Assessment of Retrofit Measures for Industrial Halls

Published in:
Sustainable Built Environment Tallinn and Helsinki Conference SBE16

DOI:
10.1016/j.egypro.2016.09.114

Published: 01/01/2016

Please cite the original version:
SBE16 Tallinn and Helsinki Conference; Build Green and Renovate Deep, 5-7 October 2016, Tallinn and Helsinki

Assessment of retrofit measures for industrial halls: energy efficiency and renovation budget estimation

Raimo Simson*a, Jevgeni Fadejeva,b, Jarek Kurnitskia,b, Jyrki Kestic, Petteri Lautsoc

aTallinn University of Technology, Estonia, Ehitajate tee 5, 19086, Tallinn, Estonia
bAalto University, School of Engineering, Otakaari 4, 00076 Espoo, Finland
cRuukki Construction OY, Panuntie 11, Helsinki, Finland

Abstract

The need for renovation is driven mostly by high energy prices and by the amortization of building envelope structures and building systems. Industrial buildings built before 1990s are usually poorly insulated and without ventilation heat recovery. When renovation is considered, it raises a question of what and to which extent to renovate, to achieve the optimal result for the investment. The current study focuses on the building envelope insulation and ventilation renovation options for hall-type industrial buildings. We have analyzed the impact of different renovation measures, regarding envelope insulation and ventilation systems, to the energy consumption and renovation budget for three typical buildings built between the 1960s and 1990s in Finland. The energy consumption calculations have been conducted with building energy and indoor climate simulation tool IDA-ICE. For the economic calculations, we have used the current Finnish energy prices and interest rates with moderate trends for the next 20 years to estimate the internal rate of return and net present value of the retrofit measures. The calculations have been done for two building sizes: a large hall, 137m x 66m, and for a smaller hall, 40m x 22m, both with an average height of 8m. The results show, that retrofitting the building envelope only for energy efficiency might not be beneficial when considering a payback period less than 20 years in the case of both large and small hall buildings. In case of smaller halls, some combinations of envelope retrofit can be also economically reasonable. Renovating the ventilation system by applying heat recovery and replacing lighting for energy efficient LEDs would be beneficial for all the initial building cases. Combination of supporting measures as a renovation package would be the most recommendable solution.

Keywords: industrial buildings; energy performance; renovation budget; IDA-ICE.

* Corresponding author. Tel.: +372 620 2405.
E-mail address: raimo.simson@ttu.ee
1. Introduction

The reduction of energy consumption and especially primary energy consumption of buildings will contribute to the reduction of energy in the total energy chain and increase sustainability. Investing in energy efficiency is essential as the overall benefits will outweigh the initial investment cost. In order to reduce the primary energy consumption in buildings, several efficiency measures can be implemented. These measures can be categorized as related to the building envelope, to the energy systems that provide heating, cooling and hot water, to electrical appliances and lighting systems. Every measure has an influence on the functioning of the building as well as to the broader effect on economic and environmental aspects and thus the building as a whole must be analyzed. There are a multitude of key performance indicators used in buildings renovation assessment, which can be used to evaluate different measures, ranging from economic and environmental to technological, social and time related approaches [1].

Building renovations undertaken to obtain energy savings are mostly driven by the potential economic benefits of the project. Often, the intent is to ensure the profitability of the retrofit project, regardless if a single energy saving measure or a combination of several energy saving measures is considered. However, several other parameters can be motivating factors for an energy renovation, for example indoor climate, energy consumption reduction or better layout of the building [2].

Simulation based energy performance assessment has been a leading practice in building optimization as well as in assessment of renovation works alternatives [3], in particular, when applied in the early design stages of the process to size the influence and energy savings of renovation measures [4-7].

Research related to renovation is mostly targeting the residential sector, offices and commercial buildings [6-8] - subjects regarding industrial facilities consist mainly of case studies, single refurbishment measures and rather specific buildings [9].

This study gives an insight of the impact of different renovation measures on energy consumption, renovation budget and net present value of savings for the measures for hall-type industrial buildings. The refurbishment measures consisted of envelope related works, ventilation systems and replacement of lighting fixtures. We have analyzed three initial configurations for two different size industrial halls representing buildings built between the 1960s and 1990s in Finland. The building sizes were chosen to represent different compactness levels: a large hall, 137m x 66m, and a small hall, 40m x 22m, both with an average height of 8m. The energy consumption calculations have been conducted with building energy and indoor climate simulation tool IDA-ICE. For the economic calculations, we have used the current Finnish energy prices with moderate trends in energy prices escalation for the next 20 years to estimate the internal rate of return and net present value of the retrofit measures.

