Energy renovation of a school building, a legacy of the cultural heritage of the City of Tournai: Ecole du Vieux Chemin d'Ere

AMARYLLIS AUDENAERT
Faculty of Applied Engineering
EMIB research lab (Energy & Materials in Infrastructure and Buildings)
University of Antwerp
Campus Paardenmarkt, BE-2000 Antwerp
BELGIUM
amaryllis.audenaert@uantwerpen.be http://www.uantwerpen.be/amaryllis.audenaert

MANUELA SCALEMBRA
Faculty of Applied Engineering
EMIB research lab (Energy & Materials in Infrastructure and Buildings)
University of Antwerp
Campus Paardenmarkt, BE-2000 Antwerp
BELGIUM

FABIEN VAN DE MEULEBROECKE
Administration communale de Tournai
Rue Saint-Martin, 52
7500 Tournai
BELGIUM

Abstract: - This paper treats on the one hand the evolution of EPB requirements in Walloon Region and on the other hand the energy audit of a building belonging to the building stock of the City of Tournai. A standards history has been established since 1985, precisely when the first insulation standards appeared in Walloon Region, while nowadays several levels of requirements, regarding the maximum heat transfer coefficient, the global isolation level or even level of primary energy consumption, are imposed. The building which this study deals with is an educational institution from the latest seventies, located in the southwest, extramural part of the city of Tournai. A detailed inventory of fixtures was conducted to estimate areas which need improvements and to reduce energy consumption (thermal, electrical,...). Various elements of the building were reviewed with the assistance of EPB software: the building envelope (insulation of different walls), the heating system, its regulation, energy consumption (fuel and electricity). At the end of this study, recommendations are offered to help the municipality, as building owner, in the choice of priority interventions to be undertaken to improve energy efficiency. Consultation of different literary sources allowed the analysis of different measures related to energy efficiency in buildings such as architectural measures, including the choice of the insulation type, and measures related to the types of technical installations, as well as installations which produced and managed energy that influences the energy performance of a building. To determine the relevance of an investment in any project, it is necessary to establish the costs it generates and the gains it provides, in other words the return which is achieved in comparison with provided energy investment. Some indicators of project profitability are briefly explained and for each proposition for the improvement of studied school building envelope is executed the calculation of energy benefit and the time of return of the proposed investment.

Key-Words: - School buildings; Standards; Energy Performance; Insulation;
1. Introduction

The main objective of this study is to establish a detailed inventory of the building in order to estimate points for the improvement and reduction of energy consumption (thermal, electrical, ...), by maintaining at the same time the user’s comfort. Initially the attention will be focused on the concept of energy performance and the various European directives transposed and adopted by frame decrees in Wallonia.

Using the EPB software, various elements of the building will be reviewed: the building envelope (insulation of different walls), the heating system, its regulation, energy consumption (oil and electricity). At the end of this study, several recommendations shall be provided in order to help municipality, as building owner, when deciding what priority interventions to undertake for the improvement of some points.

2. Energy Performance of Buildings (EPB)

In Belgium, the energy policy is regionalized. Each region has adopted decrees obligating them to obtain an energy certificate for all leased or sold buildings. The Walloon Government has transposed Directive 2002/91/EC in the Decree framework approved on April 19, 2007. The Energy Performance of Buildings (EPB) recommends a reduction of primary energy consumption of buildings. Over the years the EPB demand in Wallonia region has evolved to the current one, which has been applicable since 1 January 2014 [1].

<table>
<thead>
<tr>
<th>Building</th>
<th>New Construction</th>
<th>Transformation with change of use</th>
<th>Transformation without change of use</th>
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<tr>
<td>Residential buildings - Housing</td>
<td>K35</td>
<td>K65</td>
<td>Umax Values (for new or rebuilt parts)</td>
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<tr>
<td></td>
<td>E_w&lt;80</td>
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<td>E&lt;130*</td>
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<td></td>
<td>Umax Values</td>
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<tr>
<td>Offices and school buildings</td>
<td>K35</td>
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<td>E_w&lt;80</td>
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<td>Umax Values (for new or rebuilt parts)</td>
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<td>Umax Values</td>
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<tr>
<td>Residential buildings - Housing</td>
<td>Annex V AGW 17/04/2008**</td>
<td></td>
<td>Air supply device (in the area where frames are replaced)</td>
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<tr>
<td></td>
<td>Ventilation device</td>
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<tr>
<td>Offices and school buildings</td>
<td>Annex VI AGW 17/04/2008**</td>
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<tr>
<td></td>
<td>Ventilation device</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* E ≤ 130 kWh / m² (≤ 13 m³ 13L oil or gas) ** Ventilation requirement according to Annex V or VI of the Walloon Government Decree of 17.04.2008, as amended by Decree of the Walloon Government of 10.05.2012.

