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Analysis of the Use of Geothermal Heating/Cooling Systems for Residences in the Region of Saxony (Germany) Applying the Quality Function Deployment Method (QFD)

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Abstract

This paper describes the development of an appropriate method for identifying strengths and weaknesses in the present conditions of supply of (near surface) low temperature geothermal energy systems in Saxony (Germany). The method is based upon an instrument called House of Quality. With the use of a questionnaire, a preliminary assessment of the requirements of customers with respect to these geothermal systems has been made. The purpose of the investigation is to identify the priorities for improving the performance of geothermal systems in Saxony. Conclusions and recommendations have been presented for further discussion and research.

Keywords: house of quality, geothermal energy systems, renewable energy

Introduction

During the last decade, energy from renewable sources has been rapidly increasing, both in terms if technological development and its actual use. Whilst many governments in countries all over the world, but in particular in member states of the European Union have been developing policies for the promotion of energy from renewable resources, some technologies have revealed a much more rapid growth than others. In this paper, there is no space for a lengthy discussion of the causes of these developments. For our investigation, one important issue which we take into account is the fact that technologies based upon geothermal energy are widely available but are very rarely used in practice. Figure 1 and figure 2 illustrate this issue for a set of member states of the European Union and for Germany for geothermal technologies.

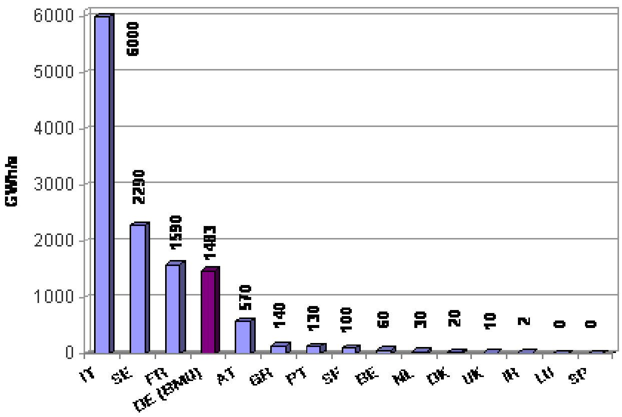


Figure 1. Geothermal energy use in the Member States of the European Union (2002). Source: Burkhard Sanner et. al., 2005, based upon data from the German Ministry of the Environment - The graph also includes data about high temperature geothermal technologies, noticeably for Italy (Sanner et al., 2005).

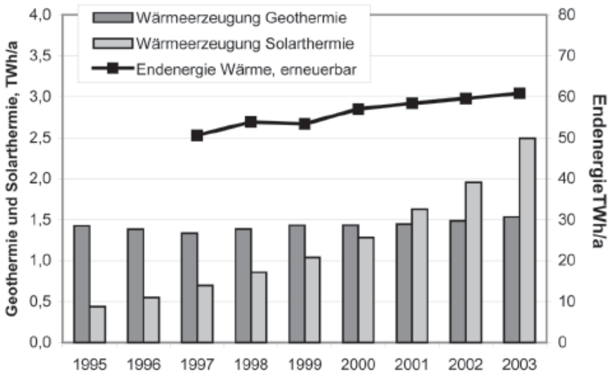


Figure 2. Geothermal and solar energy use for heat generation in Germany. Source: Burkhard Sanner et. al., 2005 (Sanner et al., 2005).

Figure 2 reveals that the generation of heat from solar energy has increased steadily from 1995 until 2003, whereas heat generated from geothermal installations was more or less constant. (The line marked "Endenergie" also includes heat from biomass.)

There may be several explanations for this poor performance of geothermal energy technologies in the comparative context of energy from renewable sources. One explanation which we intend to investigate is related to the structure and the strategy of the industry supplying such technologies, as seen from the perspectives of the availability of the technologies themselves, and the needs and requirements of potential customers. If, as in this case, the technologies are actually available, but not at all widely used, the assumption can be made that the explanation must not be found at the level of engineering but at the interface between suppliers and potential customers. It is this assumption which is being tested in this work.

Its structure is as follows. As a first step, a short overview of the geothermal technologies studied in this paper is given. Next, a brief description of the method been used, its principles and characteristics is explained. Then, the application of the House of Quality (HoQ) is used to determine the needs of customers and their relationship to the geothermal systems' characteristics. Subsequently, the results of the method were subject to an analysis in order to establish the relevance of technical and other aspects on the geothermal customer satisfaction and the relationship between customer needs and the characteristics of the geothermal systems. Finally, an interpretation of the outcomes of the matrix and an assessment of technologies and state of the art of the geothermal business in Germany is given.

Overview of Geothermal Technologies

According to the German VDI-Guideline 4640[1] (Hansen, 2004), geothermal energy is the 'energy in form of heat stored in the solid soil'. According to Hansen (2004), and from the geological and emerging conditions, geothermal energy that can be substantially used in Europe can be divided into four groups. The first three groups, which are not the subject of this paper, are Hydrothermal Energy and the deep Geothermal Borehole and Hot-Dry-Rock Process Technologies. These three types are related to high temperature geothermal resources (in general found several km deep in the earth) for the generation of electricity.

The last group comprises low temperature technologies generating energy for heating or cooling purposes. This group is called surface geothermal energy and uses heat sources found between roughly 50 and 99 meters underground. The main principle consists in the use of differences of temperature between the subsoil and the spaces which require heating or cooling with the help of a heat pump[2]. This group is studied in this paper.

Technical characteristics of the use of Surface Geothermal Energy

Surface Geothermal Energy uses a pipe loop placed under the surface (i.e. within the earth or in a water source) in order to exchange the heat between the underground and the surface. The loop is connected to a compression cycle which converts the heat supplied from the earth into a usable energy source by its increment into a higher, useful temperature. The temperature increment takes place with the addition of mechanical energy to the cycle, which is driven by a compressor that works with the help of an electric motor or a combustion engine. The heat produced is then sent into the house with the help of a duct system. (See Figure 3 for a scheme of the principle of a heat pump for a residence in a heating mode)

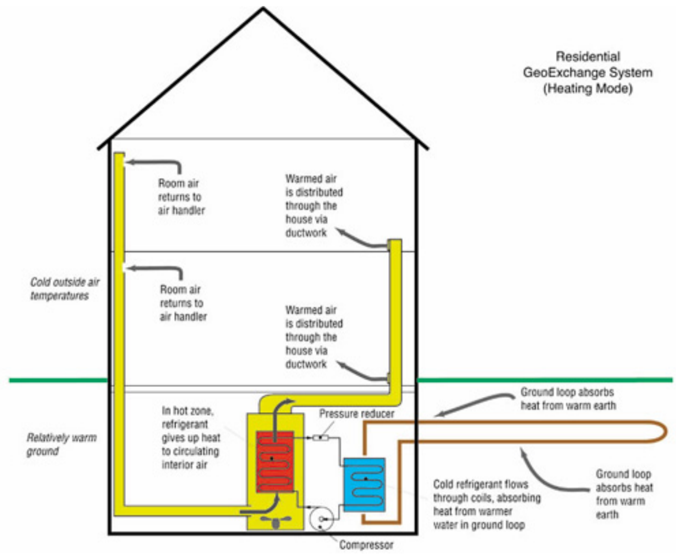


Figure 3. Scheme of a heat pump for a residence in heating mode. Source: United States Environmental Protection Agency (EPA) and Greenbuilder.com.

