EUROPEAN MAPPING OF SEASONAL PERFORMANCES OF AIR-SOURCE AND GEOTHERMAL HEAT PUMPS FOR RESIDENTIAL APPLICATIONS

Romain Nouvel[1]; Mariela Cotrado[1]; Dirk Pietruschka[1]

1: HFT Stuttgart – zafh.net, Germany

ABSTRACT

The Coefficient of Performance (COP) of heat pumps, provided by manufacturers, quantifies the heat pump efficiency in nominal conditions (laboratory tests). Therefore, it is generally far from its actual on-site performance.

In order to evaluate realistic heat pump potential in a specific climatic region for a specific use, the Seasonal Performance Factor (SPF) has been mapped for air-source and ground-source heat pump configurations in whole Europe, with a 200 km spatial resolution.

This paper presents the results of this work, as well as the different assumptions, models and calibration used to process it. Further development are finally proposed, laying in particular on the web-based GIS technologies.

Keywords: Coefficient of Performance, Seasonal Performance Factor, Heat pump potential

INTRODUCTION

The Coefficient of Performance (COP) of heat pumps provided by manufacturers quantifies the heat pump efficiency in nominal conditions, i.e. during laboratory tests, with standard and constant boundary conditions. However, heat pump performance depends in particular strongly on the on-site heat source and heat load temperatures, according to the Theorem of Carnot.

In order to evaluate realistically the heat pump potential in a specific climatic region for a specific use, the Seasonal Performance Factor (SPF) should be considered. It represents the final energy efficiency of the whole system over the whole heating/cooling season, calculated as the overall useful energy output to the overall driving final energy input. Standardized in the norm EN 15316-4 [1], it takes into consideration the variable heating and/or cooling demands, the variable heat source and sink temperatures, and includes the auxiliary energy demand like defrost cycle, circulation pumps/fans of the primary loop, storage, back-up heaters.

For HVAC planners, installers as well as building owners, this performance factor is essential to compare heat pumps with conventional heating systems, with regards to environmental criteria (e.g. primary energy saving and reduced CO2 emissions) and economic factors (e.g. yearly energy costs, pay-back period). However, the calculation of SPF applied to a given building in a given location is not trivial, involving different datasets and dynamic models which require specific competences and time.

In the perspective of identifying the renewable energy potentials in whole Europe, we've automatized the modelling and calculation process of the Seasonal Performance Factor, providing the decision takers with several European SPF mappings for air-source and ground-source heat pumps. This paper presents only the case of well-insulated refurbished/modern residential buildings. Further mappings related to other building usage (e.g. office) and insulation levels have been realized in the framework of the European Project FP7 Inspire [2].

METHODOLOGY

In order to realize a mapping of SPF over the whole Europe, a specific methodology has been developed, integrating the weather data of 300 European weather stations, a model of ground temperature, a model of heat demand profile representative for modern residential buildings, and a calibrated model for the heat pump.

Weather data source

The weather datasets used in this climatic analysis come from the database of Meteonorm 7. They contain hourly values of ambient air temperature, humidity, pressure, solar radiations, cloudiness and other meteorological parameters for a 1-year period, derived from hourly measurements recorded over the period 2000-2009.

To create meteorological mappings of Europe, more than 300 weather stations in the whole Europe, Maghreb, Middle-east and Russia have been considered, for a final spatial resolution of 200-300 km.

Figure 1: 334 considered weather station for the study (Meteonorm7 Data).

Limited phenomena which cause localised temperature peaks have been avoided. Thus, only weather stations at an altitude below 1000 metres have been considered.

Ground temperature modelling

The ground temperature variation in a specific place at a specific depth is an important criterion for the choice of a ground-source heat pump.

Under the topsoil layer (first 30 centimetres), the ground temperature isn't influenced anymore by the daily outside temperature variations, but by the monthly mean ambient air temperature evolution.

An important parameter impacting strongly the ground temperature is the thermal diffusivity of the soil, depending mainly on the soil structure. The soil structure is a very local parameter, with soil compositions variable in all Europe. There is not a general tendency per climate region, since the geological characteristics are much localised. As a simplification in this study, the thermal diffusivity of the soil has been taken constant for all geographical locations fixed at 0.05 m²/day which corresponds to the European average.

The ground temperature has been modelled according to the equation of Kasuda, as function of the time of the year and the depth below the surface.

Building heat demand modelling

For this European mapping, space heating demands representative of well-insulated refurbished/modern residential buildings have been considered, considering that building insulation standard adapts to local climates, so that the annual space heating demand reach 40 kWh/m².yr. The hourly distribution of this space heating demand is assumed to be proportional to the Heating Degree Days base 12.

