

EXPERIENCES WITH THE ANALYSIS OF HEAT PUMP SYSTEMS AT ARSENAL RESEARCH – STANDARDISED MONITORING METHODOLOGY

*H. Huber, Ing.; J. Schnitzer, DI (FH); C. Köfinger, Ing.;
arsenal research, Sustainable Energy Systems, Giefinggasse 2, 1210 Vienna, Austria*

Abstract: The application of renewable energy is, due to political aspirations particularly in the field of CO₂ reduction, an increasingly important topic. Heat pumps can thus significantly contribute to a sustainable energy supply.

arsenal research is engaged with heat pump monitoring systems since 2002. During this period, arsenal research has monitored several heat pump systems.

The standardized monitoring methodology is split into three parts: The first part involves a questionnaire regarding the non-measurable data. The second part consists in installing a system for continuous data collection and recording. The development of a database for the administration and evaluation of the measured data constitutes the third part of the monitoring.

The results should provide a base for heat pump manufacturers, installers, energy providers, stakeholders and funding agencies.

The following paper presents the monitoring methodology according to the arsenal research standards. In addition, results from several measurements as well as analysis concerning the seasonal performance factor (SPF), the energy costs and TEWI (Total Equivalent Warming Impact) are described. Finally, comparisons between the pollutant emissions resulting from the power generation for the operation of the heat pump and the emissions of a gas or oil boiler are made.

Key Words: *heat pump, monitoring, seasonal performance factor (SPF), energy efficiency, total equivalent warming impact (TEWI)*

1 INTRODUCTION

The association of Austrian Electricity companies funded a project with the aim to develop, test and evaluate a standardized monitoring methodology for heat pump systems. The results should provide a base for heat pump manufacturers, installers, energy suppliers, stakeholders and funding agencies.

For the installers and the heat pump manufacturers, the outcome of the monitoring can be utilized in various ways, for example:

- Marketing purposes for the acquisition of new customers and partners
- Optimization of heat pump systems, i.e. new system dimensioning and/or new control strategies
- Development of innovations in the plant engineering and for heat pump systems
- Analysis and improvement of the interactions of different system components and their energy efficiency within complex assemblies

From the existing records in the database, various analyses for energy providers, heat pump manufacturers, installers, stakeholders and funding agencies can be made:

- Trends of heating energy demand from buildings and the specific heat loads on heat pumps
- Evolution of SPFs, specific heating power and power demand from the heating systems
- Effect of down times on the running time and the heating behavior of the heat pump
- Provision of base data concerning the contents of funding programs

2 GENERAL CONDITIONS FOR THE MONITORING

The application of renewable energy is, due to political aspirations particularly in the field of CO₂ reduction, an important topic. Therefore, heat pumps will play an important role for a sustainable energy supply. In many European countries, heat pumps are already prevalent and the market is continuously growing according to the latest marketing research. In order to push this development further, innovation, quality assurance and training are given great priority in Austria.

The quality of heat pumps relies mostly on two factors: First, the heat pump unit itself has to meet the quality standards, which are indicated by the EHPA/DACH heat pump quality seal. Second, the planning, dimensioning and the realization of the whole system influence its efficiency and functionality; and therefore the customer satisfaction.

By initiating training for 'certified heat pump installers' through the Austrian Heat Pump Association (previously LGW) and arsenal research, Austria has significantly contributed to the quality assurance of European systems. The implementation of long-term observations and monitoring strategies forms an essential part of evaluating and documenting the effects of measures taken.

In the past few years, monitoring has been undertaken in various forms. However, a comparison between different monitoring results is not always possible. For this reason, a standardized monitoring method which, apart from the electrical energy consumption and the yielded heat quantity, also documents other important data for evaluation of the heat pump units, is necessary.

3 MONITORING CONCEPT

Results from the monitoring act as proof of the operation and efficiency of the evaluated heat pump units.

The monitoring process is divided in three parts as described in Figure 1:

1. In order to collect all required data which cannot be measured, every installer has to fill a form referring to the individual heat pump units.
2. In addition, measured data is automatically recorded by a data logger and transmitted via GSM-modem to the arsenal research monitoring server.
3. Finally, the data is evaluated and analyzed by a specially developed database.

