Total Cost Analysis for Passive Houses

A. Versele, B. Vanmaele, H. Breesch, R. Klein, B. Wauman
Catholic University College Ghent, Departement of Industrial Engineering, Ghent, Belgium

ABSTRACT: The paper analyses the life cycle cost and payback period of a retrofitted one-familiar house in Belgium. Starting from the primary drawing project, four different energy performance levels are worked out: a *Passive House*, a *low energy* house with mechanical ventilation system, a *common practice* house with natural ventilation, and a *normative* house according to the actual energy performance regulations. Starting from the existing building, i.e. the *common practice* case, following measures are implemented: increased roof, wall and floor insulation, Passive House windows, improved air tightness and ventilation with heat recovery. The energy consumption for heating of these four dwellings is compared using the energy performance software (EPBD) and the Passive House Planning Package (PHPP) software. Moreover, a cost-benefit analysis examines and compares the payback period, the net present value and the total present value of these four scenarios. The discounted payback periods and economic optimum vary according to the energy price evolution. With increasing energy prices of 2% or 5%, refurbishing as a *low energy* house is most economical. The *Passive House* standard is justified economically if energy prices increase with 8 % every year over the next 40 years. Based on these calculations, a tool has been developed to determine the payback periods of the extra investments and the economically most advantage performance level.

1 INTRODUCTION

Since the implementation of the European Directive 2002/91/EC on the Energy Performance of Buildings and the introduction of the Passive House concept in 2002, the number of very low energy buildings and passive houses in Belgium has been increasing. However, the economical benefits of very low energy dwellings are under discussion (Verbeeck, 2007) (Versele et al., 2007) (Berndgen-Kaiser, 2007). Therefore, this paper examines the cost-benefit of four different energy performance scenarios of a detached single house. This study is based on the results of Vanmaele (2008).

2 EXISTING BUILDING

Figure 1 and Figure 2 show respectively a cross section and a plan of the first floor of the dwelling. The original building has a net area of heated rooms of 107m² and was built in the 1950s. This means that the building envelope is not insulated, a controlled ventilation system is lacking and the heating system is outdated. The global insulation level of the building is K168 whereas the actual required level is K45 (VEA, 2005). Compared to the actual energy performance requirement level of E100 in Flanders (VEA, 2005), the calculated energy performance of the original building was E280. The standardized measured energy consumption for heating was 255 kWh/m²a in 2003. In 2005, the building was refurbished and extended to a floor area of 134m². The global insulation level of the building has improved to K35, the energy performance to E67. The standardized measured energy consumption for heating was reduced to 78 kWh/m²a in 2006.

The energy performance and the net energy use for heating are calculated using the Flemish EPB software (VEA et al., 2006). The EPB software is the implementation of the European Energy Performance of Buildings Directive 2002/91/EC. It is based on a large number of building and system characteristics. It calculates the U-values, the average insulation level (K-level) and the E-level (primary energy consumption) of the building and controls compliance with energy-efficiency and indoor climate requirements. It also checks the compliance with the minimum ventilation requirements.

As the E-level cannot be used as an indicator for passive houses (Van Loon & Mlecnik, 2007), the Passive House Planning Package (PHPP) software (Passivhaus Institut, 2003) is also used to calculate the net energy use for heating. The PHPP software has been created as a design tool for Passive Housing projects. It is used for the certification of houses build according to the Passive House standards, i.e. for European constructions an annual net heating demand less than 15 kWh/m²a (PassivHaus Institut, 2008).

