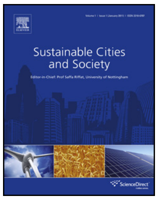
Sustainable Cities and Society 20 (2016) 71–80

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs



# Financial and economic analysis for ground-coupled heat pumps using shallow ground heat exchangers

Laura Gabrielli*, Michele Bottarelli

*Department of Architecture, University of Ferrara, Ferrara, Italy*

ARTICLE INFO

*Article history:*
Received 14 May 2015
Received in revised form
17 September 2015
Accepted 18 September 2015
Available online 9 October 2015

*Keywords:*
Discounted cash flow analysis
Payback periods
Ground-coupled heat pump
Energy efficiency
Decision support matrices
Cost–benefit analysis

ABSTRACT

A discounted cash flow analysis (DCFA) and a cost-benefit analysis (CBA) have been implemented in order to investigate the economic aspects of ground-coupled heat pump (GCHP) for space heating and cooling, in comparison to traditional condensing boiler (CB). The DCFA allows the analysis of investment costs, operating costs and savings of the two different systems in order to understand if the GCHP's payback periods (PBPs) are more interesting than that of CB in coming years. The first financial model (DCFA) takes account for economic factors as prices, costs and growth, while the economic approach (CBA) includes the carbon price into the calculation, considering the social costs of carbon dioxide emissions.

The whole analysis is implemented to adopting a parametric approach, in which all the economic terms are linked to energy labels, degree-days and energy mix ratios (EMRs), the latter obtained as the ratio between the cost of electricity and natural gas paid by the householder. Relating to different EMRs, the PBPs are presented in matrices in which energy labels and degree-days are the row/column indexes, to confront the benefits of choosing between GCHP and CB. The PBPs are also calculated with the introduction of the carbon price so that some considerations about the environmental aspects are presented. The results show that all higher energy labels have a good profitability ratio between costs and payback periods and demonstrate that GCHP system does pay off.

## 1. Introduction

Buildings are estimated to be responsible for a very high percentage of energy consumption and gas emissions. This implies a growing attention within the construction and real estate sectors regarding the building's role in exploiting renewable energy and in reducing climate change. Despite the rapid grow of green buildings supply, few works investigate the influence on financial premium of energy saving, environment design and efficient technologies, i.e. in Kulcar, Goricanec, and Krope (2008).

Here, an economic analysis is carried out to evaluate the payoff for ground-coupled heat pump system (GCHP) for space heating, in comparison to traditional condensing boiler (CB); the cooling mode has been considered only as installation extra-cost for the case CB, without taking into account the energy consumption. The two different technologies are supposed working in the same indoor system installation, so only the machines and the additional accessories are considered. The behaviour of the supposed geothermal closed loop is numerically solved in a preliminary work (Bottarelli & Gabrielli, 2011), taking into account different classes of degree-days and thermal insulations. In the present study, the cited work is detailed and partially revised to support a new economic framework in terms of energy requirements, according to climate zones and building thermal transmittances.

In our case study, in the discounted cash flow analysis (DCFA), investment and operating costs and revenues of the two different systems are calculated in order to understand if the GCHP outperform its counterpart. The whole analysis was performed adopting a parametric approach, in which all the previous terms are linked to energy label, degree-days and energy mix ratios (EMRs), the latter obtained as the ratio between the full unit cost of natural gas and electrical energy paid by the consumer. The DCFA has been then integrated with external costs in order to obtain a cost-benefit analysis (CBA). CBA is not limited to monetary considerations only, but it often includes environmental and social costs/benefits that can be quantified with a direct or indirect method. In our case study, the CBA attaches a monetary value to carbon dioxide emissions reductions and brings it into energy-related investment decisions.

The paper seeks to analyze first the economic aspects of traditional CB versus GCHP, in order to examine the benefits of choosing between the different systems. Secondly, the work focuses on CBA and some results are presented in order to express the environmental aspects.

---

* Corresponding author.
*E-mail addresses:* laura.gabrielli@unife.it (L. Gabrielli), michele.bottarelli@unife.it (M. Bottarelli).

http://dx.doi.org/10.1016/j.scs.2015.09.008
2210-6707/

**Table 1**
*k* factor for the selected energy labels.

| *a* | *b* | *c* | *d* | *e* |
|---|---|---|---|---|
| 0.37 | 0.63 | 0.88 | 1.13 | 1.50 |

## 2. Methodology

The aim of this paper is to calculate the payback period (PBP) of a GCHP versus a CB, in connection with degree-days and energy building labels, expanding the methodology reported in Bottarelli and Gabrielli (2011) to consider both the winter and summer seasons. The whole energetic analysis here employed is obtained from Bottarelli and Gabrielli (2011), Bottarelli and Di Federico (2010), to which we refer for more detailed information than those reported below. Unlike the thermo-physical approach, a more advanced financial study is performed and some specific considerations are included in this model. In particular, the cash flow of costs and savings has been discounted using a weighted cost of capital (WACC), which reflects the average benchmark parameters and drivers (cost of capitals) for the energy sector. Moreover, the analysis explicitly takes into account the time-series pattern of energy costs that are used, in the model, to forecast the evolution of electricity costs and natural gas costs in the future. Lastly, a CBA has been performed which includes the carbon price in the model, taking account the monetary value to carbon dioxide emissions reductions.