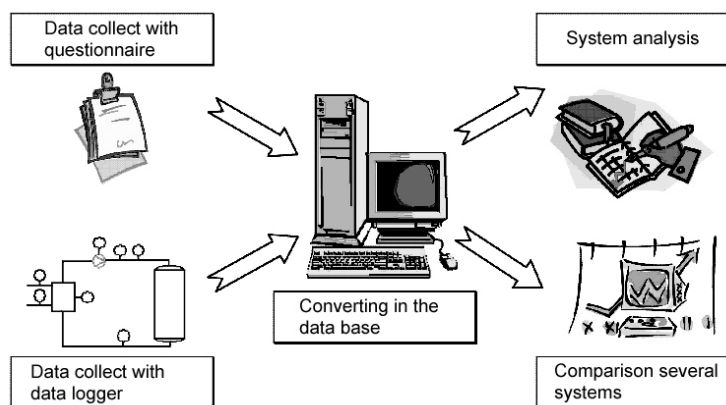


Figure 1: Data flow from the data collection to the analysis

It is important to plan the whole monitoring so that all necessary data and information required for a meaningful analysis is recorded.

In the course of this project, the focus was on the monitoring of heat pumps for space heating without domestic hot water production. However, the conception and choice of the measuring instruments also allows for the monitoring of heat pumps in combination with other heat sources such as oil, gas, biomass, solar panels as well as monitoring of heat pumps for other applications such as domestic hot water production or swimming pools.

3.2 Questionnaire for Heat Pumps Systems

The aim of the questionnaire, presented in Figure 2, is to describe the heat pump units as reliably as possible and to establish a consistent documentation structure for the heat pump units which allow further processing in a database. In a first step, it was therefore necessary to find out which information is essential.

This questionnaire collects data on the heat pump system:

- Who is the designer, owner?
- The dimensioning of the installation
- Which heat pump is used?
- Which refrigerant is used?
- Which heat source/sink is used?
- The type of hot water production system

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Information and deadlines of monitoring see the attached monitoring information.

Please note that only completely answered questionnaires can taken into account
For questions please call phone number: +43(0) 50 550-6303 Fax: +43 (0) 50550 - 6613

MONITORING - QUESTIONNAIRE

Applicant
Name _____
Address _____
Postal Code _____
City _____
Phone _____
E-mail _____

Designer
Name _____
Address _____
Postal Code _____
City _____
Phone _____
E-mail _____

Owner (Location of installation)
Name _____
Address _____
Postal Code _____
City _____
Phone _____
E-mail _____

Utilization:
One family house ☐
Two family house ☐
Multi family residence ☐

Content of refrigerant _____ kg

Figure 2: Questionnaire for heat pumps systems

3.3 Planning the Data Acquisition

The monitoring of the heat pump unit has to be as efficient and as informative as possible. Therefore, selection of measured data which should be recorded must be established in advance. This requires previous definition of which results the evaluation should deliver.

The following results are essential for further analysis:

- Energy input (power input)
- Energy output (heat supply)
- Annual, monthly and daily coefficient of performance
- Operating hours of the heat pump
- Average power input
- Average heating output
- Average operating time per day
- Operating cycles / 24 h
- External / internal temperatures
- Heat source and sink temperatures
- TEWI
- Pollutant emissions

3.3.1 Measuring points

Based on preceding considerations, measuring points have been defined. Figures 3 and 4 present the most important of these points.

Measuring point scheme

View of the measuring points proposed for the installed units.

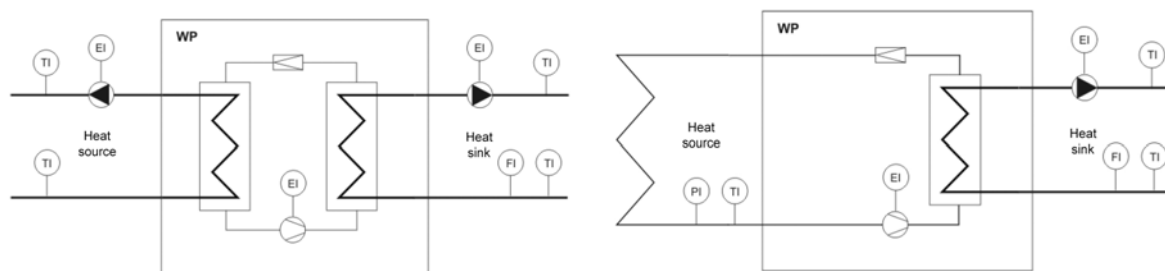


Figure 3, Left: Measuring point scheme for water/water and brine/water heat pumps
Figure 4, Right: Measuring point scheme for direct expansion heat pumps

3.3.2 Carrying out data acquisition

In the course of the project, the measuring of the required data was partially carried out through measuring devices from the installers. However, a calibration and adjustment of the installed measuring devices was necessary (confirmation with quality seal or calibration certificate).