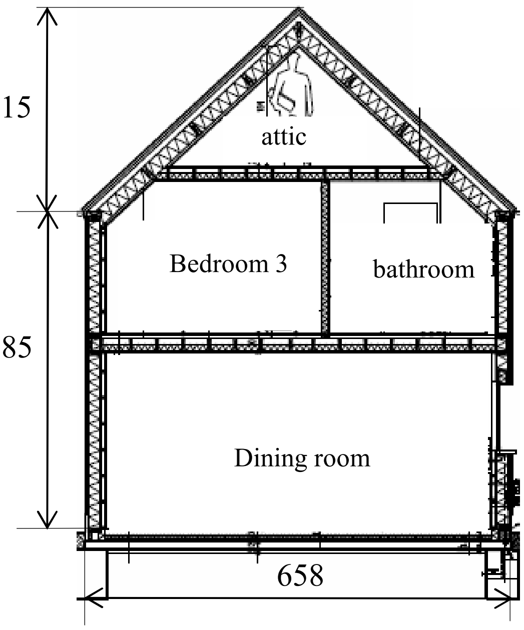

Figure 1 Cross section of the studied dwelling

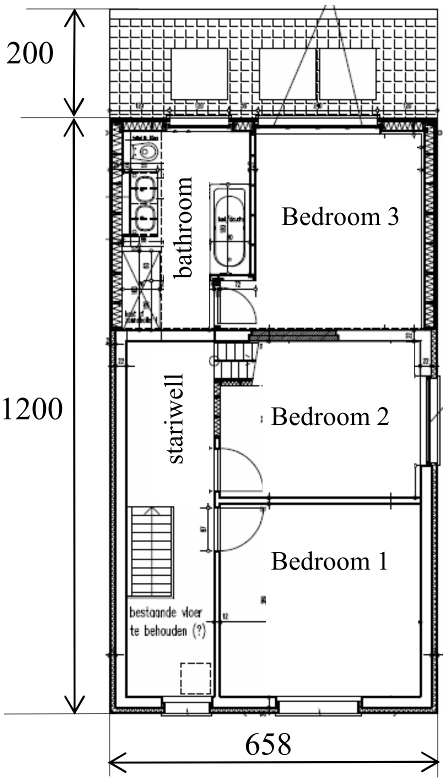

Figure 2 Plan of first floor of the studied dwelling

Both software tools are used in this paper to interprete data of the existing building and to evaluate the impact of the proposed measures. Therefore, the end energy consumption for heating is calculated and the results are compared to the real energy use in Figure 3. A good agreement between measurements and calculations for the renovated dwelling can be noticed. However, a large difference is noticed for the energy use before renovation. Difference in user behaviour explains this. In the original house, part of the building was not heated to reduce the energy consumption. This difference between predicted and measured energy consumption in badly insulated dwellings is confirmed by observations in social housing projects (Herregodts, 2005).

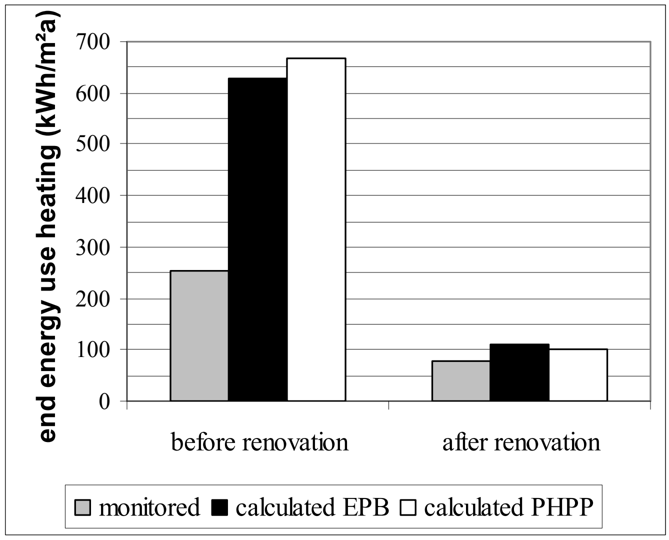

Figure 3 Comparison of end energy consumption for heating

3 FOUR SCENARIOS IMPROVING ENERGY PERFORMANCE

Four different energy performance scenarios are created starting from the refurbished dwelling:

1 The *normative* scenario is based on the legal K45–E100 Flemish EPBD requirements (VEA, 2005).
2 The renovated real building, *low energy* K35-E67 model.
3 For the *low energy* scenario, a global insulation level of K30 was combined with an air handling unit with heat recovery to reduce the ventilation heat losses. This results in a E38 model.
4 The *Passive House* scenario has been worked out according to the Passive House standards, i.e. the net energy demand for heating must not exceed 15 kWh/m².a and the n_{50}-value is lower than 0.6 h^{-1}. This corresponds in this case to a K20-E23 dwelling.

The energy performance of the building has been improved by implementing the measures listed in Table 1. These measures concern increasing the insulation of the walls, avoiding cold bridges, increasing the air tightness of the building envelope and improving the effenciency of the ventilation and heating system. Table 1 also shows that the net heating demand in the *common practice* dwelling is decreased to 65% compared to the *normative* dwelling. Moreover, the net heating demand in the *low energy* and *Passive House* scenario respectively equals only 36% and 13% of the energy demand in the normative case. The end energy use for the *Passive House* and low energy scenario is significantly lower, i.e. 8% and 19% of normative scenario respectively. This is particularly caused by a higher efficiency of the heating system.