2. Methods

We have analyzed renovation measures for industrial hall-type buildings by using dynamic energy performance simulations and economic calculations to estimate the energy savings and profitability of different measures.

2.1. Description of the studied buildings

The studied building type and its geometry was chosen as a representation of a typical single floor hall-type building such as industrial halls, factories, warehouses and retail buildings with geometrical simplifications. We used two different sized models: a large hall, and envelope area per building volume (compactness) of 0.29 m²/m³ and a small hall, with compactness of 0.38 m²/m³. The floor dimensions of the large hall are 137.4m x 66.0m and 40 x 22m for the small hall. The large building is divided into three identical bays on the short side, each 22m of width (Fig. 1). The roof consists of three double slope sections with a maximum height of 8.4m.

Three reference cases were chosen for both large and small buildings, accounting for the different construction types and era specific configurations. The thermal transmittances and areas of the building envelope parts of the base cases are given in Table 1.
Table 1. Building envelope description of the reference cases.

<table>
<thead>
<tr>
<th>Building envelope part</th>
<th>Ref. case #1 (Pre 1970)</th>
<th>Ref. case #2 (1971-80)</th>
<th>Ref. case #3 (1981-90)</th>
<th>Large hall</th>
<th>Small hall</th>
</tr>
</thead>
<tbody>
<tr>
<td>External walls</td>
<td>0.6</td>
<td>0.4</td>
<td>0.35</td>
<td>2 855.7</td>
<td>841.4</td>
</tr>
<tr>
<td>Roof</td>
<td>0.47</td>
<td>0.35</td>
<td>0.29</td>
<td>9 079.7</td>
<td>308.4</td>
</tr>
<tr>
<td>Floor towards ground</td>
<td>0.47</td>
<td>0.47</td>
<td>0.36</td>
<td>9 068.4</td>
<td>194.9</td>
</tr>
<tr>
<td>Windows</td>
<td>2.8</td>
<td>2.1</td>
<td>2.1</td>
<td>289.0</td>
<td>14.3</td>
</tr>
<tr>
<td>Doors</td>
<td>2.2</td>
<td>1.4</td>
<td>1.4</td>
<td>85.0</td>
<td>6.9</td>
</tr>
<tr>
<td>Air tightness, q_{50}, m³/(h m²) ext. surface</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>21 377.8</td>
<td>2 746.6</td>
</tr>
</tbody>
</table>

Fig. 1. Floor plans and side-views of the large (left) and small (right) industrial hall (dimensions in meters).

2.2. Renovation measures

The renovation measures considered for the building envelope were a combination of different measures: adding additional insulation to walls and roof, changing windows and doors (Fig. 2). It was accounted, that improvement of a part of the building envelope would result in improved air tightness of the building and also, that some combinations, that in reality would not be considered, would be left out. For example, when only insulating the walls, it is also reasonable to change windows and doors, thus improving air tightness of the building. Besides the envelope and ventilation system renovation options, we have also considered change in lighting installation. The retrofit measures, in case of building envelope, are defined by change in U-value, and in case of lighting – changes in electric power and internal gains. For the external walls and roof, three renovation options were chosen and for windows, doors, ventilation system and lighting one renovation option for each was defined. (Table 2).
2.3. Energy performance simulation

To estimate the energy performance of the building, we have conducted dynamic whole-year simulations with well validated indoor climate and energy simulation tool IDA-ICE v4.7, developed by EQUA Simulations AB [10]. The buildings were modelled as single zones (Fig. 3) with models of heating and ventilation systems using the input parameters for building systems shown in Table 3. The annual energy consumption was calculated using hourly weather data from for Helsinki-Vantaa Test Reference Year specifically constructed for energy and climate change impacts calculations [11]. For existing, as well as for retrofitted building cases, cooling was not accounted, because cooling systems were not installed in the majority of these particular era buildings. The buildings were oriented so, that the longer sides would face North and South orientations. The operating hours of the building, which controlled the occupancy, lighting and appliance electricity usage, were set from 7:00 to 18:00 from Monday to Saturday. Infiltration for the building was calculated using equation (1), according to the Finnish Building Code [12]:

\[ q_i = q_{50} \times A_{ext} / (3.6 \times z) \]  