During the period of data acquisition, the data was measured at 2 seconds intervals and recorded in 15 minutes mean values in order to describe a meaningful trend. The data, which was also transmitted to the monitoring server, was periodically checked for plausibility and finally analysed at the end of a data acquisition cycle.

4 ANALYSIS OF HEAT PUMP UNITS

Data acquired by measurement and questionnaires had to be recorded and managed. As the measured raw data of the heat pump units cannot directly be interpreted, a conversion into information characterising the heat pump units was necessary.

For this purpose, a database was developed and programmed to obtain the list of results described in Section 3.3.

The main aim, during the planning of the database, was to develop a mostly automated process to allow for the reporting of the analysis of heat pump units as well as for a quick and efficient comparison of several units.

4.1 Description of the Database Analysis

4.2.2 Evaluation of a heat pump unit

The database generates diagrams of the relevant temperatures (Figure 5), daily seasonal performance factor and the energy consumption and supplied heating energy for each month.

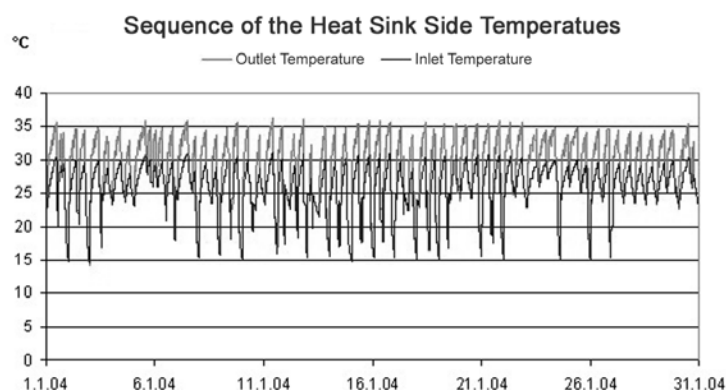


Figure 5: Temperature evolution of the supply and return temperature for one month (example)

The annual evaluation summarises all monthly results and processes them into informative and meaningful diagrams.

Figure 6 shows the evolution over a year of the energy consumption, output heat energy and monthly coefficient of performance.

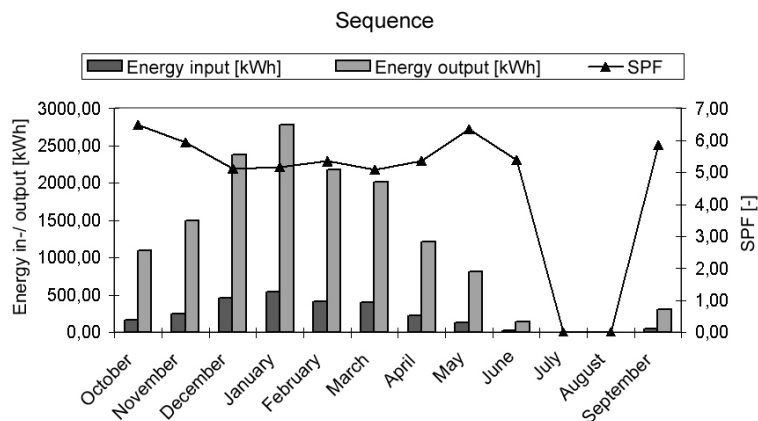


Figure 6: Monthly seasonal performance factor, electricity input and heat output

An ecologic assessment, based on the study from Gilli (Gilli 1990), where the pollutant emission of heat pumps with different types of power generation is compared to the emission of gas and oil boilers (Figure 7), was carried out. Data used to perform the assessment comes from the "Energy Report 2003" (BMWA 2003).