These four scenarios correspond to the classification of Hens & Janssens (2005): a *low energy* dwelling has a standardized primary energy use for heating of maximum 60MJ/m³.a, i.e. 68 kWh/m².a in this dwelling. Moreover, the *common practice* scenario corresponds to the energy savings scenario of Hens & Janssens (2005) with a maximum of 100 MJ/m³.a (or 113 kWh/m².a in this dwelling) for primary heating consumption.

Table 1 Characteristics of four energy performance scenarios

Measures		**normative**	**common Practice**	**low energy**	**Passive House**
U_{Walls} (W/m²K)	Wall exist.	0.45	0.31	0.24	0.13
	Wall new	0.30	0.24	0.24	0.11
	Roof	0.39	0.14	0.14	0.11-0.13
	floor	0.29-0.35	0.21-0.32	0.20	0.12
	Floor attic	0.23	0.23	0.23	0.16-0.17
	glazing	1.3	1.1	1.1	0.6
	frame	2.4	2.4	2.4	0.8
$\Psi_{cold\ bridge}$ (W/mK)	wall/floor	0.26	0.19	-	-
	existing/new	0.06	0.04	-	-
Air tightness n_{50} (h^{-1})		9.3	4.0	1.0	0.6
Ventilation system		natural	natural	Balanced mech + Air HX	Balanced mech + ground HX
Heating system		Boiler	Cond. Boiler	Cond. Boiler	Air to air HX
domestic hot water		Solar	Solar	Solar	Solar
EPBD	**K**	45	35	30	20
	E	98	67	38	23
net heating demand heating (kWh/m².a) PHPP		**118**	**77**	**44**	**15**
End energy use heating (kWh/m².a) EPB		**185**	**112**	**35**	**15**

4 COST BENEFIT ANALYSIS

4.1 *Investment costs*

For the four scenarios, a detailed financial analysis has been made in order to determine the total investment costs and the additional price compared to the *normative* scenario. Figure 4 compares the investment cost of the different energy performance levels. The *Passive House* scenario has an investment cost of 214718 euro or 1602 euro/m². It represents an additional cost of 27.0 % compared to the *normative* scenario, which has an investment cost of 169054 euro or 1262 euro/m². The *low energy* and *common practice* dwelling only have an additional cost compared to the *normative* dwelling of respectively 9.3% and 5.7%.

To explain this significant additional cost for the *Passive House* scenario, the additional investment cost is subdivided and examined in detail. Figure 5 shows this division for each scenario. For the *Passive House*, the additional costs are mainly caused by the insulation of the external walls, the air handling unit with heat recovery combined with the air-to-earth heat exchanger and the triple glazed windows in frames with thermal break. Because there is no conventional heating system, a saving of 11% of the total additional costs is noticed. This conclusion is in contrast to the other scenarios in which the additional cost is mainly caused by extra insulation of walls and roofs. Only in the *low energy* scenario, the balanced mechanical ventilation system also accounts for a quarter of the additional costs.