The whole equipment is therefore working as compression cycle system. The energy input must be adjusted according to the performance required by the heat pump. The heat pump itself must be calculated according to the residence's requirements.
Underground pipe loops for heat pump systems can be closed or open. Open loops are used in underground water sources and are limited to the amount and characteristics of the water source, the 'regularity' of the source and on the policies for the use of underground water for a specific region or country. Closed loops use a heating/cooling medium, which is a mixture between water and an antifreeze medium in proportion 2:1 to 3:1 or a salt solution (calcium chloride), which is not in direct contact with the surroundings (Hansen, 2004). The pipe loops are normally made of High Dense Polyethylene (HDPE).

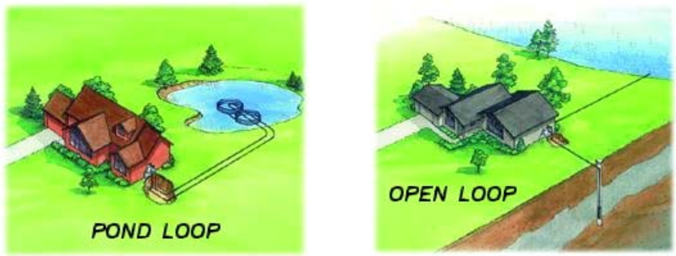


Figure 4. Scheme of a pond (lake) loop and an open loop design. Source: PA Hydronic Company.

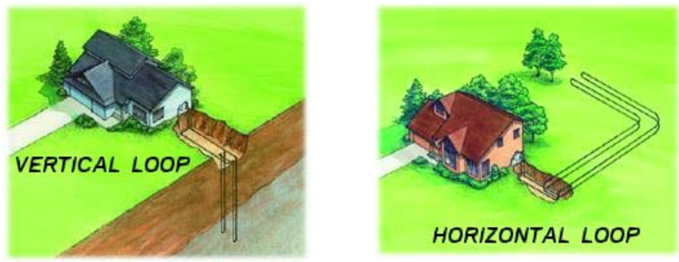


Figure 5. Scheme of a vertical loop and a horizontal loop design. Source: PA Hydronic Company.

In terms of the spatial conditions of the location, there are three basic designs for closed loops, known as vertical, horizontal and pond designs. Vertical designs are based upon a drill piping system up to 100 m on average. Horizontal systems use pipes located below the surface not exceeding 1.5 meters in depth. Pond or lake designs comprise the use of a water reservoir besides the space to be heated. Figures 4 and 5 show the schematic overviews of the basic technological concepts.
Another important aspect of Geothermal Heat pumps consists in the performance of the conversion of underground heat to 'usable' warming energy. When comparing this performance, it is best to avoid the word "efficiency", as it has many different meanings. The term coefficient of performance or COP is used to describe the ratio of heat output to electrical power consumption or the supplied work (Wikipedia, n.d.).

$$COP = \frac{|Q|}{W}$$

A typical heat pump has a COP of about four, whereas a typical electric heater has a COP of one, indicating units of heat exchange performance per units of electrical power input (resistive electric heat being 100% efficient whereas heat pump heating offering up to 400% efficiency).

The COP of a heat pump is restricted by the second law of thermodynamics, as follows:

$$COP_{\text{heating}} = \frac{\Delta Q_{\text{hot}}}{\Delta A} \leq \frac{T_{\text{hot}}}{T_{\text{hot}} - T_{\text{cool}}} = \frac{1}{\eta_{\text{carnotcycle}}}$$

$$COP_{\text{cooling}} = \frac{\Delta Q_{\text{cool}}}{\Delta A} \leq \frac{T_{\text{cool}}}{T_{\text{hot}} - T_{\text{cool}}}$$

Commercial heat pump technologies, and in special Geothermal heat pumps, are currently in a stage of rapid improvement: the COP for commercially available heat pumps has risen in the last 5 years from 3 to 4 and even (in a few cases) 5 (FWS, n.d.).

Aspects of the use of Surface Geothermal Energy in Germany

The market conditions for the use of renewable energies in Germany are based on many factors: the technological availability for the replacement of conventional energy sources, the political and law enforcement, the commitment of non-governmental institutions, the structure of the research and private sectors have contributed to the growth of this energy sources on the German market.

According to Sanner *et al.* (2005), the participation of renewable energies respect to primary energy sources has increased from 0,5% to 3% in the past 15 years. Specifically in the geothermal sector, political initiatives for the promotion of this renewable energy became visible with the 'European initiative for legislation for heating and cooling from renewable energies' in 1994. Additionally, the German government stimulated the investments for the improvement of the energetic infrastructure with KfW Programs[3] like the 'CO2-Reduction' (CO"-Minderung) and CO2-'Redevelopment' (CO2-Gebäudesanierung) from the 90's und until now (IZW, 2002).

The Quality Function Deployment (QFD) analysis

Quality improvement has been related to the relationship between the development of a standard and its connection with customer requests. Moreover, and according to Garvin (1987), from the managerial point of view, 'Managers have to take a more preliminary step – a crucial one, however obvious it may appear. They must first develop a clear vocabulary with which to discuss the quality as strategy. They must break down the word quality in manageable.'

From an industrial point of view, the technical aspects of product development are linked with the quality characteristics of the product itself and their relationship with the prioritization of future improvements. In those cases, the Quality Function Deployment (QFD) as a quality technique can be applied.

DIN describes a Quality Technique as 'the implementation of scientific and technical knowledge into main guidelines for quality assurance purposes' (DIN, 1992). At the present, a wide variety of quality techniques is available. In the literature (Breitkopf, 1997) a categorization of Quality Techniques between old instruments (i.e. the Value analysis, revisions, audits and the consequent analysis) and new instruments for Quality Analysis (quality cycle, statistic industrial process control, Taguchi-Method and QFD, among others) can be found.

QFD is a new instrument for quality management. Its systematic, progressive and preventive proceeding is focused on discovering errors prevention and not on error correction. This analysis is oriented to the continuous improvement of a product and on the solution of typical entrepreneurial problems. An alternative name for the QFD Analysis is the 'Customer Driven Engineering' or the 'Matrix Product Planning' (American Supplier Institute, Inc., n.d.)

QFD was created in 1966 by the Japanese Akao and was implemented for the first time by Mitsubishi Heavy Industries Ltd. in Kobe, Japan (Hauser, 1988). In German industry, QFD was used for the first time on the second half of the 80's by Bläsing (1989).

In principle, QFD is developed through an interdisciplinary group conformed by specialists of diverse areas. For product development through QFD a multifunctional expert team e.g. of Marketing, Development, Production Planning and Manufacturing is important (Hartung, 1994).

As a communication tool between the participants of the QFD Method the use of a graphic key document, a transformation matrix, is constructed. The first step of the analysis consists on the generation of the matrix that, due to its configuration, is called House of Quality (HoQ). It was developed by the Japanese Nishimura and Takayanagi and it is divided into several tables and works as an outline map that will be the planning and communication tool of the QFD Process (Reid *et al*., 1989). The method described above is the one to be employed on this paper.

The HoQ is a two-dimensional transformation matrix that relates the customer's wishes to the technical specifications of the product. In order to find this design, the technically oriented designer must identify or define product specifications or characteristics, which are usually described in a technical language and which very often contain some quantitatively formulated characteristics about the properties of materials and the principles of construction. The objective of this exercise is to find those specifications which meet the needs of the customer, at best in an optimal manner. In this context, optimization implies finding the highest possible satisfaction by the customer which can be achieved with the lowest possible effort by the producer. Figure 6 shows the basic structure of the House of Quality (ITI, n.d.).

