Energy Strategy Reviews 18 (2017) 53–62

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.ees.elsevier.com/esr

Methodology for energy strategy to prescreen the feasibility of Ground Source Heat Pump systems in residential and commercial buildings in the United States

Soolyeon Cho [a], Saurabh Ray [a], Piljae Im [b], Hamed Honari [c], Jonghoon Ahn [a, *]

[a] College of Design, North Carolina State University, Raleigh NC27695, USA
[b] Building Technologies Research and Integration Center, Oak Ridge National Laboratory, Oak Ridge, TN37831, USA
[c] Electrical & Computer Engineering Department, Johns Hopkins University, Baltimore MD21218, USA

ARTICLE INFO

Article history:
Received 8 February 2017
Received in revised form
23 June 2017
Accepted 12 September 2017

Keywords:
Energy strategy
Ground Source Heat Pump
Energy use intensity
Residential and commercial buildings
Integrated feasibility score

ABSTRACT

Geothermal resources have potential to reduce dependence on fossil fuels. The viability of geothermal heat pumps or ground source heat pumps (GSHPs) is significant as a potential alternative energy source with substantial savings potential. While the prospect of these systems is promising for energy efficiency, careful feasibility analysis is required before implementation.

This paper presents the results of evaluation of the application feasibility for GSHPs in buildings across seven climate zones in three United States regions. A comprehensive methodology is developed to measure the integrated feasibility of GSHPs using compiled data for energy use intensity, energy cost and design parameters. Four different feasibility metrics are utilized: ground temperature, outdoor weather condition, energy savings potential, and cost benefits. For each metric, a corresponding feasibility score system is developed. The defined integrated feasibility score classifies the locations into five different feasibility levels ranging from Fair (0–20), Moderate (21–40), Good (41–60), High (61–80), and Very High (81–100). Conclusions show the GSHP feasibility level is High for 3 sites, Good for 8 sites and Moderate for 4 sites. Through the methodology, it is possible to develop a practical energy strategy for more economic and sustainable GSHP systems at an early design stage in the various viewpoints of geometries, climate conditions, operational factors, and energy costs.

1. Introduction

Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy [1]. From 1980 to 2006, primary energy production grew 6%, from 19,694 TWh (67.2 quad) to 20,808 TWh (71 quad), while primary energy consumption increased 29% over the same period [2–4]. According to the Energy Information Administration (EIA), the United States (US) population will increase at an annual rate of 0.7% from 2012 to 2040, and the projected growth of the nation's energy consumption is expected to be 12% during this period [5]. This constant growth in the demand for energy requires an increase in US energy production. Primary energy production in the US is predicted to rise by 29% from 19,694 TWh (67.2 quad) to 29,482 TWh (100.6 quad) [6–8].

Residential and commercial sectors accounted for about 40% of the total energy use of the nation among the main energy consuming sectors in the US in 2012 [9]. Residential buildings consumed 22.3% and commercial buildings 46.0% of the US building-energy consumption [3,10]. According to the most recent "Residential Energy Consumption Survey (RECS)", 48% of 2983 TWh (10.18 quad) were consumed for heating and cooling purposes. Hence, taking up appropriate energy conservation measures and approaches in Heating, Ventilation, and Air Conditioning (HVAC) systems ascertains energy savings and pares down greenhouse gas emissions. From the data including geometrical and operational

---

This manuscript has been authored by UT-Battelle, LLC under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan).

[*] Corresponding author.
E-mail address: architectism@gmail.com (J. Ahn).

http://dx.doi.org/10.1016/j.esr.2017.09.012
2211-467X/

Nomenclature

Symbols

HVAC	Heating Ventilation and Air Conditioning
EUI	Energy Use Intensity
ECI	Energy Cost Intensity
EER	Energy Efficiency Ratio
GSHP	Ground Source Heat Pump
HDD	Heating Degree Days
CDD	Cooling Degree Days
RECS	Residential Energy Consumption Survey
CBECS	Commercial Building Energy Consumption Survey
IECC	International Energy Conservation Code
EIA	Energy Information Administration
GSF	Gross Square Footage
O&M	Operation and Maintenance
TWh	Terawatt hour
BTU	British Thermal Unit
Quad	Quadrillion (10^{15}) Btu
FL	Feasibility Level
VH	Very High
H	High
G	Good
M	Moderate
F	Fair

factors in buildings, several energy benchmark methodologies associated with mathematical and simulation models were examined to evaluate the energy performance of building thermal systems [11–15].