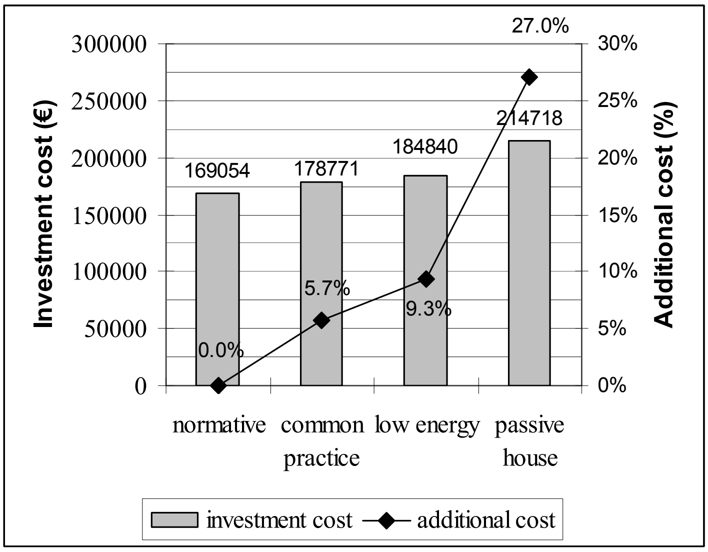

Figure 4 Comparison of investment costs of four scenarios

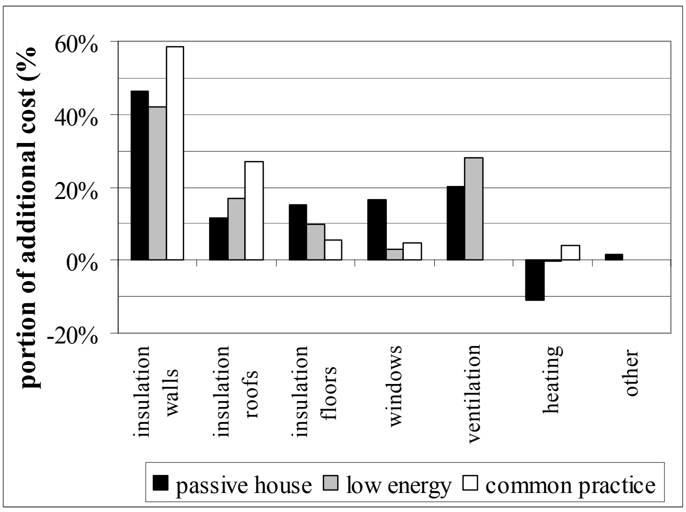

Figure 5 Division of additional costs per scenario

4.2 *Total Cost Analysis*

In order to determine the cost benefit of the different energy performance scenarios and the economic optimum, the discounted payback period (PB), the net present value (NPV) and the total present value (TPV) are calculated. The *payback period* is the term that has to be expired before the investment costs are recovered. For the calculation of a discounted payback, the actualised cumulative cash flows are taken into account. The investment costs are the additional costs compared to the *normative* case and the replacement and maintanance costs of the heating and ventilation system. The benefits are the savings in energy use compared to the *normative* scenario and the subsidies given by energy providers or the federal, regional, provincial and local funding.

Nevertheless, the global profit of a scenario cannot be analysed by the PB. Therefore, the NPV and TPV are used. The *NPV* is the present value of the future cumulated cash flows K_j of an investment minus the initial investment I_0 (see Equation 1, with i = intrest rate, j = particular year and n = investment horizon). An investment should be made if the NPV is positive. The TPV is comparable to NPV. However, instead of additional costs, the yearly total costs of each scenario are considered.

$$NPV = \sum_{j=1}^{n} \frac{K_j}{(1+i)^j} - I_0 \qquad (1)$$

Following assumptions are made determining the cost benefit of the four scenarios. The investment horizon, i.e. the expected term of the investment to refurbish the building, is considered to be 40 years (Verbeeck, 2007). The Value Added Tax (VAT) for residential buildings older than 5 years in Belgium is 6%. The actual objective of the European Central Bank for the inflation rate is 2%. For the interest rate 6% has been taken into account. This means that the calculated real rate of interest is 3.9%. Moreover, three energy price forecasting scenarios are made (see Table 2). Statistics of energy prices of natural gas for households in Belgium on Eurostat show a yearly increase of 4.5% for 1996-2007. The first two forecasts correspond to the assumptions of Verbeeck (2007). An extra high forecast (nr. 3) is added.

Table 2 Energy price forecasting scenarios

	Natural gas
forecast 1	+2%
forecast 2	+5%
forecast 3	+10%

The four energy performance scenarios are analysed considering the three energy price forecasting scenarios. The cumulated cash flow in function of the time is shown on Figure 6 and Figure 7 for an energy price forecast scenario of respectively 2% and 10%. The discounted payback period is the term at which the cumulative cash flows crosses the line of 0 euro. These values are also compared in . The NPV is the cumulated cash flow at the end of the investment horizon and is also shown on Figure 8. In addition, Figure 9 compares the TPV of the four scenarios.