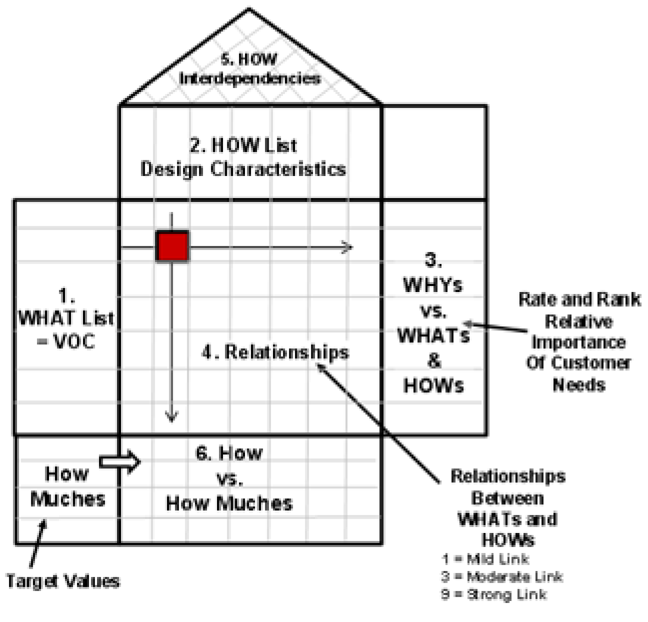


Figure 1. Basic structure of the House of Quality matrix-Source: International TechnoGroup Incorporated (ITI, n.d.).

Application of the House of Quality (HoQ) Methodology to Surface Geothermal Energy

With the purpose of assessing the different types of geothermal systems as well as the general circumstances that are given for the development of the geothermal industry in Saxony, the HoQ Analysis was used. The result was then applied to a group of low temperature geothermal systems with specific characteristics.

Figure 7 depicts the House of Quality analysis for geothermal energy, as developed in our project. The "reading" of the HoQ starts on the left-hand side in the blue rectangle (see number❶ on the graph), where the needs of the customers are identified and assessed in the shape of priorities (identified with number❷). From there, one moves to the green box upwards to the right (see number❸). This box contains the product specifications. These are being compared with each other in terms of compatibility or mutual exclusion. The outcome is shown in the triangle on top ("the roof", signalled with number❹). The most important part of the HoQ shown in this analysis is the large box with the grey entries below the green box and to the right of the blue box. This box contains the evaluation in terms of the needs of customers and the product specifications as identified by product designers. The better this interaction, the better the specifications are contributing to the satisfaction of the customers (please refer to number❺). The final evaluation of our analysis is shown in the pink row (the "floor", identified with number❻)[4] and with column number❼ with the rate of importance of customer needs to our technical specifications is given.

Defining the needs of customers

As explained above, the analysis starts with the identification of the needs or customers with respect to the product or the service under study. These needs are not restricted to technical functionalities but also include the transfer of relevant information, elements of comfort, such as customer service, and the economic conditions, such as costs. In order to identify these customer needs, one has to put oneself in the position of a customer and try to imagine the needs that are of relevance. In the House of Quality analysis, this is known as the Voice of the Customer (VOC)[5] (Six Sigma Dictionary, n.d.).

In our case of low temperature Geothermal Energy, the procedure for identifying the needs of customers can be described as follows. In the first place, information offered by individual suppliers and industry associations[6] (National Ground Water Association, n.d.) was evaluated. This step is based upon the assumption that suppliers have some level of information about what customers want. In essence,

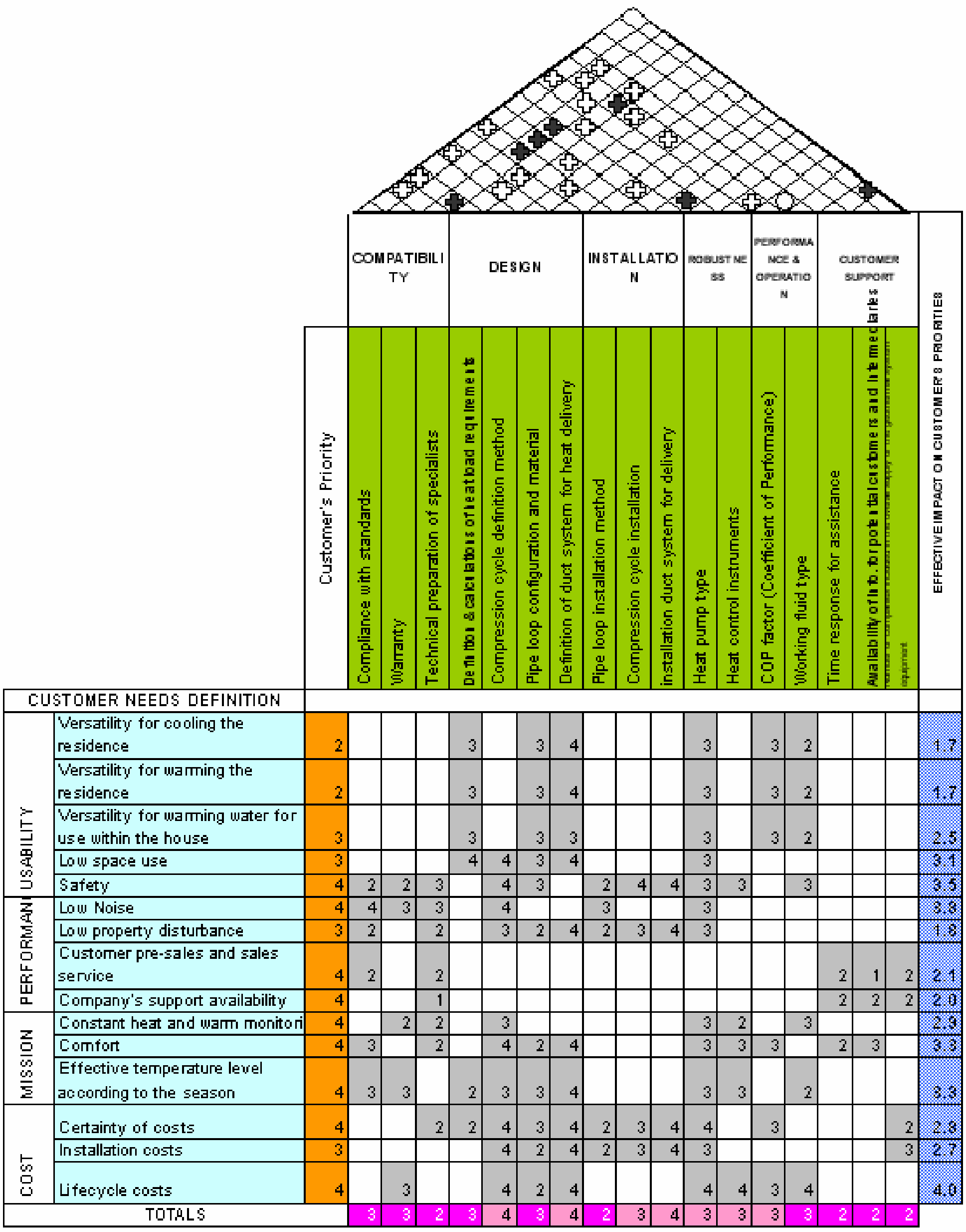
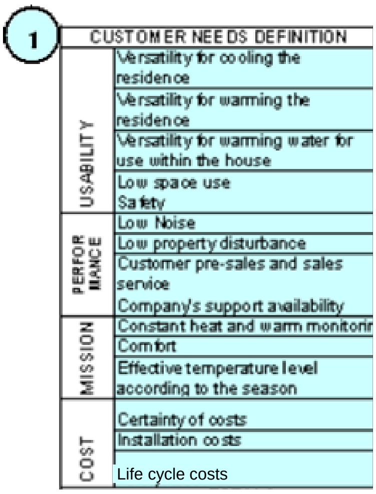


Figure 7. Basic elements of a House of Quality matrix for low temperature geothermal systems. Source: Outcome of this project.

there is no justification for the validity of this assumption but it can be assumed that suppliers care for the needs of the customers and, hence, the information given by them is useful and may be subject to further scrutiny during the analysis of the HoQ. Another valuable source dealt with information comes from the customers themselves in the shape of complaints[7]. Thirdly, various public and private organizations promoting certain interests such as consumer protection organizations publish information on geothermal technology systems, in particular with the intention of giving advice to potential buyers.