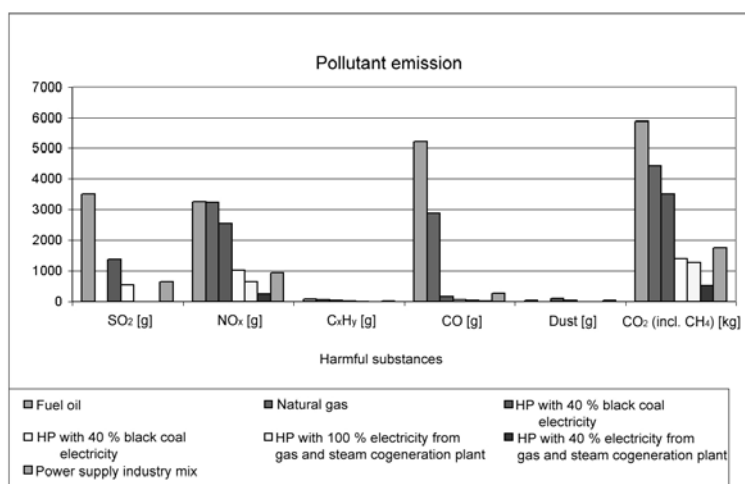


Figure 7: Comparison of pollutant emissions during the testing period

Finally, a calculation of the Total Equivalent Warming Impact (TEWI) of the investigated heat pump unit was done and the results were compared to the TEWI of oil and gas boilers according to EN 378 (CEN 2003) with the leakage amounts of heat pumps from the study TEWI Phase 3 (Sand et al. 1997), shown in Figure 8.

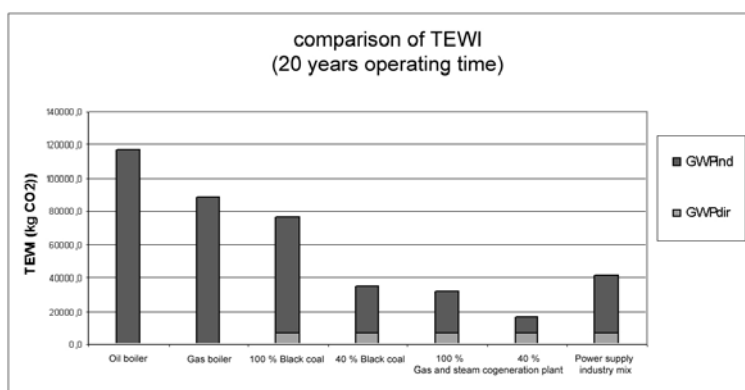


Figure 8: Comparison of the TEWI of the analysed heat pumps

4.3.2 Evaluation of several heat pump units

For the evaluation, several heat pump units are selected for comparison. In this first project, nine direct expansion heat pumps have been selected in order to establish a meaningful comparison. All heat pumps have been operational no longer than three years and, apart from the "Pfaffstätt" heat pump, which uses propane as refrigerant, a safety refrigerant (R 407C or R 410A) was used.

First, the key data of the selected heat pumps are summarized. Then, the seasonal performance factor (SPF) together with the electric power input and the heating output are computed as shown in Figure 9.

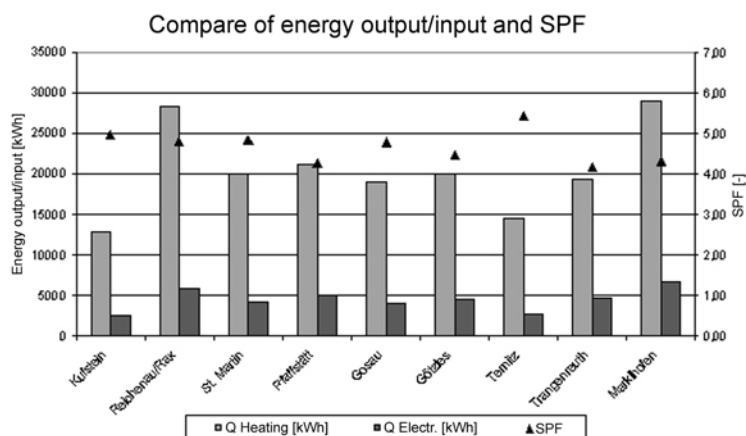


Figure 9: Diagram of the SPF, energy input and output of the compared heat pumps

The heating costs/a and the specific heating costs/m²a are also computed. For this purpose, the current fuel costs/kWh of “IWO-Österreich” (IWO 2005) have been used. The results are displayed in Figure 10.

