Renewable Energies in Historical Buildings (REHIB project)

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Abstract

The project REHIB (Renewable Energies in Historical Buildings) seeks to develop a decision-making tool to help in the integration of renewable energy systems for heating and cooling, into older and historical buildings architecture. In particular, sustainable and cost-effective solutions will be developed, combining integrated renewable energy sources, energy storage for active and passive uses, and smart monitoring and controls for combination and adaptation into historical (built before 1945 through pre-industrial techniques) buildings. These buildings are usually considered as low efficiency construction and are often protected by law from alteration hence, reducing energy consumption and CO₂ related emissions is identified as a challenge and opportunity.

Introduction

Historical buildings (defined as those built before 1945), which are usually low-performance buildings by definition, represent almost 30-40% of the whole building stock in European countries (Fabbri, 2012). Historical buildings often contribute to townscape character and create the urban spaces that are enjoyed by residents and attract tourist visitors (Fabbri, 2014). They may be protected by law from alteration, hence reducing the heating and cooling energy consumption and CO₂ related emissions is identified as a challenge and opportunity (Arkande, 2014).

Research has been carried out in the frame of optimizing decisions and actuations in the retrofitting process of a building, especially for passive actuations (Haase, 2015). These kind of studies are usually focused in parametric analysis of a given technology (insulating layers, green roofs...). This study has been done in the frame of REHIB project, which will develop a decision-making tool and a standardized technology-installation package for heating and cooling, to impulse the implementation of renewable energy technologies in the retrofitting of buildings. This decision-making tool will provide optimized selection of passive and active technologies to architects and engineers in the first steps of a retrofitting process. The parametric analysis will combine for the first time different passive technologies (insulation in different

surfaces, windows and frame replacement...) and active systems including production and distribution of heating and cooling. The proposed passive and active actuations will consider legal, cultural, heritage conservation, and technical limitations due to the historical nature of the building, as well as investment cost restrictions.

Methodology

Decision making tool description

Based on several inputs from architects and/or engineers, such as building geometry, occupancy schedule, and location, a building simulation numerical model based on Energy Plus is used to calculate the space heating and cooling demand of the current building. These inputs include:

- Maximum cost of investment
- Geometry of building and description of envelopes and windows at current state.
- Schedule of HVAC system and comfort limits (both heating and cooling set points).
- Building elements not allowed to be retrofitted due to artistic, legal, or historical limitations. This aspect is of key importance in historic buildings as many elements are preserved.
- Location of building and definition of boundaries.

The optimization algorithm behind the decision-making tool is fed by a cost database of all possible actuations and will try to reduce this demand by implementing the combination of the following passive technologies:

- External insulation in walls
- Internal insulation in walls
- External insulation in roofs
- Internal insulation in roofs
- Insulation in floors
- Replacement of existing windows for:
 - Double glass 4-12-4 (air)
 - Double glass 6-12-4 (argon)
 - Tripe glass 4-16-4-16-4 (argon)
- Replacement of existing frame for:
 - Wood

- PVC
- Aluminium (No thermal bridge)

In case of adding insulating layer, different thicknesses will be evaluated. Specific questions such as how to integrate insulation, or if the access to the building is limited, or the existing envelope is flat will be asked to the architect to modify the cost of the previously cited actuations.

Afterwards, if any of the proposed passive technologies is acceptable in terms of cost, heritage preservation and other limitations defined by the architects and/or engineers, a set of case studies will be automatically evaluated using Energy Plus engine. Afterwards, the space heating and cooling demand of the passively improved historical buildings, will be considered to select the most appropriate active system to meet that thermal demand. A set of non-iterative physical numerical models and/or meta-models based on experimental and/or numerical data will be used by the optimizer to select the most appropriate active system to minimize operational environmental and economic cost for space heating and cooling.

The considered active systems will include production and distribution of heating and cooling. In case of production units, different sizes of the following technologies will be considered to meet the demand of each refurbished building:

- Air to water heat pump.
- Water to water heat pump (geothermal)
- Direct expansion with air.
- Direct expansion with water
- Natural gas boiler
- Diesel boiler
- Biomass (pellet) boiler
- Biomass (chips) boiler

On the other hand, the following distribution systems will be analyzed based also on requirements and limitations from architect:

- Radiant floor
- Fan coils
- High temperature radiators
- Direct expansion

Number of different areas to provide space heating and cooling as well as total surface will be provided by the architect to calculate the cost of distribution systems.