Table 01: EPB requirement since (Source: Portail de l’énergie en Wallonie)
3. Case study : Ecole du vieux chemin d’ere

The school building this study deals with was constructed in the late seventies. It houses a primary school from Ere. It consists of a ground floor containing five classes, two offices, a computer room, bathrooms and a basement where the boiler is placed.

Fig. 01: Aerial view

Fig 02: Main entrance

The building framework with an average thickness of 45 cm, is in masonry (solid bricks and/or stones), exteriorly covered by coating and interiorly with plastering. The soil is composed of slabs of reinforced hollow bricks, lightweight concrete, sand and of a ceramic pavement. Above the reinforced concrete ceiling, the attic is not equipped or converted. The main entrance consists of a metal door surrounded by natural stone. The lower part of the door is in metal while the upper part consists of a glass surface. The insulation is non-existent in this construction. At the beginning of this study, the windows were original metal chassis with single glaze. Replacement of these windows with new PVC with double glazing was performed in last year’s August. Considering that the frame and doors surface amounts to 38,40 % of the total area of external features of the building, this study will demonstrate that a simple replacement will already provide a significant contribution to energy savings. The protected volume $V_p$ consists of all spaces heated directly or indirectly which also require protection from heat loss to the outside, including soil and unheated spaces. $V_p$ of our building is 2288.32 m$^3$. The total floor area amounts to 605.01m$^2$ and is calculated between the exterior walls whose thickness is not taken into account surface.

4. Literature review

Maintenance of existing building stock and improvement of its thermal performance is part of the current policy of sustainable development. It is necessary to analyze the existing buildings and then take structural measures and adequate technical facilities to improve their energy efficiency and sustainability while protecting their structural integrity and historic character. [2]

4.1. Architectural measures

The insulation of buildings is an important measure to save energy while preserving the character or appearance of an old building. The choice of insulation type, production facilities and energy management influences the energy performance of a building. Significant energy savings can be achieved with exterior insulation. The latter is solely possible for non protected facades and has many advantages including preserved thermal mass, which results in less abrupt indoor climate cooling and warming and it also reduces the risk of overheating in summer. For this type of insulation, thermal bridge effect is greatly reduced. This solution can be profitable if renovation of facade is anyhow required. [3] [4] [5] [6] In the renovation process of a historic building with protected facade, it is possible to apply interior insulation or not insulate the wall at all. This technique is delicate and can cause problems such as thermal bridges, vapour condensation, risk of freezing and thermal mass reduction. The type and thickness of the insulation depends on the performance to be achieved and the available space. The low thermal capacity of old windows causes significant energy
losses requiring therefore a replacement of entire windows as the simplest and most effective solution. An exception needs to be made for cases of historic buildings where windows are rather restored than replaced. [3] [7]

4.2. Types of technical installations

**Solar thermal collectors:** The solar collector converts sunlight into heat. Depending on the nature of heat transfer elements, there are two main types of collectors; more precisely collectors using liquid heat transfer fluid (such as water mixed with antifreeze water) and collectors using air as heat transfer liquid.

**Photovoltaic panels:** A photovoltaic cell is a device that converts sunlight into electrical energy by photovoltaic effect. The photovoltaic cells are arranged on a panel to form a solar module. Several modules are then successively connected to form a solar panel. The choice of an appropriate orientation of the solar panel is important to generate significant energy efficiency.

**Passive solar thermal heating:** Its operating principle is simple: the solar shortwave radiation penetrates the transparent walls, it is absorbed by elements of construction, and then released as heat. It is particularly profitable if the building is made of solid materials (concrete, masonry,...) with a high thermal mass which can absorb, store and distribute heat.