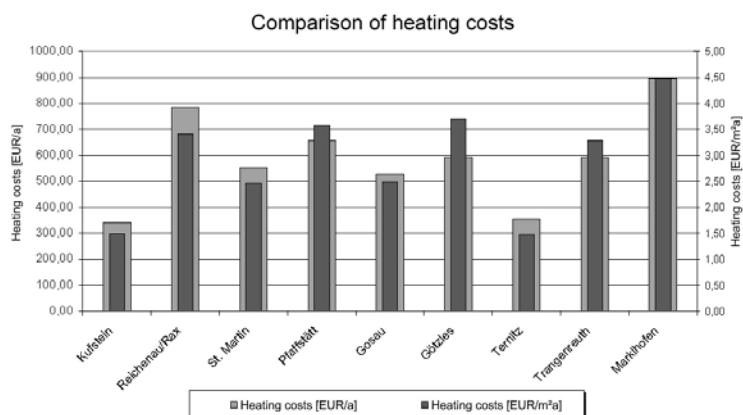


Figure 10: Comparison of the absolute and specific heating cost of the selected heat pumps

Finally, the TEWI factors of the evaluated heat pumps are compared as shown in Figure 11. For this implementation, the TEWI refers to the kWh heating energy. This is necessary since the calculation of the TEWI according to EN 378 (CEN 2003) refers to only one heat pump and therefore an evaluation of heat pumps of different sizes is not possible.

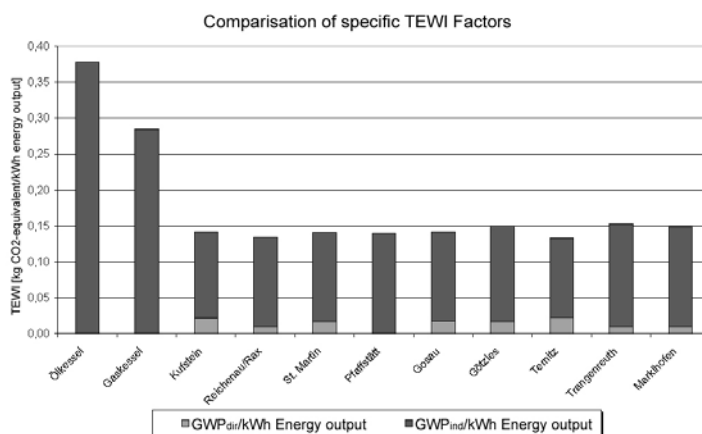


Figure 11: Diagram of the specific TEWI factors

5 EVALUATION AND ANALYSIS OF THE MEASURING DATA

After defining the required data and selecting the corresponding measuring instruments, nine different heat pumps have been monitored for the length of an entire heating season. This data has been evaluated with the database and the results have been interpreted.

For this paper, only direct expansion heat pumps without domestic hot water preparation have been chosen in order to establish a practical comparison. For future monitoring, other types of heat pump units can be monitored and analysed, which will enable a comparison of different systems.

The analysis of the investigated heat pump units shows that the mean seasonal performance factor (SPF) is 4.7. The average heating costs amount to 589 EUR/a, whereas the lowest heating costs amount to 341 EUR/a. The specific heating costs of the investigated heat pumps are between 1.48 and 4.48 EUR/m²a.

The comparison of the specific TEWI shows that, on average, the nine heat pumps emit about 50 % less carbon dioxide than a gas boiler and 62 % less than an oil boiler. This implies a reduction in emissions of 861,000 t CO₂ in comparison to heat production with oil and a reduction of 519,000 t CO₂ in comparison with natural gas over a period of 20 years. The evaluation of emissions confirms that, for the Austrian electricity mix used in this study, heat pumps are far more eco-friendly than gas and oil boilers concerning the substances SO₂, NO_x, C_xH_y, CO and CO₂. In the case of a 100 % coal power generation, the dust emissions from heat pump operation exceed the emissions of a gas or oil boiler by 186 % and in the case of the Austrian electricity mix (EVU-Mix), by 97 %.

6 SUMMARY

The monitoring example of nine heat pumps shows that the heat pump technology has the potential to significantly contribute to the aims of the Kyoto protocol.

It is now necessary to further develop this monitoring standard and apply it to other heat pump units. The heat pump units which are used for both space heating and domestic hot water preparation will provide a particular challenge. This is due to fluctuations in the domestic hot water production and storage possibilities which imply a modification in the energy balance. In addition, many more heat pumps have to be evaluated in order to present a statistically and scientifically valid description of the current state of the art of heat pump technology.

7 REFERENCES

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