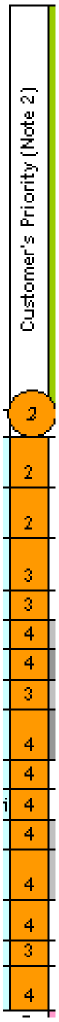
The needs are grouped into four main types: usability, performance, mission and cost. These needs were evaluated in order to arrive at customer priorities. Table 2 shows a description of the customer needs.

	CUSTOMER NEEDS	DESCRIPTION
USABILITY	Versatility for cooling and warming the residence	The product must be able to work for warming and cooling functions.
	Versatility for warming water to be used in the house	The product shall be able to be used for heating water.
	Low space use	The product must have dimensions that can be adapted to the space inside and outside the house. It has to be competitive with other similar products in size.
	Safety	The product must ensure safe operation for people, properties and the environment. In case of malfunctioning, the design must ensure that preventive measures are taken to avoid danger for people, properties and the environment.
PERFORMANCE	Low noise	The product must ensure acceptable noise levels that don not affect people's activities inside and outside their houses.
	Low property disturbance	During installation and operation, the risk to property disturbance (land, habitat, noise, other ground and underground installations) is minimized.
	Customer pre-sales and sales service	The customer requires precise information about the product, the risks, the advantages in order to build confidence about the technology. This implies also transmitting information at the right moment.
	Company's support availability	The company must ensure proper support (at any time, during the minimum time possible and with effectiveness) in order to solve a problem raised in the system.
MISSION	Constant heat and warm monitoring	No interruptions as well as effective heat or cold delivery monitoring (avoiding oscillations) must be ensured by the equipment.
	Comfort	The product shall be easy controlled and operated by the user. Maintenance shall be also easy achievable.
	Effective temperature level according to the season	The product shall be designed in order to bring the right temperature at a constant rate at any time during any season
COSTS	Certainty of costs	The customer shall have certainty of all costs before ordering the product (installation, operation, maintenance)
	Installation costs	Installation costs must be competitive with other similar products
	Lifecycle costs	These costs must be competitive with other similar products

Table 2. Customer needs description. Source: Outcome of this project.

Obtaining customer priorities

Once the customer needs are defined, an assessment on the priorities was made through a questionnaire asking for an evaluation of the customer needs. The outcome is a ranking on a 1 to 4 point scale of these customer needs in terms of priorities. A score of 1 indicates a low priority, a score of 4 indicates a high priority and scores of 2 and 3 indicate in-between priorities. The content of the questionnaire included sixteen questions related to (geothermal) heating systems, such as versatility, comfort, costs, customer service by suppliers and the attitude of customers to environmental issues. The original (German) text of the questionnaire is added to this paper in Annex I. The respondents were asked to evaluate all customer priorities by assigning values to each of them, with 1 representing the lowest and 4 revealing the highest priority.



The questionnaire was distributed to three different groups with a more or less clearly expressed relationship with low temperature geothermal energy: firstly to potential customers in Germany, secondly to academics and research people working in the geothermal area, and thirdly, to a group of technical experts working in geothermal activities, such as hydrology, geology and drilling. The answers (in the shape of weightings) provided by the potential customers were given a relatively higher importance than those of the other two groups. In essence, the values provided by potential customers were multiplied by two before being summed up with the values provide by the other two groups. Hence, the aggregation of the individual responses was achieved through a weighted procedure.

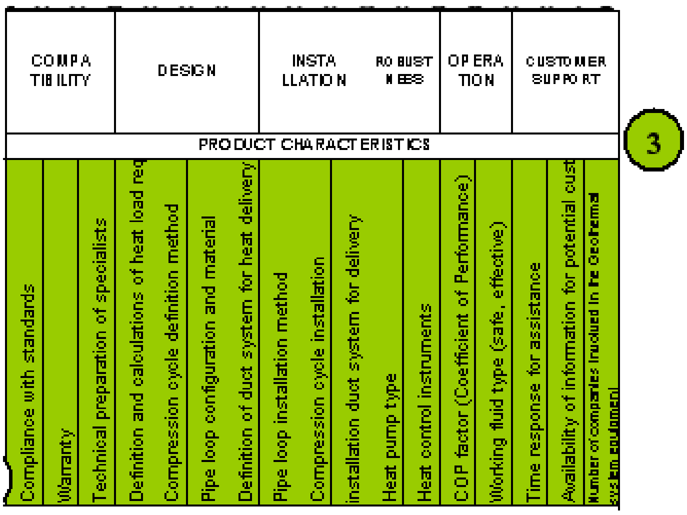
In total, 30 responses were received (See Annex II, Table of answers). At this stage of the research, we did not have the intention to achieve a fully validated and representative overview of the actual assessment of customer priorities. We are aware that such a representative overview is required in order to apply the HoQ Analysis for the sake of drawing practical conclusions, such as recommendations for policy makers. In that context, it may be of interest to test certain assumptions, e.g. the assumption that certain assumptions, e.g. the assumption that potential customers have priorities which are different from or more varying than those of "professionals". Our purpose with the current research is more related to the methodological intention of demonstration how such a HoQ Analysis may be applied to low temperature geothermal heating. Even with this small amount of respondents, we already noticed that different groups hold different opinions about certain priorities. Potential customers, for example, did not care as much for environmental issues as the professionals did.

The aggregated responses to questions 1 to 13 of the questionnaire are shown in the column labeled "Customer priorities" in the HoQ. They reveal that almost all requirements scored with values of 3 and 4. This outcome might suggest that the survey did address priorities which are indeed important for customers. In particular, the availability of assistance by industry and the level of the costs of installation but also the predictability of the operation costs are seen as important. In contrast, the versatility of technologies (i.e., the ability to switch from heating to cooling services) is not important. Hence, there is not really a demand for air conditioning, a phenomenon which is obviously explained by the geographical range of our sample. Not shown in the HoQ are responses to three more questions which were seen as interesting from the point of research. In Annex I these questions are numbered 14 to 16 and they relate to the environmental aspects of geothermal energy, the fact that the energy is self-supplied (no dependence or oil or gas) and does not depend on a grid and the degree of innovation. Responses show, however, that, in particular, potential customers do not attach much importance to these three items. After identifying the needs of customers and assessing their priorities in the views of the same customers, they are confronted with the technical product characteristics in order to determine how they are being met.

Determining the characteristics of geothermal energy systems

The third stage of the HoQ analysis consists in the identification, selection and definition of quantifiable characteristics, technical and non-technical, of the geothermal energy systems. This identification is necessary in order to assess which characteristics can meet which needs of the customer.

Examples of such characteristics include compatibility and standardization of processes and final products, the configuration of pipes, the installation of the compression system etc. Since we are dealing with geothermal heat, i.e. a service delivered to certain customers, the technical characteristics cannot be restricted to descriptions in technical language relating solely to parts and products of the technology itself. Customers obviously also want a “reliable” source of energy which requires warranties and quick maintenance services. As with many products and services, the quality is experienced by the customer during use. Hence, technical requirements with a direct impact of use, such as maintenance, must also be included. The identification of the technical characteristics for the geothermal energy systems investigated for this study was performed in the following manner.