(1)

where \( q_i \) is the total infiltration of the building (l/s), \( q_{50} \) is building air permeability at 50 Pa pressure difference (m\(^3\)·h\(^{-1}\)·m\(^{-2}\) of external surface area), \( A_{ext} \) is total area of building envelope (m\(^2\)) and \( z \) is building height factor: for the current cases \( z = 24 \).
2.4. Economic calculations

In this study, we have calculated the present value (PV) and net present value (NPV) of the cash flow for energy retrofit measures combinations over a period of 20 years, with relative energy price escalation of 2% and real interest rate of 4% to consider an investment for renovation work. The NPV method gives an indication of the energy renovation budget, which can be the base for decision making, when considering different retrofit packages. The renovation budget is calculated using the following equation (2):

\[
PV = \frac{\Delta E_{a}}{[1 + (i_r - e)^n]} \cdot A_{floor}
\]

(2)
where $PV$ is the present value of energy savings per heated floor area of the building (or energy renovation budget) ($€/m^2$), $\Delta E_a$ – annual energy savings ($€$), $i_r$ – real interest rate (%), $e$ – relative energy prices escalation (%), $A_{floor}$ – heated floor area of the building (m$^2$) and $n$ – payback period in years. The profitability of a renovation measure or renovation package was assessed with net present value (NPV) method, which accounts for initial investment and present value of cash flow from energy savings:

$$NPV = -\frac{I_0}{A_{floor}} + \frac{\Delta E_a}{[1 + (i_r - e)^n] A_{floor}}$$

(3)

where $I_0$ is initial investment cost of renovation measure(s) ($€$). The latter estimation method is a simplistic approach in which we do not account for the change in maintenance or repair cost, nor the amortization of a retrofit measure, leaving some of the benefits to act as a reserve.

The typical construction design and structure of the walls and roof, as well as types and use of different building materials has changed drastically over the decades, thus it is difficult to estimate the cost of renovation measures for different era buildings. For example, when considering envelope renovation options, depending on the existing construction, it might be possible to either add insulation to the exterior surface or to only remove the existing envelope part and keeping the existing frame and installing new insulated parts, e.g. three-layer PU-steel panels, which could result in relatively large difference in the material and work costs. The cost of renovation measures used in economic calculations is given in Table 4 [7, 8, 13].

Table 4. Estimated cost of renovation measures.

<table>
<thead>
<tr>
<th>Renovation measure</th>
<th>Cost, €/m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>External walls insulation</td>
<td></td>
</tr>
<tr>
<td>• 150mm, (U-value 0.25 W/(m$^2$ K))</td>
<td>68</td>
</tr>
<tr>
<td>• 200mm, (U-value 0.20 W/(m$^2$ K))</td>
<td>70</td>
</tr>
<tr>
<td>• 250mm, (U-value 0.17 W/(m$^2$ K))</td>
<td>75</td>
</tr>
<tr>
<td>Roof insulation</td>
<td></td>
</tr>
<tr>
<td>• 200mm, (U-value 0.20 W/(m$^2$ K))</td>
<td>60</td>
</tr>
<tr>
<td>• 300mm, (U-value 0.15 W/(m$^2$ K))</td>
<td>65</td>
</tr>
<tr>
<td>• 400mm, (U-value 0.12 W/(m$^2$ K))</td>
<td>75</td>
</tr>
<tr>
<td>Windows (U-value 1.0, W/(m$^2$ K))</td>
<td>135</td>
</tr>
<tr>
<td>Doors (U-value 1.0, W/(m$^2$ K))</td>
<td>135</td>
</tr>
<tr>
<td>Ventilation system w/ heat recovery</td>
<td></td>
</tr>
<tr>
<td>(cost per heated area)</td>
<td>10</td>
</tr>
<tr>
<td>Lighting installation (8 W/m$^2$)</td>
<td>9.5</td>
</tr>
<tr>
<td>(cost per heated area)</td>
<td></td>
</tr>
</tbody>
</table>

3. Results and discussion

The energy performance and NPV values for single measures for the cases are shown in Fig. 4. Measures with negative NPV are considered non-profitable, measures with positive NPV would be beneficial under the given circumstances. The primary energy consumption of the “worst” reference case reaches up to 167 kWh/(m$^2$ a), for the second and third reference case, the primary energy values are 155 and 146 kWh/(m$^2$ a) respectively.