**Solar water heater:** This system provides heat which can be used for domestic hot water, heating and cooling. Solar collectors absorb energy from sunlight and convert it into heat then transferred to a heat transfer fluid that flows through collectors.

**Heat pump for heating:** A heat pump is a device that, thanks to a fluid which describes a thermodynamic cycle, transfers heat from a low temperature source, such as outdoor air, water or soil, to a so-called hot source by using compressor that brings to it the energy needed for its functioning. [2] [3] [8]

4.3. Ventilation

In Wallonia, since 1 May 2010, new non-residential buildings or under renovation must comply with Annex VI of the EPB. The latter is essentially based on the EN-13-779 European standard (ventilation in non-residential buildings - Performance Specifications for ventilation and air conditioning).

4.4. Lighting

The European standard EN 12464-1: 2002 specifies the lighting of workplaces that answer to visual comfort and performance requirements. The substitution of artificial light with efficient natural lighting techniques combined with eco-energetic lighting system can result in energy savings of 25-75%.

5. Funding

In the course of this study, we identified two possible financing methods: third party financing and direct investment subsidies from public funds. The public-private partnership is an interesting solution. The private company supports planning, construction, maintenance and financing, it takes risks and reimburses itself through the economy of energy generated by the outcome of the project. The municipality continues to pay energy bills (without additional costs) to third-party investor that will reimburse himself through the realized economies. At the end of the contract the municipality retakes possession of an efficient equipment/building. [9][10][11][12][13] [14] The simplest and most common method is to get subsidies for investments directing attention towards public funds from different governmental levels: national, provincial and regional. Considering that this type of financing is partially based on municipality’s own funds and partly on subsidies, it quickly reaches two limits: the limit of administrations financial capacities and the limit of budgetary resources that may be allocated by region. [15]

In Wallonia, there are two possibilities for financial assistance in public sector in relation to works aiming to reduce energy consumption within municipal buildings. The first subsidies, allocated for public-law legal persons and non-commercial organizations, aim to increase studies and works necessary to improve the energy performance and the Rational Use of Energy in Buildings (UREBA) funded by the Public Service of Wallonie (SPW) (Order of the Walloon Government of 28 March 2013), while the second one is the Priority work Program (PPT ) funded by the Wallonia-Brussels Federation for school buildings (Order of Government of the French Community of 18 April 2008). The amount of the UREBA subsidy varies
from 30% to 50% of costs depending on the chosen approach, while the amount of PTT subsidy varies from 60% to 80% of costs depending on the renovated property.

6. Application of EPB software in school buildings

In the case of this study, the EPB software is recommended to review the existing situation of the building and to provide solutions to approach as close as possible the U or R and K level required values. [16] [17] [18] The building includes a protected volume containing a EPB unit. The K volume includes EPB units of Vp (protected volume) having the same requirement at level K. The EPB unit defines the precise intended purpose of the building that is to say a non-residential unit for teaching. We performed encoding of spaces, their categories and types of occupation, their surface and capacity occupation. [19] [20] [21]

![Fig. 03: K and Ew values of the school building before August 2013 (Source: EPB software)](image)

As expected, the software informed that the project does not reply to any current energy requirement. According to the EPB which became effective on January 1, 2014, the new building requirements are 35 for K values and under 80 for Ew. As for renovated buildings the K value is about 65. For old and uninsulated buildings, such as “Vieux Chemin d’Ere” school, the Ew end K values are clearly insufficient.

7. Analysis of Energy Balance

<table>
<thead>
<tr>
<th>Type of energy vector</th>
<th>Electricity</th>
<th>Fuel oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average specific consumption</td>
<td>22.747 kWh</td>
<td>249.756 kWh</td>
</tr>
<tr>
<td>Average consumption/student</td>
<td>193.80 kWh/student</td>
<td>2.454 kWh/student</td>
</tr>
</tbody>
</table>

*Tabla 02: Specific average consumption in 3 schools*
The average specific fuel consumption of three municipal schools studied enters in the 2.596 kWh/student of the Institute of Consulting and Studies in Sustainable Development (ICEDD) of the school network as well as the average education in Wallonia (2.566 kWh/student). The specific consumption per student in free and private schools is significantly lower than the regional and municipal average (1.199 kWh/student) which confirms mismanagement of existing equipment seems obvious. A normalized consumption is necessary to be able to compare from one year to another the fuel consumption between buildings of the same tertiary sector, and identify any abnormalities in the evolution of consumption. Consumption needs to be made insensitive to climatic conditions, and returned to terms we would have "if the climate of the year was that of an average year."