In the first place, similar to the identification of the needs of consumers, the industry constitutes an important source of information. In this context, two main bodies of information must be evaluated. On the one hand, there are data of a technical background related the technological aspects of materials choices, design of equipment, manufacturing and installation.

Another important technical aspect corresponds to the troubleshooting of potential problems related to the operation itself, such as ductwork leaks and heating circulation issues that become more relevant as they depend on specific characteristics of a residence, such as design, insulation and age of the building[8] (Alliant Energy, n.d.).

A second important source of information relates to technical standards on performance, the compatibility of parts and conditions of warranty which are issued by specific organizations such as standards setting bodies. In the case of Germany, DIN (Deutsches Institut fuer Normung) is the most important organization for geothermal energy systems. Other organizations, such as the Fördergemeinschaft Wärmepumpen Schweiz (FWS), publish recommendations for minimum warranties for equipment in terms of quality and related durability characteristics[9] (FWS, n.d.; BFE, n.d.). For the purpose of an evaluation of current practices in the geothermal industry, these standards were compared with analogue standards applicable in the USA[10] (Air-Conditioning and Refrigeration Institute of the United States, n.d.).

Moreover, the use of low temperature geothermal energy systems is also subject to environmental regulations, since in most cases the fates of soils and of ground water may be affected. Hence, specific information provided by environmental regulatory agencies on issues such as restrictions on working fluids (cooling and heating agents), compatibility of systems equipment with environmental requirements, appropriateness of installation machinery, and training of installation staff has also been used[11] (Wirtschaftsministerium Baden-Württemberg, 2005).

All characteristics which were identified with the help in the information sources mentioned above were finally grouped into the following categories: Compatibility, design, installation, robustness, performance, customer support elements. Table 3 shows a description of the technical characteristics.

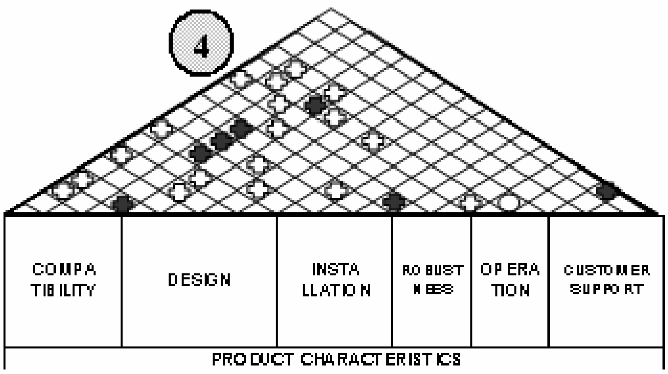
In essence, the technical characteristics are supposed to match one or more needs of the customers and, in addition, a good product is designed in such a way that no customer need is left out. Moreover, technical characteristics should be determined in such a way that they do not have mutually negative interactions but rather reveal synergies. If, for instance, a certain loop system of pipes increases the performance in terms of heat and it is very easy to install, there are synergies between these technical characteristics. If the opposite occurs, these are conflicts and a decision involving a trade-off is required.

Determination of positive and negative interactions between the characteristics of geothermal systems

	TECHNICAL SPECIFICATIONS	DESCRIPTION
COMPATIBILITY	Compliance with standards	Available number and type of standards used to design, build and operate the product applied by the company.
	Warranty	Number of years and type of warranty given to the client.
	Technical preparation of specialists	Number and type of certification that the company, designers, field workers and other members of the staff have in order to ensure the quality of the product. Years of experience of the company/workers on the field.
DESIGN	Definition and calculations of heat load requirements	Type of calculation, number of variables included, precision as well as safety factors.
	Compression cycle definition method	Size and type of heat pump (suction pump, compressor, pipe diameters, materials, operation and safety control devices).
	Pipe loop configuration and material	Length, configuration, pipe diameter.
	Definition of duct system for heat delivery	Type and amount of circulating fluid, control and operation devices, duct system configuration.
INSTALLATION	Pipe loop installation method	Installation type, amount of equipment required, noise, safety measures.
	Compression cycle installation	Duration of installation works, house disturbance (area), safety measures.
	Installation duct system for delivery	Duration of installation works, house structure disturbance (area), safety measures.
ROBUSTNESS	Heat pump type	Pump and compressor power, efficiency, materials.
	Heat control instruments	Number of instruments, number of locations where they have to be implemented, level of confidence.
PERFORMANCE & OPERATION	COP factor (Coefficient of Performance)	Heat amount produced/ energy input.
	Working fluid type (safe, effective)	Concentration and amount per unit of heat required, compliance with environmental and legal regulations.
CUSTOMER SUPPORT	Time response for assistance	Availability of customer support service, time required by the company to respond to a client's request.
	Availability of information for potential customers and intermediaries	Availability of information for potential customers and intermediaries. Effective marketing tools that respond to the clients demand for clear and important information about the technology, quality and prices.
	Number of companies included in the overall supply of the geothermal system equipment	Number of phone calls the customer needs to make in order to find a solution to his problem or request and time invested on the request.

Table 3. Description of technical characteristics in the HoQ.Source: Outcome of this project.

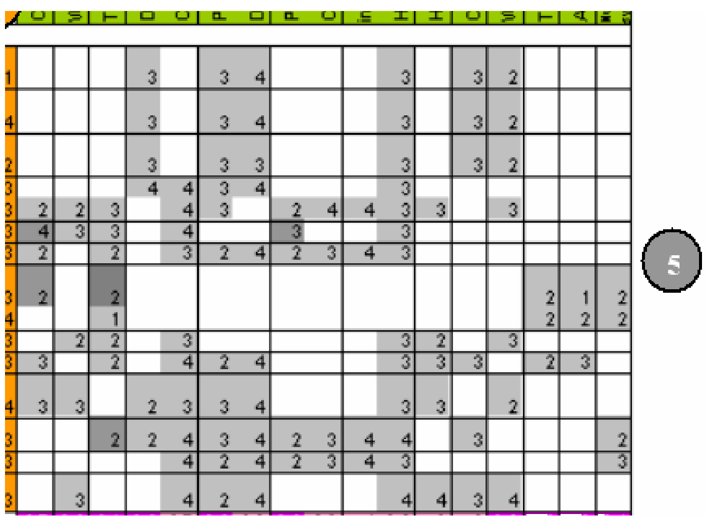
This is the fourth stage of the analysis of the House of Quality. It aims at finding synergies and mutually negative interactions among the technical characteristics of low temperature geothermal systems. The outcome of the analysis is represented in the top triangle of the HoQ, i.e., the "roof", identified by the number❹ in the HoQ. Taking the technical characteristics vertically "upward" and "bending" them into the roof – either to the left or to the right – generates a triangle with cells. Each cell can be filled in with a particular symbol showing synergies, negative effects or no effects at all between the respective characteristics. The higher the numbers of synergies, the better the technical characteristics are mutually compatible. The opposite is the case for negative interactions.