The algorithm (shown in Figure 1) will select the best combination of passive actuations and active systems to minimize total cost after a certain life time, or to minimize the operational cost of the building to meet the required heating and cooling demand, based on the limitations imposed by the architect (cost of investment, historical and legal aspects).

Figure 1: Summary of decision making tool algorithm.

Case study

The building used as case study is a one floor building with one thermal zone of 10m x 10m x 4 m, and two single layer windows, and a wooden door as shown in Figure 2.

Figure 2: Sketch of building used as case study.

Building walls are based on 0.9 cm of wood, 6.15 cm of foam insulation and 10 cm of concrete. Moreover, roof is based on roof deck of 1.9 cm, 11.2 cm of fiberglass and 1 cm of plasterboard. Double glazed windows were used with layers of 4 mm and argon in the chamber. Internal gains were considered as 2 people inside the thermal zone and 200W of electrical equipment. The thermal zone is exposed to 0.018 m³/s of infiltrations. Thermal properties of the different materials can be found in Table 1.

Material	Thermal conductivity (W/m·K)	Heat capacity (kJ/kg·K)	Density (kg/m ³)
Wood	0.14	900	530
Foam insulation	0.04	1400	10
Concrete	0.51	1400	1000
Roof deck	0.14	900	530
Fiberglass	0.04	840	12
Plasterboard	0.16	840	950

The building to be retrofitted is located in two different cities (Madrid and Helsinki) to analyze the effect of the weather conditions in the decisions made by the algorithm. The heating period and cooling were set from September to April, and from June to August, respectively, for all analyzed climates. The HVAC system follows a 24 h schedule demand with a heating set point of 22°C and a cooling set point of 25°C.

The output of the decision making tool is analyzed for three different levels of maximum initial investment (10 k€, 20 k€ and 40 k€). Moreover, the case study assumes that the current building before refurbishment is equipped with a heat pump (COP=2.5) connected to a fan coil to provide cooling, and with a diesel boiler (efficiency=0.8) connected to high temperature radiators to provide heating.

Results and discussion

In this chapter the best combinations of active systems and passive actuations will be provided for each level of investment and each analysed location. The results will provide the five best solutions in terms of total cost with a total life of 50 years (1 to 5), and the five best solutions regarding yearly operational cost (A to E) expending the maximum level of investment.

Madrid case study

Table 2 shows the cost of the best suggested passive and active actuations according to the different levels of initial investment.

Table 2: Set of solutions for Madrid case.

	Case	Passive Invest (€)	Active Invest (€)	Total cost 50 years (€)	Operat.cost (€/year)
10 k€	1	0	9125	46236.63	742.23
	2	0	9237	51770.82	850.68
	3	0	9125	61384.51	1045.19
	4	0	9237	66918.70	1153.64
	5	0	7579	66927.75	1186.96
	A	0	9124.931	46236.63	742.23
	B	0	9236.77	51770.82	850.68
	C	0	9124.931	61384.51	1045.19
	D	1959	7579.721	67174.76	1152.72
	E	0	9236.77	66918.70	1153.64
20 k€	1	0.00	9124.93	46236.63	742.23
	2	1959.00	9124.93	46879.83	715.92
	3	1375.26	9124.93	46979.05	729.58
	4	2705.00	9124.93	47314.52	709.69
	5	3334.26	9124.93	47614.05	703.10
	A	10892.89	10892.89	52391.05	653.72
	B	10698.64	10698.64	52385.62	657.50
	C	9952.64	9952.64	52305.21	664.55
	D	10309.15	10309.15	52930.32	669.92
	E	9368.89	9368.89	52519.56	680.51
40 k€	1	0.00	9124.93	46236.63	742.23
	2	1959.00	9124.93	46879.83	715.92
	3	1375.26	9124.93	46979.05	729.58
	4	2705.00	9124.93	47314.52	709.69
	5	3334.26	9124.93	47614.05	703.10
	A	23568.15	16020.91	69176.60	591.75
	B	23694.22	16020.91	69320.10	592.10
	C	21609.15	16020.91	67369.72	594.79
	D	21186.15	16020.91	66960.64	595.07
	E	22753.97	16020.91	68611.52	596.73

It can be seen that in case of low initial investment, the algorithm prioritizes the purchase of active equipment instead of improving the building envelope, as it was already insulated. Moreover, the algorithm selected to use the already existing heat pump to provide cooling for all levels of investment. The best active system to provide heating is also for all cases a biomass boiler connected to already existing high temperature radiators.