Considering the domestic hot water demand, also covered with the heat pump, a typical annual demand of 20 kWh/m².yr, distributed uniformly over the whole day (and year) has been assumed.

The hypotheses concerning the supply hot water temperatures correspond to the mean values from a large scale measurement study [2].

Hypotheses:

- Supply hot water temperature for space heating: 36°C
- Supply hot water temperature for DHW: 52°C
- Heating demand = 40 kWh/m².a (distributed over the year, proportionally to the Heating Degree Days base 12)
- DHW demand = 20 kWh/m².a (distributed uniformly over the year)

Heat pump modelling

For this European scale modelling study, a simplified model of heat pump based on the Carnot efficiency is used:

$$COP = \eta_C * \frac{T_{hw}}{T_{hw} - T_{source}} \tag{1}$$

Where

- T_{hw} : supply hot water temperature for space heating or DHW [in Kelvin]
- T_{source} : temperature of the heat source, in our case ambient air or ground [in Kelvin]
- η_C : Carnot performance factor, defining as the quotient of the real over the ideal from the Carnot reversible cycle.

The value of the Carnot performance factor depends on the efficiency of the heat pump installation. Generally, it varies from 0.3 for small scale heat pumps designed for domestic use, to 0.65 for the most efficient heat pumps.

In our simplified model, auxiliary energy consumption needed for the circulation pumps/fans of the primary loop (evaporator side), heating rods and defrost cycles (necessary to melt the ice formed on the outdoor unit's heat exchanger when the ambient temperature gets below 0°C) are counted in the considered Carnot performance factor

Model calibration

The Carnot performance factor has been calibrated for both air-source and ground source heat pumps, based the results of a recent 3-years measurement campaign in 77 German residential buildings equipped with air-source and ground-source heat pumps [3].

According to the technical report, the mean SPF measured on the air-source heat pumps of this study reached 2.88, for an average heating demand of 72 kWh/m².a, an average DHW demand of 16 kWh/m².a, a supplied hot water temperature of 36°C for space heating and 52°C for DHW. The heat pumps have an average $COP_{A2/W35}$= 3.48, for a Carnot performance factor of 0.36.

For the ground-source pumps with horizontal collectors, the mean measured SPF reached 3.75, for approximately the same heat demands and supply hot water. The heat pumps present $COP_{B0/W35}$ = 4.66, for a Carnot performance factor of 0.36 identical to the air-source heat pumps.

EUROPEAN MAPPING OF AIR-SOURCE AND GROUND-SOURCE HEAT PUMP PERFORMANCES

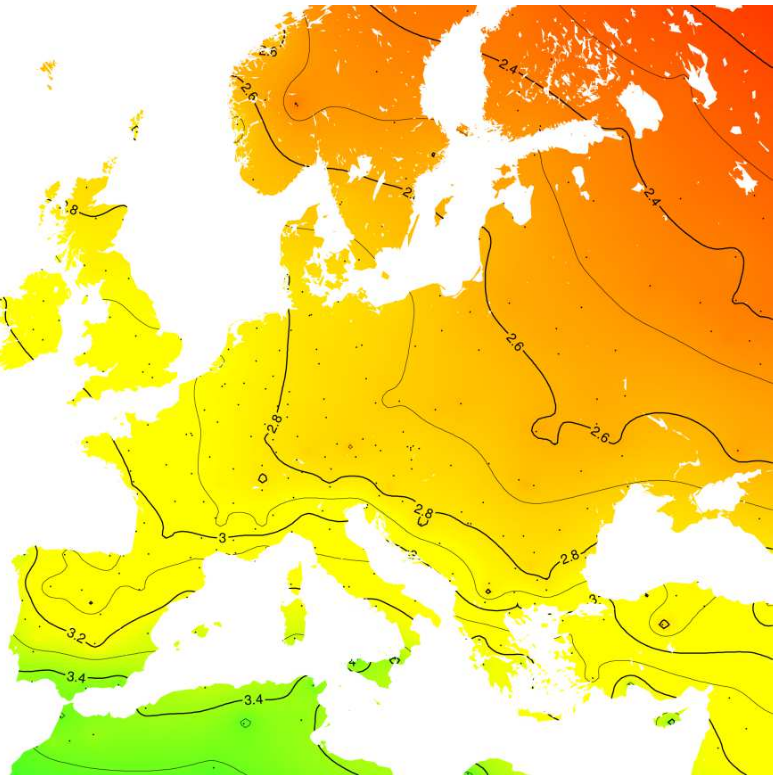

Figure 2: Seasonal Coefficient of Performance of Air source heat pumps in Europe, residential buildings.

Figure 2 represents the European Mapping of SPF of air-source heat pump, generated by using the methodology previously described.