In the "roof", black crosses ✚ represent strong positive interactions (synergies), white crosses ✚ stand for weak positive effects (synergies) and the white circle ○ represents weak negative effects. An inspection of the "roof" reveals that, in summary, most cells do not have a mark, and, hence, there are not many interacting effects between the technical characteristics of the geothermal systems. There are only a few strong positive effects and quite a number of weak positive effects. Whenever there are positive interactions, they occur between, on the one hand, robustness and compatibility and design on the other hand and, again, between compatibility and installation. The conclusion drawn from the analysis points out the potential for optimization of the interactions between the characteristics of geothermal systems. By way of example, an attempt could be made to turn as many white crosses as possible into black crosses. Another way could lead to filling up more cells with either white or black crosses. At this stage, it is not possible to make a theoretical decision about which particular pathway one should select. In practice, however, taking into account budgetary and other means, which are available (e.g. alternative materials or processing techniques, etc.) it is important to come to a decision which leads to a practical approach.

Establishing the relationships between customer needs and technical characteristics

The fifth stage of the analysis of the House of Quality consists in the determination of the interaction between the needs of the customers and the technical characteristics of the geothermal systems. In essence, this part of the analysis leads to the identification of, on the one hand, gaps and lacks, and on the other hand, successful matches between customer needs and technical characteristics. There are several ways to perform this analysis. One way is to simply point out the gaps and the matches on a "yes – no" basis.
An alternative way, which is followed in the study, is to give quantitative weightings to the gaps and the matches. The weightings run from 1 (small interaction) to 4 (very strong interaction) and the outcomes of the analysis are shown in the House of Quality – see number❺. An inspection reveals that there are a number of empty cells. Depending on the way of reading (top to bottom), they represent a technical characteristic which does not meet the corresponding need or (reading left to right) a particular need which is not met by the corresponding technical characteristic. Since they are no empty columns, there is no technical characteristic which does not touch upon any need. Similarly, since there is no empty line, there is no need which cannot be satisfied. In that sense, one can point out that the needs of the customers are being covered by the totality of the technical characteristics.



According to the scale used in this research, a weighting of 4 corresponds to a technical characteristic that performs well with the customer need, in other words, this technical characteristic is able to respond to the corresponding customer need. A weighting of 1 means that this technical characteristic only responds weakly to the particular customer need. An example can be seen in Figure 2 regarding the interaction between the customer need for low noise and the technical requirement “compliance with standards”. In this case, meeting the standards for allowable noise limits inside and outside the house for the installation and the normal system operation of a geothermal system is seen as very adequate for meeting the particular customer need, and, hence, the weighting 4 is given.

Inspecting with some more detail, we see that all customer needs are met by more than one technical characteristic. Similarly, all technical characteristics meet more than one customer need. In one way, this may be described as a positive result, suggesting a good fit between the technical characteristics and the customer needs. In another way, the same outcome may be interpreted more critically, in the sense that it might not be necessary to have many technical characteristics meet one customer particular need or one particular technical characteristic serving many customer needs. From the design point of view, such a situation would imply that, in some way, there are too many technical characteristics serving a particular customer need. Some of these might not be required for the meeting of that particular customer need, and, hence, there is room for optimization. This applies especially to technical characteristics with similar columns, such as those labelled: “Pipe loop configuration and material” and “Definition of duct system for heat delivery” which serve almost the same customer needs in almost the same manner. From the point of view of the customer, one of both is superfluous. Whether it is technically possible or feasible to leave one of them out is a matter to be decided by the designer or the construction engineer.

An analogous inspection can be made with respect to the weightings. In principle, empty cells show gaps and lacks and high rankings are better than low rankings. Again, however, one faces the issue that many cells filled with many high rankings may be excessive from the point of view of the customer. A “slim” design may be such that all needs are being met by the smallest possible number of characteristics, which can be seen as essential. By way of example, this is the case for the customer need labelled ”Customer pre-sales and service” which is met by five technical characteristics labelled “Compliance with standards”, “Technical preparation of specialists”, “Time response for assistance”, “Availability of information for potential customers” and “Number of companies included in the overall supply of the geothermal system equipment”. The customer need labelled “Availability of company support” is met by only four technical characteristics. (Other customer needs are served by ten or more technical characteristics.) Hence, these four or five technical characteristics are essential and one may attempt to asses the consequences if one of them is missing or not performing. Actually, from an inspection of the weightings, one can see that the latter are low, scoring with 1 and 2. In addition, the corresponding customer needs have been given high priorities with rates of 3 and 4. Hence, two important customer needs are met by only a few technical characteristics with low weightings. This outcome shows that there is room for optimization.

This analysis can be continued and refined almost endlessly. One can, by way of example, also see that three technical characteristics of a typical technological nature labelled “Pipe loop configuration and material”, “Definition of duct system for heat delivery” and “Heat pump type” serve many customer needs (one of them with the lowest possible customer priority) with high and very high very weightings but without any impact on the two consumers needs just mentioned (”Customer pre-sales and service” and “Availability of company support”) which are, however, important. One has the impression that these two customer needs cannot be met by technical characteristics of such a specific technological nature. This seems to suggest that technical characteristics related to after sales customer service and maintenance should be seen as very important by suppliers: the job seems not to be done after the installation of the equipment. We saw, however, that the actual interactions rates are low.

Taking all outcomes together, one could draw a tentative conclusion stating that present-day geothermal systems dispose of technologies with good performances but without meeting the needs of customers with respect to after sales services and maintenance.

As a result, two ways for optimization seem to be advisable: either improve the technical characteristics related to technologies, in order to improve the reliability of the operation of the geothermal systems, or increase the quality of the after sales services and maintenance. In the absence of such an optimization, the use of geothermal energy systems will remain limited.

Construction of “totals“

The sixth stage of the analysis carried out in this research relates to the construction of totals for each technical characteristic of geothermal systems.

It consists in the calculation of an average value for the overall performance of each technical characteristic. Once this value is found, one can compare it with the values of other characteristics and do an appraisal of its relative performance in comparison to other technical characteristics. This comparison may lead to specific pathways for improvement. Note, however, that the performance, as measured by the “totals” is subjective, since it does take the weightings of the customer priorities on the 1 to 4 scale into account.

The procedure for the calculation is as follows: the interaction values of a given technical characteristics – as constructed in the previous step of the House of Quality in the matrix of Figure 2 under number❺ - are multiplied with the values of the customer priorities (identified in the same scheme under the orange column❷). The “total” for each technical characteristic is equal to the sum of all values in the respective column multiplied by the priority values and divided by the sum of all priority values. The final values for each characteristic are shown in Figure 2 in the bottom row of the HoQ (the “floor”), marked by the number❻.

In mathematical terms we can write the following:

$t_j = [\sum^n v_i * c_{i,j}] / n$

with

t_j = „total” of technical characteristic j

v_i = value of priority i

$c_{i,j}$ = interaction coefficient between customer need i and technical requirement j

n = number of customer needs

Since the priorities are given values between values 1 to 4, technical characteristics of the geothermal system meeting customer needs with a high priority (with values of four) will have more relevance in the final result, provided there is some interaction. As an example, the customer need “Company’s support availability” scores with a 4. If the technical characteristic “technical preparation of specialists” and the three characteristics under the ‘customer’s support’ category at the very right hand side of the HoQ would be very strongly meeting this need, the “totals” for these four technical characteristics would be comparatively high and one could conclude that their overall performance would be good. For a potential customer, this would be good news.

In reality, this is not the case, since all four technical characteristics have a “total” of 2 or 2.1. These values are far away from the maximum possible level of 4 and they confirm our findings in a more systematic manner: customer assistance is seen as very important by the customers but it is not adequately provided by the suppliers. In comparison, the “totals” in the “floor” of the HoQ for the technical characteristics relating to the “technology part” of the geothermal systems are much higher. Hence, we seem to have a general picture of a good technology and a poor service. The question remains whether good technologies lacking the appropriate after sales service will sell well.

