different energy saving variations were applied. Two different strategies to enhance the energy performance were used. The first consisted in reducing the heat transfer by transmission, the other implied the decrease of the heat transfer by ventilation.

Potential energy savings were calculated by transient simulation using Trnsys software and three hypothetic retrofitting cases were exploited. The first took into account the replacement of all the windows, the second consisted in installing a total energy ventilation recovery system and the last one contemplated both the solutions. Finally, an evaluation of the simple payback time and the net present value was performed.

From the conducted analysis, only changing the windows (Scenario 1) does not produce an interesting value of NPV, unless one could benefit from a tax refund.

Notably, the installation of a total energy recovery system resulted in sensible reduction of energy consumption and gave good values of NPV for all the three different analysed variation of the cost of energy. This is particularly relevant since the case studied was an office with high ventilation flow rate to guarantee a good air quality.

Clearly, when the cost of energy arises, individuals are driven to find energy-saving measures. Nevertheless, given the actual cost of energy, energy-saving measures in building renovation and subsequent maintenance, the key strategy to make the retrofitting on existing dwellings economically appealing is to introduce or maintain tax refunding.

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References

Directive, 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

Dodoo A., L. Gustavssona L., Sathrea R., Primary energy implications of ventilation heat recovery in residential buildings, Energy and Buildings, vol. 43, pp. 1566–1572, 2011.

European Commission, 2020 Vision: Saving energy, 2011, web accessed at https://www.energy.eu/ publications/saving-energy-2011.pdf.

Jeong J., Mumma S.A., Practical thermal performance correlations for molecular sieve and silica gel loaded enthalpy wheels, Applied Thermal Engineering, vol. 25, pp. 719-740, 2005.

Legislative Decree n 192, August 19, 2005.

Legislative Decree n 311, December 29, 2006.

Legislative Decree n 28, March 3, 2011.

Simonson C., Energy consumption and ventilation performance of naturally ventilated ecological house in a cold climate, Energy and Buildings, vol. 37, pp. 23–35, 2005.

Solar Energy Laboratory, Manual of TRNSYS 17 – a TRaNsient SYstem Simulation program, Solar Energy Laboratory, University of Wisconsin-Madison, 2012.Reference List, Entry number 2. Reference style according to Chigaco Manual of Style. Paragraph style: Reference List Entry.

UNI EN 308, Heat exchangers - Test procedures for establishing performance of air to air and flue gases heat recovery devices, 1998.