The SPF of air-source heat pump varies between 2.4 and 3.4 in European modern residential buildings. With an average Primary Energy Factor for electricity of 2.5 in Europe, the primary energy-conversion factor of a heat pump is in the northern half of Europe is barely more than 1 (equivalent to an high efficiency condensing gas boiler).

Figure 3 represents the Seasonal Performance Factor of ground-source heat pumps with horizontal collectors (buried 2 meters deep into the soil) in Europe.

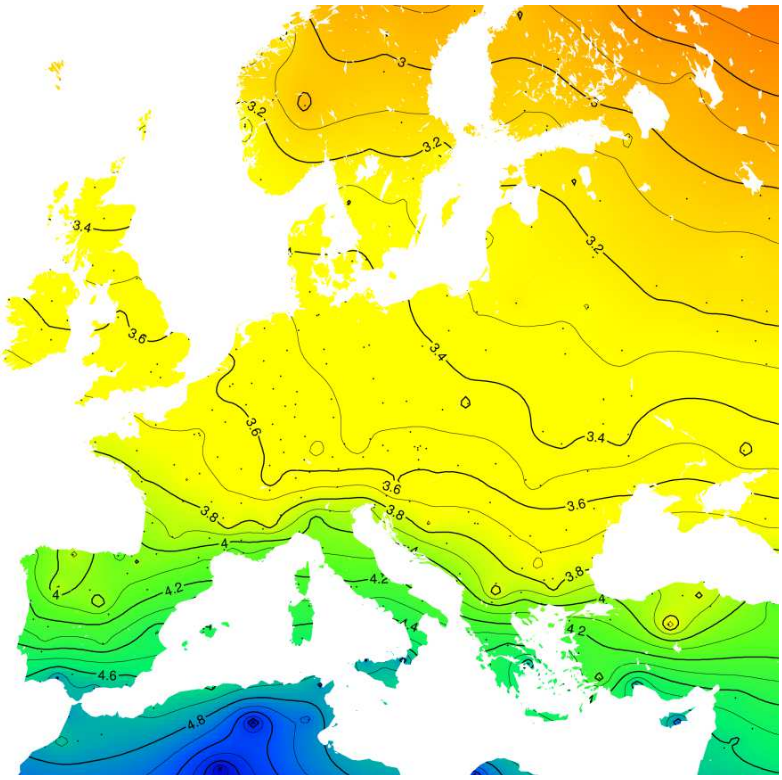

Figure 3: Seasonal Coefficient of Performance of Ground-source heat pumps in Europe, residential buildings.

In Europe, the Seasonal Performance Factor of ground-source heat pump can vary between 3 and 4.6 in refurbished residential buildings, between 0.5 and 1 higher than the ones of air-source heat pump.

In the European Project FP7 Inspire, the same study has been realised for office buildings. Because they don't require domestic hot water, whose temperature is higher than for space heating, the calculated SPF are higher than for residential buildings, up to +0.5 in some European regions.

CONCLUSION AND PERSPECTIVES

These European mappings provide an important decision making support for HVAC planners, installers as well as citizens, wondering about the benefit of installing a heat pump in a specific region of Europe.

By considering this locally simulated SPF instead of the single nominal COP as it is widely done, planning failures with dramatic consequences on both economic and environmental levels will be avoided. For instance, in particular regions of Europa, heat pumps may have a worse environmental impact that conventional gas boilers. This first version of European SPF mapping focuses on the different models and their data requirements. For ground source heat pumps the required size of the geothermal system can vary significantly according to the found ground configuration and humidity. The influence of these differences are not considered in the calculations.

However, a very natural evolution of the presented analysis would be a conversion of these static mappings in a Geographical Information System (GIS). Additionally to the navigability benefits, GIS technologies would enable to take into account other geo-localized parameters such as the very local soil properties or precipitation, for a more precise estimation of the ground-source heat pump potential. The European Project ThermoMap, which aimed at mapping the very shallow (up to 10m) Geothermal Potential, has already developed a GIS layer of the soil thermal conductivity, it could be very easily integrated for the purpose addressed here.

By using web-based GIS, all the assumptions of this paper related to the building (insulation level, domestic hot water demand) and the heat pumps system (Carnot efficiency) could be specified interactively in a web platform, in order to improve the customization of the calculation and obtain more precise results.

For the regions of Europe with a cooling demand, a much needed further development is the modelling of reversible heat pumps producing also cooling in summer. In this case, the whole yearly impact of the heat pump system would be considered. However, the cooling loads are much more complex to model at large scale for the mid European climates, depending highly on the building design, internal load situation and passive strategies. Reflecting this issue, no Cooling Degree Day method has been standardized until now in Europe, contrary to countries like U.S.A.

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