Calculation of effective impact of customer needs

On the seventh and final stage, a construction of the effective impact of customer priorities is aimed to find which customer needs have more relevance regarding to the performance and characteristics of the product. Customer needs have an effect on the product analysis in two ways: first with the prioritization of those needs and second, with the amount and type of relationship of technical variables respecting those needs. The more the technical characteristics are related to a customer need and the higher the prioritization of this customer need, the more careful and attentive industry should be towards that customer need. In order to identify the relevance of the customer needs for the geothermal industry, a calculation of the effective impact of each customer need on the technical characteristics of the geothermal system was made.

Lifecyle costs	3		3			4	2	4				4	4	3	4			
TOTALS		2,7	2,6	2,1	2,8	3,7	2,6	3,9	2,2	3,3	4	3,2	3	3	2,6	2	2	2,1

6

According to Fehlmann (2003), the procedure for the calculation is as follows: for each customer need, the value of the customer priority (identified in column❷ of the HoQ) is multiplied with the sum of its respective weightings for each related technical characteristic (the rows within the matrix identified with number❺), in order to get a one single value. As an example, for the customer need 'versatility for cooling and warming the residence' the priority value of 2 is multiplied with the sum of the values of the
first raw of the matrix (the product characteristics' interactions) i.e., the numbers related to 'Definition and calculations of heat load requirements', 'Pipe loop configuration and material', 'Definition of duct system for heat delivery', and so on. The result of the calculation for each customer need will be then scaled between 1 (lowest value found) and 4 (highest value found among all results). The final values for each customer need are shown in Figure 2 in the left column of the HoQ, marked by the number❼.
As a result from these calculations, one can divide the customer needs into three groups: customer needs with a highly ranked prioritization (with values of three or four) with a highly ranked effective impact, customer needs ranked with lowest values which also have lowest effective impacts on the technology, and a third group consisting of customer needs with high prioritization but low effective impact. For the first group one can say that very important customer needs are well interpreted by the product characteristics, and therefore, the relationship between needs and the way the product is responding to those needs meets the expectations. For the second group of less important customer needs, the product characteristics are not well suited to meet those needs. Customer needs in the third category reveal the problem, since these needs are highly ranked by not highly reflected in the product characteristics.

Results of the house of quality analysis applied to various Surface Geothermal Energy system configurations

Given the fact that there are various types of geothermal systems and accounting for the general circumstances for the development of the geothermal industry in Saxony, the analysis of the HoQ was refined and applied to a group of low temperature geothermal systems with specific characteristics (see Annex III for the HoQ Analysis given for the group of configurations selected).
As a first step, the structure of each system can be divided into three main elements: the underground or underwater loop system which is the element that removes or releases heat to the surface due to temperature gradients, the second element is the heat pump, which uses this difference of temperatures between subsoil and atmosphere to exchange heat within the house, and, as the third element, the heat delivery system into the house.

		RESULTS																
EQUIPMENT LOOP TYPE		PRODUCT CHARACTERISTICS (Area ❸ of the HoQ matrix)																
		COMPATIBILITY			DESIGN				INSTALLATION			ROBUSTNESS		OPERATION		CUSTOMER SUPPORT		
Vertical	Exist.	3.0	2.6	2.3	3.0	3.7	2.8	3.9	2.2	3.3	4.0	3.2	3.2	3.0	3.2	2.3	2.0	2.1
	New	3.0	2.6	2.5	3.2	3.8	2.8	3.9	2.4	3.3	4.0	3.2	3.2	3.0	3.2	2.3	2.0	2.1
Horizontal	Exist.	3.0	2.6	2.3	3.0	3.7	2.6	3.9	2.6	3.3	4.0	3.2	3.2	3.0	3.2	2.3	2.0	2.1
	New	3.0	2.6	2.5	3.2	3.8	2.6	3.9	2.8	3.3	4.0	3.2	3.2	3.0	3.2	2.3	2.0	2.1
Pond	Exist.	2.7	2.6	2.2	2.4	3.7	2.3	3.9	2.2	3.3	4.0	3.2	3.2	3.0	3.2	2.0	2.0	2.1
	New	2.7	2.6	2.3	2.6	3.7	2.3	3.9	2.2	3.3	4.0	3.2	3.2	3.0	3.2	2.0	2.0	2.1
Open	Exist.	2.7	2.6	2.1	2.6	3.7	2.6	3.9	2.2	3.3	4.0	3.2	3.0	3.0	2.7	2.0	2.0	2.1
	New	2.7	2.6	2.1	2.7	3.7	2.6	3.9	2.2	3.3	4.0	3.2	3.0	3.0	2.7	2.0	2.0	2.1

Table 4. Total outcomes for the eight geothermal systems. Source: Outcome of this project.

These three elements, however, are always present in any geothermal system and, hence, they do not imply any categorization or distinction between systems. With respect to the loop system, such a distinction with respect to the configuration can be made. In this study the following four configurations, as explained in the first chapter of the paper, were studied: Open loop, vertical loop, horizontal loop and pond loop types. For the last three categories that work in a closed mode, the heat exchange medium analyzed as an exchange heat media was defined as glycol or a mix of water and glycol since this is widely used in practice.

In addition to these technical specifications, the type of residence on which the geothermal system is to be used was taken into account; in this case, the difference between an existing and a residence still to be built was made in order to analyze the implications of the various elements that could affect the final design, costs as well as possible difficulties that can arise from each specific situation.

After applying the House of Quality analysis to the four types of configuration and to an existing and a new residence, we obtain the following outcomes, as listed in Table 4.

With regard to the 'totals' (listed in Table 4) one can see, that in general, characteristics such as compatibility (see the third column corresponding to technical preparation of specialists) and customer support elements (availability, time response and interaction among companies) score rather low with respect to customer needs. One also sees that characteristics inherent to the product, such as installation and design of the duct system for heat delivery show that the technologies score higher in terms of customer needs. An alternative way to present the results from Table 4 consists in transforming them into bar charts. Figure 8 represents one example of the eight outcomes. Once again, this figure reveals the

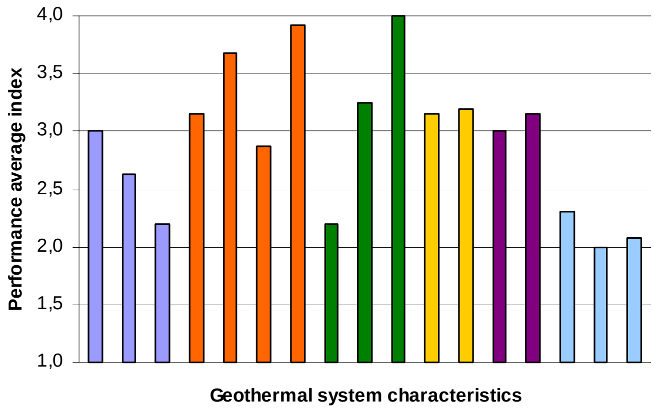


Figure 8. Total outcomes for a system comprising heat pump, heat distribution and an underground vertical loop configuration to be used in an existing residence. Source: Outcome of this project.

From the point of view of the effective impact of customer needs on product characteristics, two important aspects can be put into consideration. Inspecting Table 5, which shows the values of the effective impact for each customer need and type of configuration, we see that 'safety' and 'certainty of costs' score highest. It appears that these two aspects can be 'handled' well by the geothermal industry, since they belong to the characteristic of the geothermal system which the industry can control. Hence, in that respect, customer priorities are met.