The energetic analysis in Bottarelli and Gabrielli (2011) links the building energy requirements for air-conditioning to climate aspects and energy labels taken from the Italian regulation that origins as adoption from European directive. However, they can be easily extended to any other country setting different degree-days and energy requirements. The climate conditions are generated from a parameterized hourly time series air temperature, through which specific degree-days are obtained. Because both air-conditioning systems are supposed working at fixed low temperature (44 °C, radiant floor), the indoor distribution plant is avoided from the study in terms of installations and operations costs. The GCHP is a HP vapour compression type coupled to a shallow ground heat exchanger (GHE), while the CB is a boiler with high performance.

The coefficient of performance (COP) of the GCHP basically depends on the temperature at the evaporator, if the temperature at the condenser is considered fixed, owing to the indoor heating plant temperature. Moreover, the evaporator temperature is depending on the climate and the thermal behaviour of the GHE and surrounding soil, so that this last coupling is considered as a key factor to a correct approach to the problem.

The GHE's heat exchange is solved implementing a numerical model in unsteady state, as reported in Bottarelli and Di Federico (2010). Moving from a benchmark case of degree-days, the energy supply is calibrated to maintain an average temperature not lower than 0 °C in the ground surrounding the exchanger, in order to exclude the usage of glycol. The combination between degree-days and power trend for exchanger unit length represents the limit that every other combination must respect. So, all the other cases are gathered as different combinations among climate zones and energy requirements.

**Table 3**
Overall equivalent transmittance coefficient, W/m$^2$K.

| | *B* | *C* | *D* | *E* | *F* |
|---|---|---|---|---|---|
| *a* | 0.95 | 0.82 | 0.71 | 0.60 | 0.44 |
| *b* | 1.61 | 1.40 | 1.20 | 1.02 | 0.75 |
| *c* | 2.25 | 1.95 | 1.68 | 1.42 | 1.04 |
| *d* | 2.89 | 2.51 | 2.16 | 1.83 | 1.34 |
| *e* | 3.83 | 3.33 | 2.87 | 2.43 | 1.78 |

The thermal analysis has generated all the data for the following economic valuations, where installation and operating costs are considered to achieve a full price for unit building volume. The economic analysis is performed adopting different ratio between the full unit cost of natural gas and electricity, and their potential growth, in order to connect the payback and pay-off to an energy mix ratio (EMR). In the following sections, the former steps are reported to explain the approach of the research.

### 2.1. Building energy requirements

The building is here simplified as a closed thermodynamic system, characterized by lumped parameters, as proposed in Bottarelli and Gabrielli (2011). The lumped parameters control the heat transfer through its envelope, according to the different air temperature between outdoor and indoor, and the overall thermal transmittance. This last one is related to the Italian regulation, which acknowledges the European directive on energy savings. Indeed, the regulation defines the building energy labels ($a^+$, $a$, $b$, $c$, $d$, $e$, $f$, $g$), according to the maximum energy requirements for space heating of building's unit volume ($EP_i$) in seven climate zones ($A$, $B$, $C$, $D$, $E$, $F$) defined by degree-days ($DD$), and the building shape ratio ($S/V$). Thus, Bottarelli and Gabrielli (2011) introduced the overall equivalent transmittance $\hat{U}$, as follows:

$$\hat{U} = \frac{k \cdot EP_i}{(S/V) \cdot DD \cdot t} \tag{1}$$

where the $k$ factor is setting the energy requirement of the specific energy label, and $t$ is the daily operation time expressed in hour if $EP_i$ is given in kWh/m$^3$ per heating season. Table 1 reported the five selected $k$ factors; each factor represents the mid-value of the corresponding energy class ($a$, $b$, $c$, $d$, $e$), which range is fixed by the Italian regulation.

To generalize the climate zones through the degree-days ($DD$), a time series for the outdoor air temperature has been conceptualized as hourly sinusoidal trend, superimposed between the daily maximum and minimum variation of the seasonal temperature. The method is broadly presented in Bottarelli and Di Federico (2010) and employed in Bottarelli and Gabrielli (2011) and Bottarelli and Di Federico (2012). As a consequence, the overall equivalent transmittance only becomes related to climate zones and energy label. As reported in Bottarelli and Gabrielli (2011), for the given boundary conditions of Tables 1 and 2, the resulting overall equivalent transmittance coefficient is depicted in Table 3, where the best and the two worst energy labels ($a^+$, $f$, $g$), and the climate zones $A$ are omitted due to their extreme values. Expressly for the daily operation time, the reported values are the average of

**Table 2**
Data for selected climate zones (*heating mode*).

| Data | Unit | *B* | *C* | *D* | *E* | *F* |
|---|---|---|---|---|---|---|
| Daily operation time | h/day | 7.2 | 8.0 | 9.0 | 9.6 | 10.5 |
| Heating degree-days | DD | 750 | 1150 | 1750 | 2550 | 3550 |
| $EP_i$ | kWh$_t$/m$^3$ year | 8.1 | 11.2 | 15.4 | 20.4 | 22.9 |