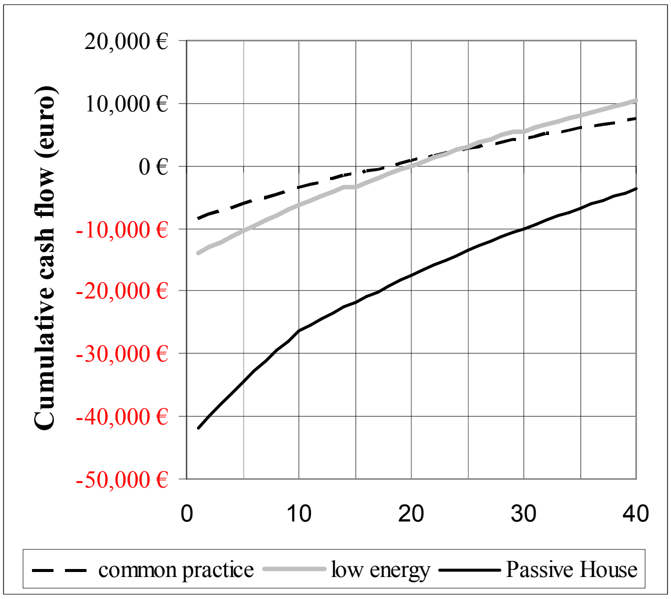

Figure 6 Cumulated cash flow for enery price forecast 1

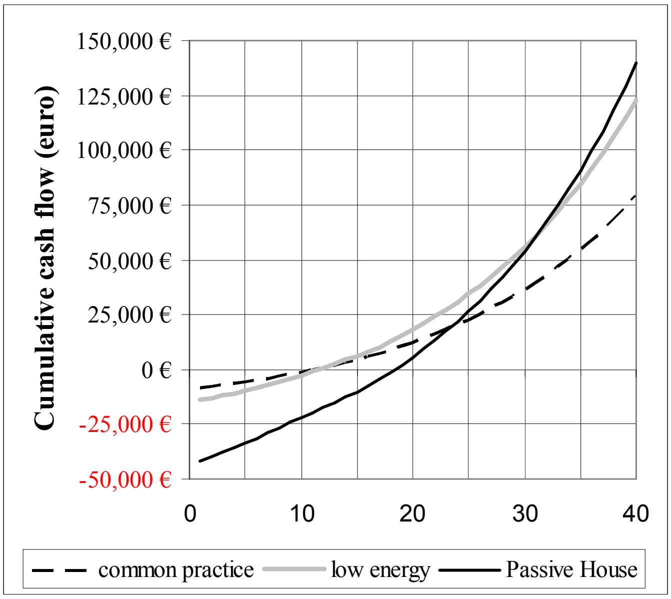

Figure 7 Cumulated cash flow for energy price forecast 3

Table 3 Discounted payback period

Discounted Payback (year)	**Common practice**	**Low energy**	**Passive House**
forecast 1	18.1	20.0	> 40.0
forecast 2	14.2	15.6	27.4
forecast 3	11.2	11.6	18.4

It is shown that for all energy price forecast scenarios, the *common practice* dwelling has the lowest discounted payback period, closely followed by the *low energy* house. The payback period equals 11.6 to 20.0 year for the *low energy* house. The *Passive House* is not paid back within 40 years with 2% increase of the energy price.

The economic optimum can be found by analysing the NPV. In case of an increase of energy prices with 2% or 5%, the *low energy* house has the highest

NPV. This net present value equals respectively 6793 euro and 28953 euro. The NPV of the *Passive House* dwelling is -6381 euro for the first energy price forecast scenario. It means that, from an economic point of view, the investment should not be done when the energy prices are increasing with 2%. However, the *Passive House* scenario becomes the economic optimum for the energy price forecast scenario of 10%. The NPV is 137086 euro in that case.

The comparison of the TPV of the four energy performance scenarios in Figure 9 confirms the conclusions of the analysis of the NPV.

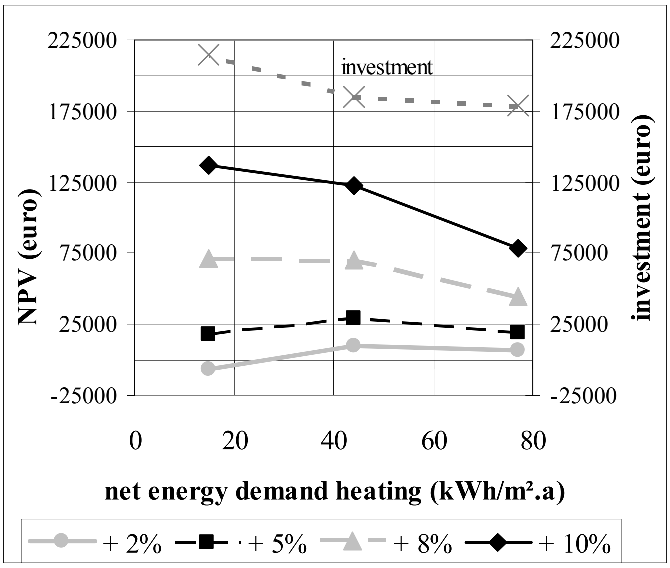

Figure 8 Comparison of net present value (NPV)