First of all, it is necessary to convert records into standard values by multiplying consumption in physical units (liters) by the value of NCV (Net Calorific Value of fuel).

What follows is consumption normalization by returning consumption of the building to the value it would have for an average year, which can be established by knowing the Normal Degree Days in the region and the number of degree-days of the year. The number of degree-days of a heating period is equal to the number of heated days multiplied by the difference between the average indoor temperature of the space concerned and the average outdoor temperature.

Normalized consumption = (observed consumption x Normal Degree Days of place of consumption) / degree days of the observation period place

The evolution of normalized consumptions varies from one year to another, it highlights an isolation and control problem in the building. Differences in relation to the average are substantial and highly variable ranging from -17% to +14%. Normalized annual average consumption is 259,644 kWh. It is then possible to draw the energy ratio Q / S [kWh / m² year x]

Q: total annual kWh consumed
S: the reference surface
The total heated area is +/− 541 m², the average specific fuel consumption is 480 kWh / m² year or 48L fuel / m². [22] [23] The building is supplied with low voltage, counting system is provided by a low voltage meter. The annual consumption is +/− 12.000 kWh. To locate the power consumption compared to the sector, it is necessary to establish the ratio of building consumption (kWh / m²), based on surveys of electric bills and building area.

Fig. 07: Ratio consumption of electricity

8. Recommended improvements

To accomplish a rational use of energy it is necessary to choose solutions for an energy consumption reduction while simultaneously maintaining the same level of comfort. RUE's technologies present a more attractive return on investment. The first action to take is to optimize existing facilities. A significant economic potential with limited investment is feasible immediately. Pasting an insulating cover with reflective back of the radiator is very profitable with a return time (RT) ranging from 1 to 3 years. [24] [25] [26]

A barge behind the radiator, consisting of a 44 cm masonry wall, loses during the heating season for 1 m² wall:

\[
\frac{0.98 \times 1 \times (24^\circ - 6^\circ) \times 5800}{847} = 121 \text{ kWh}
\]

The economy is 22 kWh / m² x per year, approximately 2.2 L / m² oil or € 1,76 / year / m², which makes the investment for about 3 € / m² profitable in 1.7 years.

The "Ecole du Vieux Chemin d'Ere" was furnished with single glazing surrounded by outdated and inefficient metal frame windows. These frames were responsible for significant heat loss. They no longer ensured their waterproofness function with water infiltration during rainy and windy periods. Hereinafter shall be performed a calculation of financial profitability concerning replacement of single glazing with double high-yield, which replacement has already been done. It is considered that the internal temperature is maintained at 22 °C during the day. The school is equipped with an oil heating installation whose performance is rated at 84.7 %. The cost of high-performance glazes amounts to 230 € / m² (hardware and placement, including taxes).

Annual energy economy:

- \( U_{\text{exist}} = 6.8 \text{ W/m}^2\text{K} \)
- \( U_{\text{prj}} = 2.00 \text{ W/m}^2\text{K} \)
- \( \Delta U = 4.80 \text{ W/m}^2\text{K} \)
- The average internal equivalent temperature: \( 22^\circ\text{C} - 6^\circ\text{C} - 3^\circ\text{C} = 13^\circ\text{C} \)
- The average external equivalent temperature is 6.0°C
- \( \Delta T_m = 13^\circ\text{C} - 6^\circ\text{C} = 7^\circ\text{C} \)
- \( S = 1 \text{ m}^2 \)
- The heating period = 242 jours = 5 800 heures
- The annual energy savings per m² replaced window therefore amount to:

\[
\frac{4.8 \times 1 \times 7 \times 5800}{847} = 230.1 \text{ kWh}
\]
**Profitability calculation**

Oil prices = € 0.80 / L
€ 0.8 / L x 23L / m² = € 18.40 / m² x year (annual financial economy of m² window)

The return time of the insulation is 230/18, 4 = 12.5 years.