Among the building thermal systems, Ground Source Heat Pump (GSHP) systems are one of the most efficient and reliable systems for providing heating and cooling in buildings. Today, there is an enormous potential for GSHP systems in continental United States, but high capital cost of GSHP systems (without Federal tax credits) has limited the growth rate of this technology.

As most HVAC systems in existing buildings approach the end of their service life in 15–25 years, GSHP systems could be a cost effective alternative for retrofitting purposes [16,17]. GSHP systems are now installed in many newly constructed buildings to provide thermal energy in several effective ways. GSHP systems take advantage of the nearly constant temperature of the ground and uses ground-sourced energy to meet indoor heating and cooling loads during winter and summer periods. The ground serves as heat sink in the summer and heat source in the winter for GSHPs. A GSHP consists of three main components: a heat pump, ground loop heat exchanger, and a heating and cooling distribution system. The heat pump is the component of the system since it transfers heat between the ground source and the indoor building spaces. The ground connections consist of pipes filled with an anti-freeze solution, acting as the heat exchanger for the ground and the heat pump [16–18].

In order to identify the economic effectiveness of GSHP, several studies were conducted in various fields. According to a report, it was analyzed that operating savings was from $500–1900 per year as compared to natural gas system, $900–2500 to electricity, and $900–2300 to oil fuel based on averagely 140 m^2 residential houses in Canada [19]. In addition, in 289 m^2 residential houses, typical GSHP system accomplished about 28–31% primary energy savings as compared to typical gas-fired furnace system in 9 different climate areas [20]. Also, by use of simulation methods, the effectiveness of GSHP systems was examined. According to a simulation study, annual savings are $1357 of electricity in Montreal area, $2098 of heating oil in Halifax area, respectively [21]. One simulation research showed that all higher energy labels have a good profitability ratio between costs and payback periods, and that GSHP system fairly quickly did pay off [22]. Through the simulation study, it was confirmed that the borehole thermal interaction increased the energy consumption by about 3.5%, while the horizontal piping reduced by about 2.5% [23]. With the variations of envelopes and climate conditions, it was found that there was a considerable energy savings in primary energy, which was up to 23.5% and 25.4% for the single-family and the multi-family buildings, respectively [24]. Even assuming climate change, it was confirmed that there was no significant change in the cost benefits of GSHP systems [25]. Through the regression with measured data from real buildings, the total cost of the GSHP system was 13.5% lower than that of the air-cooled heat pump chiller system [26]. Also, the simple payback of open loop GSHP system was estimated by 5.7 years in small residential house, and some feasibility studies focuses on installations for renewable energy source, capacity of the systems, or cost problems for market assessment [27–31].

These projects involve intensive expenses and require some level of prescreening analysis prior to detailed investment-grade analyses [8]. This study serves to probe the project planning process in order to understand the feasibility of ground source heat pump systems for residential and commercial building applications across the US.

2. Methodology

The methodology uses data sets from various resources for energy use, energy cost, and design parameters, to introduce different feasibility criteria across seven climate zones and three climate regions in the US. The four criteria defined are based on outdoor weather conditions, ground conditions, energy savings, and cost savings. A feasibility score corresponding to each criterion is generated. Resources are described in more detail in Section 2.1.

2.1. Data and resources

2.1.1. Heating and Cooling Degree Days

Heating Degree Day (*HDD*) and Cooling Degree Day (CDD) are the metrics for heating and cooling requirements in buildings for any specific location. These metrics are calculated based on a certain reference temperature known as the base temperature. This temperature is defined as the lowest outdoor temperature at which the heating system is not required to operate to keep comfort conditions indoors. *HDD* is the difference between the base temperature and the average temperature for a given day.

A positive difference means *HDD* for that day is the difference between the base temperature and the average temperature, whereas *HDD* is considered to be zero if the difference between two temperatures is negative. Annual Heating Degree Days are the summation of all *HDDs* for a specific location over a calendar year. In similar fashion, *CDDs* are defined as the difference between the average temperature and the base temperature. In the present study, 16 locations representing the various climate zones in the US were considered. With a base temperature of 65°*F*, values of annual *HDDs* and *CDDs* were collected from ASHRAE Handbook Fundamentals [32,33]. Table 1 is the summary of HDDs and CDDs of 16 representative cities in the US.