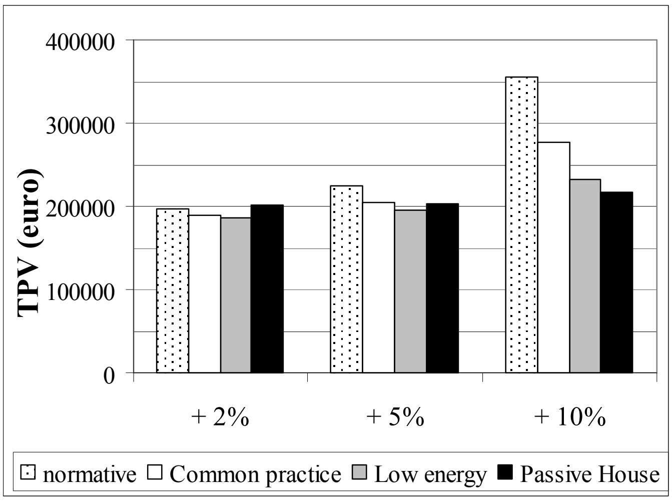

Figure 9 Comparison of total present value (TPV)

Based on these calculations, Vanmaele (2008) developed a tool to determine the discounted payback period, the NPV of the extra investments and the economically most advantage performance level. The tool is written in visual basic and is based on an annuity method. A lot of parameters, such as interest rate, inflation, energy price and its increase can be varied by the user.

5 CONCLUSION

Four different energy performance levels of a renovated dwelling are examined: a *Passive House*, a *low energy* house with mechanical ventilation system, a *common practice* house with natural ventilation, and a *normative* house according to the actual energy performance regulations. The additional investment costs for the *low energy* and the *Passive House* retrofit scenario are situated between respectively 9.3% and 27.0% compared to the *normative* scenario.

The discounted payback periods and economic optimum vary according to the energy price evolution. The *Passive House* standard is justified economically if energy prices increase with 8 to 10 % every year over the next 40 years. If prices increase with 2% or 5%, refurbishing as a *low energy* house is most economical.

REFERENCES

Berndgen-Kaiser, A. 2007. *Evaluation of 150 Passive Houses in Nordrein-Westfalen*. Proceedings of PassiveHouse 2007. Brussels, Belgium

Eurostat. *Energy statistics: natural gas prices for households: 1996-2007*, http://epp.eurostat.ec.europa.eu

Hens, H., Janssens, A. 2005. Buildings, living and energy. in W. D'haeseleer (ed) *Energy: today and tommorrow: 133-152*.Leuven, Belgium: Acco. (in Dutch)

Herregodts, K. 2005. Rational energy use in social housing projects (in Dutch). VMSW, www.vmsw.be/objects/VMSW/DuurzaamWonen/2005.02.21%20-20REG%20binnen%20Sociale%20Huisvesting1.ppt

Passivhaus Institut. 2003. *Passivhaus Projektierungs Paket (PHPP) version 2003,* http://www.passiv.de/index.html

Passivhaus Institut. 2008. *What is a Passive House,,* http://www.passiv.de/English/PassiveH.HTM

Van Loon, S., Mlecnik, E. 2007. *EPB calculations of Passive Houses*. Proceedings of PassiveHouse 2007. Brussels, Belgium *(in Dutch)*

Vanmaele, B. 2008. *Cost benefit analysis of renovation to low energy dwelling*. M. Sc thesis. Cath. Univ. Coll. Ghent *(in Dutch)*

VEA, WTCB, Decysis 2006. *EPB software 1.0*, http://www.energiesparen.be/epb/software *(in Dutch)*

VEA 2005. *Flemish requirements for energy performance of buildings*, http://www.energiesparen.be/epb/overzichteisen *(in Dutch)*

Verbeeck, G. 2007. *Optimisation of extremely low energy residential buildings.* PhD thesis. K.U.Leuven

Versele, A. , Schepens, J., De Kimpe, J. 2007. *Cost efficiency of a terraced house: a case study*, Proceedings of PassiveHouse 2007. Brussels, Belgium *(in Dutch)*