The local school Vieux Chemin d'Ere got UREBA subsidy of 30% which lowers the windows price to 161 € / m², as well as the payback period to 8.6 years.

The ceiling floor is currently on concrete with a 8 cm thickness with a coefficient of thermal transmittance (U) of 3.76 W / m² K. The various possibilities of insulation were studied with an assessment of profitability. The thermal transmittance of the ceiling floor after isolation varies between 0.12 and 0.25 W / m² K with annual energy economy per m² in order of + / - 20 liters of oil.

<table>
<thead>
<tr>
<th></th>
<th>ROCK WOOL PANEL</th>
<th>FLEXIBLE PANEL ON WOOD FIBRE</th>
<th>WOOL INSULATION BASED WOOD FIBRE</th>
<th>PANEL ON RIGID POLYURETHANE FOAM</th>
<th>EXPANDED PERLITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (W/mK)</td>
<td>0.035</td>
<td>0.038</td>
<td>0.038</td>
<td>0.023</td>
<td>0.05</td>
</tr>
<tr>
<td>U (W/m²K)</td>
<td>0.18</td>
<td>0.2</td>
<td>0.2</td>
<td>0.12</td>
<td>0.25</td>
</tr>
<tr>
<td>Energy economy (kWh/year)</td>
<td>172</td>
<td>171</td>
<td>170,64</td>
<td>174,48</td>
<td>168,25</td>
</tr>
<tr>
<td>financial gain (€/year)</td>
<td>13.73</td>
<td>13.65</td>
<td>13.65</td>
<td>13.96</td>
<td>13.46</td>
</tr>
<tr>
<td>Payback period (years)</td>
<td>1.8</td>
<td>2.6</td>
<td>1.8</td>
<td>2.3</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**Table 03: Types and values of insulations**

According to the study the most interesting choice concerns the use of insulation based on wood fiber, a recyclable and ecological insulation which also respects the environment.

**Annual energy economy:**

- $ U_{\text{exist}} = 3.76 \text{ W/m²K} $
- $ U_{\text{pp}} = 0.2 \text{ W/m²K} $
- $ \Delta U = 3.56 \text{ W/m²K} $
- The average internal equivalent temperature: $ 22°C - 6°C - 3°C = 13°C $

- The average external equivalent temperature is 6,0°C
- $ \Delta T_m = 13°C - 6°C = 7°C $
- $ S = 1 \text{ m²} $
- The heating period = 242 jours = 5 800 heures
- The annual energy savings per m² replaced window is therefore:

$$ \frac{\Delta U \times S \times \Delta T_m \times \text{heating period}}{\text{heating performance}} = \frac{3.56 \times 1 \times 7 \times 5800}{847} = 170.64 \text{ kWh} $$
Profitability calculation

Oil prices = € 0,80 / L
€ 0,8 / L x 17,1L / m² = 13,68 € / m² x year (annual financial economy of m² insulated ceiling floor)

Knowing that the cost of insulation work is estimated at 25 € / m² (hardware and placement, taxes included) the return time of the insulation is 25/13, 68 = 1,8 years. Given that we are dealing with a non protected building, it is possible to use external insulation of the façade. This type of insulation has many advantages because it is generally possible to ensure continuity of insulation without obstacles causing its interruption. Systems such as insulating panels with coating or prefabricated insulating elements assure a quality insulation continuity. The installation of panels of rock wool reinforced by coating which incorporates a frame and panelled with a coat was also included as subject of this study.

The value of the coefficient of thermal transmittance amounts to 0,72 W / m² K. It is referred to 44cm wall of terra-cotta brick covered by an external coating of 0,01 m and by an internal plastering of 0,01 m within school building heated to 22 °. After isolating the wall with rockwool of 8 cm thickness, covered by external coating, the U-value increased to 0,27 W / m² K. The overall efficiency of the heating system is estimated at 84,7%.