Finally, authors want to highlight that increasing the level of investment improves the building and active systems, and hence reduces the operational cost of the case study (€/year) from 742 € in case of investing 10 k€, to 654 and 592 in case of investing 20 k€ and 40 k€, respectively. The building with less operational cost (€/year) after investing 40 k€, has been improved in terms of 12 cm of internal insulation in walls, 24 cm of external insulation and 8 cm in internal insulation in roof, replacing windows for double glassed with argon. However, the total cost in a 50 years' life span is not reduced, after investing 10 k€ for the case of Madrid.

Helsinki case study

In the case of Helsinki, the first that the decision making tool suggests is to add 8 cm of internal insulation and replace windows even with low levels of investment. That is justified due to high heating requirements due to cold weather conditions.

Table 3: Set of solutions for Helsinki case.

	Case	Passive Invest (€)	Active Invest (€)	Total cost 50 years (€)	Operat.cost (€/year)
10 k€	1	1959.00	7830.00	123637.56	2276.97
	2	1375.26	7830.00	123996.23	2295.82
	3	1375.26	8381.99	124876.55	2302.39
	4	0.00	7830.00	124897.21	2341.34
	5	0.00	8381.99	125830.81	2348.98
	A	1959.00	7830.00	123637.56	2276.97
	B	1375.26	7830.00	123996.23	2295.82
	C	1375.26	8381.99	124876.55	2302.39
	D	0.00	7830.00	124897.21	2341.34
	E	0.00	8381.99	125830.81	2348.98
20 k€	1	3334.26	10689.87	78201.65	1283.55
	2	0.00	11002.86	78319.05	1346.32
	3	1375.26	11002.86	78401.79	1320.47
	4	1959.00	11002.86	78454.63	1309.86
	5	4080.26	10689.87	78501.52	1274.63
	A	8933.89	10689.87	80729.72	1222.12
	B	7993.64	10689.87	80778.18	1241.89
	C	4080.26	12784.02	80595.67	1274.63
	D	4080.26	10689.87	78501.52	1274.63

	E	8007.26	10689.87	82439.46	1274.85
40 k€	1	3334.26	10689.87	78201.65	1283.55
	2	0.00	11002.86	78319.05	1346.32
	3	1375.26	11002.86	78401.79	1320.47
	4	1959.00	11002.86	78454.63	1309.86
	5	4080.26	10689.87	78501.52	1274.63
	A	29086.49	10376.88	95211.94	1114.97
	B	29161.22	10376.88	95616.15	1121.56
	C	23694.22	10376.88	90166.06	1121.90
	D	23694.22	12784.02	92573.19	1121.90
	E	28146.24	10376.88	94624.17	1122.02

In terms of active system, in case of spending 10 k€ the best combination is to purchase a diesel boiler coupled to a radiant floor, while if having more possibility to invest (20k€ or 40 k€) the suggested active system to provide heating is a biomass boiler with high temperature radiators. It is important to notice that considering a 50 years' life span the total cost is significantly lower when high investments are available, changing from 123.6 k€ in case of having 10 k€ to invest, to 78.2 k€ in case of having 20 k€. Here is also important to notice that no benefits were achieved in terms of total cost when investing 40 k€ instead of 20 k€, so an optimization study is advised to determine which level of investment minimizes the total cost.

On the other hand, in case of minimizing the operational cost (best possible building and active system with a 40 k€ as maximum investment), the decision making tool suggests to add internal (12 cm) and external (12 cm) insulation in the walls, add 12 cm of internal insulation in the roof, replace windows and purchase the biomass boiler with high temperature radiators. The benefits of providing more investment in the operational cost is clear, especially when increasing the level of investment from 10 to 20 k€ (2277 €/year to 1222 €/year).

Conclusion

This paper presents a decision making tool developed in the frame of REHIB project. This decision making tool is based on Energy Plus simulation models, and a complete cost database of passive actuations and active systems. Based on a specific level of initial investment, the developed tool provides the best combination of passive refurbishment actuations and purchase of active systems to minimize the total cost after 50 years of life time of a giving current building.

This study analysed the solutions provided by the decision making tool for a one floor building located in Madrid and Helsinki.

In case of Madrid, the decision making tool, demonstrated that levels of investment higher than 10 k€ does not reduce the total cost of the building after 50 years of operation. Also, in that climate, in case of low level of

investment, the algorithm prioritizes the purchase of a biomass boiler instead of any passive actuation. On the other hand, for the case of Helsinki, the algorithm suggested to replace windows and add 8 cm of insulation in the roof as first priority. Moreover, in Helsinki, 20 k€ of initial investment are suggested.

Finally, the study demonstrated that the decision making tool can provide useful information to architects and engineers in charge of retrofitting processes of buildings.

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