As can be seen from the figure, the most cost effective single measure, in case of the large hall (Fig. 4, a) as well as for the first and third reference case of the small hall (Fig. 4, b), is the ventilation system renovation with heat recovery, which would also give a 12% decrease in primary energy consumption for large hall reference case #1, 13% decrease for case #2 and 14% decrease for case #3. The second most profitable investment for large hall reference
cases #2 and #3 is replacement of lighting installation to energy efficient LED fixtures. For buildings with relatively high initial envelope thermal transmittance, such as reference case #1, the second most beneficial single measure is adding additional insulation to external walls, which would also result in 9 to 11% decrease in primary energy consumption depending on the measure. For the first reference case, reducing lighting power would affect internal gains and increase the heating need so that the benefits from electric energy decrease would not be as effective.

In case of the small hall (Fig. 4, b) most beneficial besides ventilation system renovation is renovating the roof – resulting in NPV values 47 to 63 €/m² for reference case #1, 29 to 34 €/m² for reference case #2, and 6 to 10 €/m² for reference case #3. As the opposite for the large hall, the most ineffective energy renovation measure is adding roof insulation – the better the initial condition of the building, the less profitable it would be, due to the fact, that effect on energy savings is relatively low.

For all the reference cases, changing only windows or doors would not be beneficial alone and should be considered as part of full envelope renovation.

![Fig. 4. Primary energy and NPV values for single renovation measures for large (a) and small (b) halls. Code: for envelope part related measures number shows thermal transmittance; Lights – lighting installed power in W/m²; HR – ventilation system heat recovery.](image-url)
Fig. 5. Investment cost and primary energy consumption of the renovation measures combinations for large (a) and small (b) buildings for the three reference cases.

Fig. 5 shows the investment cost and primary energy consumption of the cases with various renovation measures applied. The Pareto frontier indicates the most optimal solutions which have the highest decrease in primary energy consumption for the lowest investment. For the large hall (Fig. 5, a), when applying the most effective measures, primary energy consumption can be cut up to 57% for the first initial case from 167 to 72 kWh/(m$^2$ a) with the investment cost of 124 €/m$^2$ and under the given economic parameters, the energy renovation budget (PV) would be 160 €/m$^2$. As (Fig. 5, a) indicates, reducing primary energy consumption to lower than 100 kWh/(m$^2$ a), would result in significantly higher investment costs.

As the less compact small hall building, with the selected measures, the maximum reduction achievable in primary energy consumption is 58% - from 211 to 89 kWh/(m$^2$ a) with the investment cost of 121 €/m$^2$ for the reference case #1.
In Fig. 6, it can be seen, that the less compact the building is, the more profitable the renovation can be from the energy cost view. The initial situation of the building has a large effect on the profitability of the renovation measures, for example for reference case #1 most configurations are showing positive NPV values, whereas for reference case #3 most values are negative. As some of the measures might not be beneficial alone, the combination of different measures would lower the negative effect of the non-profitable options. In case of the large hall most renovation measures combinations would not be beneficial, thus it is important to carefully select the measures to be applied, when only energy savings are considered.

4. Conclusion

In this study, we have analyzed the impact of different renovation measures on energy consumption, renovation budget and net present cost of hall-type industrial buildings. The refurbishment measures consisted of envelope related works, ventilation systems and replacement of lighting fixtures. We have analyzed three initial configurations for two different size industrial halls built between the 1960s and 1990s in Finland.

With the right renovation measures, it is possible to reduce primary energy consumption with relatively low investment cost. As some of the measures might not be beneficial, the combination of different measures would lower the negative effect of the non-profitable options. Also, it might not always be profitable to renovate from energy savings viewpoint alone, but when considering the maintenance and repair work of an amortized envelope part or
building system, renovation can still pay off. In most cases, combination of supporting measures as a renovation package would be the most recommendable solution.

The most cost effective single measure, in case of the large hall as well as for the first and third reference case of the small hall is the ventilation system renovation with heat recovery, which would also give a 12 to 14% decrease in primary energy consumption for large hall cases. The second most profitable investment for reference cases was replacement of lighting installation to energy efficient LED fixtures.

For all the analyzed reference cases, changing only windows or doors would not be beneficial alone and should be considered as part of full envelope renovation. The most ineffective energy renovation measure, in case of the large hall, is adding roof insulation – the better the initial condition of the building, the less profitable it would be, due to the fact, that effect on energy savings is relatively low.

Acknowledgements

The research was supported by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant 2014-2020.4.01.15-0016 funded by the European Regional Development Fund, by the Estonian Research Council with Institutional research funding grant IUT1–15 and by the Ruukki Construction.

References