Annual energy economy:
- \( U_{\text{exist}} = 0,72 \text{ W/m²K} \)
- \( U_{\text{pre}} = 0,27 \text{ W/m²K} \)
- \( \Delta U = 0,45 \text{ W/m²K} \)
- The average internal equivalent temperature : 22°C - 6°C - 3°C = 13°C
- The average external equivalent temperature is 6,0°C
- \( \Delta T_m = 13°C - 6°C = 7°C \)
- \( S = 1 \text{ m}^2 \)
- The heating period = 242 jours = 5 800 heures
- The annual energy savings per m² replaced window is therefore:

\[
\frac{\Delta U \times S \times \Delta T_m \times \text{heating period}}{\text{heating performance}} = \frac{0,45 \times 1 \times 7 \times 5800}{847} = 21,6 \text{ kWh}
\]

Profitability calculation

Oil prices = € 0,80 / L
€ 0,8 / L x 2,2L / m² = 1,76 € / m² x year (annual financial economy of m² insulated wall)

Knowing that the cost of insulation work is estimated at 80 € / m² (hardware and placement, including taxes) the return time of the insulation is 80/1,76 = 45,5 years!

9. Improvement and management of equipment

The boiler is located in the basement and it consists of a hot water non-condensing boiler (Fig. 08) which feeds the cast iron radiators and fuelled by oil.

![Boiler type Paromat-Duplex PD-015](image)

The boiler replacement would be feasible if the replacement of glazes was already performed and ceiling floor insulation was already proposed. A change of boilers would allow gain in first estimation of 20% of its consumption. The seasonal efficiency of the existing heating system amounts to 84,7%. Following the installation of a condensing boiler the calculated seasonal efficiency would amount to 101%. The annual energy savings is estimated at 3.712 L of fuel. With an oil price of 0,8 € per liter for a gain of 3.712 liters of oil, the annual financial economy is € 0,8 / L x 3.712L = € 2.970 x year . The cost of boiler replacement amounts to 15.000€, while the time of return is 15.000/2.970 = 5,1 year. Considering all various proposed or performed works activities, the level of insulation K goes from 248 to 77 and the overall useful power to install will reach 70kW instead of and as opposed to the existing 170kW.
The main consumers of electricity are lighting, office equipment (computers, printers, photocopiers...) and the auxiliary heater (burner, pumps, ...). As first actions we considered replacing fluorescent 26 mm tubes (older generation T8) with 16 mm tubes (T5) having a higher luminous efficiency and the replacement of electromagnetic ballasts with electronic ballasts. This can bring an economy of 20%. In the classroom, it would be useful to break down the lighting system in homogeneous areas of illumination so as to have an independent management lights near windows and area of activity. The lights illuminating the table should have their own commendation. Lighting should also be managed responsibly by local users.

![EPB report after windows replacement, ceiling floor insulation, boiler and lighting replacements (Source: EPB report)](image)

**Fig. 09:** EPB report after windows replacement, ceiling floor insulation, boiler and lighting replacements
(Source: EPB report)

## 10. CONCLUSION

This study aimed to find priority actions for the improvement of energy performance regarding the school “Vieux Chemin d'Ere”. It shows that certain investments can generate significant savings on both energy and economic levels.

Thanks to the established values of consumption ratios I was able to analyze consumption and determine that an energy-guzzling building requires action on the envelope and strict regulation of heating.

The first action to undertake concerns a better power management through education of staff and students in the rational use of energy.

After the execution of chassis replacement, what becomes necessary is ceiling floor insulation. The energy gain is important for an inexpensive and profitable investment in a relatively short period.

The external wall insulation was preferred to the internal one because it has some advantages such as the limit of thermal bridges, preservation of both inside place and thermal mass. However, this solution was not taken into account considering the importance of the investment for the work advocated, the limited energy gain and a high return time, as well as the fact that the façade does not require renovation.

The installation of new windows allows the use of a boiler lower power. The boiler replacement would be appropriate and interesting since it would allow a further significant reduction of fuel as well as an important decrease in the level of primary energy consumption.

Modes of financing investment are many and varied, but currently, the City of Tournai prefers stockholders' equity financing investments with
direct subsidies from public funds, allowing the municipality to retain all gains from projects.

Generally speaking, there are several solutions for the improvement of buildings energy performance. Possible investments, not necessarily expensive and low risk, can generate sufficient gains to repay themselves. Recently, the City of Tournai has developed a policy aimed at reducing its energy footprint, an approach that requires a long-term look, which is not always obvious due to short-term financial constraints.

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