		EFFECTIVE IMPACT OF CUSTOMER NEEDS ON PRODUCT CHARACTERISTICS														
EQUIPMENT LOOP TYPE		CUSTOMER NEEDS (Area ❶ of the HoQ matrix)														
		USABILITY					PERFORMANCE				MISSION			COST		
Vertical	Existent	1,4	1,4	1,6	1,7	4,0	2,4	2,3	1,3	1,0	2,0	3,4	3,3	3,8	2,3	3,4
	New	1,4	1,4	1,7	1,7	4,0	2,4	2,5	1,4	1,0	2,0	3,4	3,3	3,9	2,3	3,4
Horizontal	Existent	1,3	1,3	1,6	1,6	4,0	2,3	2,2	1,3	1,0	1,9	3,3	3,2	3,7	2,3	3,3
	New	1,3	1,3	1,7	1,6	4,0	2,3	2,4	1,4	1,0	1,9	3,3	3,2	3,8	2,4	3,3
Pond	Existent	1,3	1,3	1,7	1,6	4,0	2,5	2,3	1,2	1,0	2,0	3,5	3,2	3,9	2,4	3,5
	New	1,3	1,3	1,8	1,6	4,0	2,5	2,4	1,2	1,0	2,0	3,5	3,2	3,9	2,4	3,5
Open	Existent	1,2	1,2	1,6	1,8	4,0	2,5	2,4	1,2	1,0	1,9	3,5	3,2	4,0	2,4	3,4
	New	1,2	1,2	1,7	1,8	4,0	2,5	2,4	1,2	1,0	1,9	3,5	3,2	4,0	2,4	3,4
	Average	1,3	1,3	1,7	1,7	4,0	2,4	2,3	1,3	1,0	2,0	3,4	3,2	3,9	2,3	3,4

This looks different for customer needs related to the performance aspects of the product such as 'customer pre-sales and sales service' and 'company's support availability'. For theses needs, the priorities of the customers are much higher than the effective impact with regard to the technical characteristics described in the HoQ matrix. Figure 9, which shows the difference between the prioritization made by the client and the effectiveness impact of customer priorities, helps to understand this tendency. We see that there are large discrepancies between priorities and effective impacts in particular in the case of performance aspects. Hence, there is substantial room for improvement from the point of view of the geothermal industry.

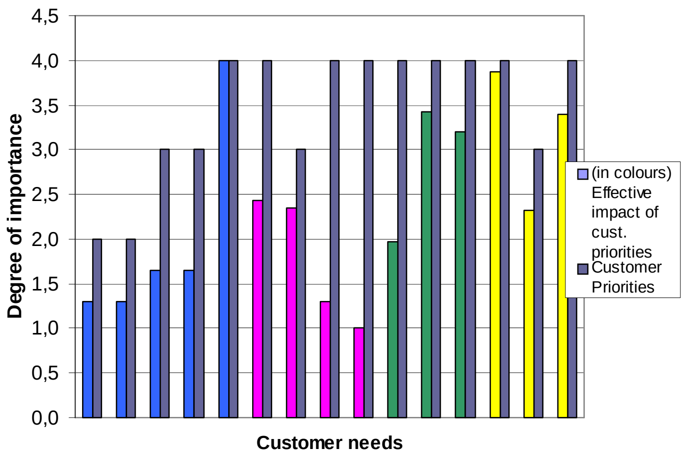


Figure 9. Comparison between customer priorities and the effective impact of customer priorities on the technical specifications of geothermal systems. Source: Outcome of this project.

Conclusions and recommendations

In terms of methodology we see that the House of Quality is a good tool for answering the question raised at the outset of the paper, i.e. whether there are any weaknesses and strengths in the geothermal industry as it stands today in Saxony (and probably elsewhere too). As shown, one can see that the technologies which are in place meet customer requirements very well, but other important technical characteristics, such as customer assistance, do perform les well. The instrument of the House of Quality helps to clarify this matter and puts a perspective for improvement.

The paper does not show final results, since some of the research tasks have been performed at a preliminary level. There is certainly a need to present the questionnaire to a larger sample of respondents in order to find out to what extent individual weightings differ and what kind of statistical distributions of such weightings around means or modal values should be used. In the same context, a question for further research relates to the degree the answers of the specialists and of potential customers tend to converge around certain values.

Moreover, not all the linear mappings available within the House of Quality Analysis have been used and there is room for further investigations, such as finding the overall degree of performance of the technical characteristics with respect to the overall picture revealed by the customer needs (the so-called convergence factor)[12] (Fehlmann, 2003) and the market analysis regarding the performance of geothermal technologies with regard to other technologies for the same use.

However, even at the current stage of the research, the results do reveal quite a high level of plausibility and, hence, some recommendations can be made.

It has become obvious that the performance of low temperature geothermal systems shows the following important elements:

- The level of technology as such as in terms of components (heat pump design, loop design and installation) has reached a mature stage of development.
- Vertical as well as horizontal loop types are the ones showing a better performance in most aspects than other geothermal loops.
- The type of residence (existing or new) affects significantly factors such as the difficulty of installation and the costs
- The questionnaire shows that customer priorities are not only oriented towards the technology performance itself but also to costs and the support by servicing companies. Less important are the environmental and 'versatility' factors.
- The geothermal industry business (support and infrastructure) and the technical expertise of companies can be improved greatly.

This last factor certainly merits attention for possible improvement. In the following and final section, we list some suggestions for such an improvement which may be the subject of further study.

Recommendations

- Improve the strategies of companies regarding the channels and transmission of the information. This will facilitate the contact between the enterprises and the customers and intermediate agents (e.g. architects) as well as promotion on the use of geothermal energy. One way to achieve this is through the creation of multidisciplinary alliances (i.e. ensuring similar quality performance)
- Improve communication among partners or associates in order to bring to the client less risk factors during the pre-sales and lifecycle stages
- Integrate the quality requirements, including customer support elements (warranty and customer assistance), among partner companies into one single system. This system should be seen as a single product instead as the sum of independent units to the client.
- Homogenize rules of design, installation and maintenance among companies or groups of companies (standards, warranty, and technical background of human resources). This will bring confidence in the use of geothermal systems.
- Improve the handling of technical procedures and the level of standardization of some loop types with less level of performance in the HoQ (pond and open loops) in order to increase their competitiveness.
- Develop a procedure for cost analysis evaluation in order to generate important information about the future prospects of geothermal energy use and its competitiveness in house heating.

Annex I

Questionnaire for Clients or Potential Geothermal system clients.

Annex II

Table of Answers.

Annex III

HoQ Analysis for the group of geothermal systems studied in this project.

Notes

1. VDI-Guidelines Abbreviation for Verein Deutscher Ingenieure e. V. Rictlinien (German Engineering Association)
2. A heat pump is a device that warms or cools a building by transferring heat from a relatively low-temperature reservoir to one at a higher temperature. The U.S. Department of Energy presents on his web page an overview about the basics (description, use, and main parameters for evaluation) of a heat pump http://www.eere.energy.gov/consumerinfo/heatcool/hc_space_geothermal.html
3. From the German 'Kreditantstalt für Wiederaufbau', Credit for Reconstruction and Development
4. The House of Quality contains some more rooms such as "the basement" which are not used in our analysis.
5. According to Six Sigma®, the "voice of the customer" is the term used to describe the stated and instated needs or requirements of the customer. The voice of the customer can be captured in a variety of ways: Direct discussion or interviews, surveys, focus groups, customer specifications, observation, warranty data, field reports, complaint logs, etc.
6. A good example of such information web site is provided by the National Ground Water Association (USA) on the "Frequently Asked Questions about GeoExchange Units" brochure. Address: ww.wellowner.org/public/public.html.
7. In this context, the project report made by the Geothermal Heat Pump Consortium in the USA entitled "Investigation of Multiple Callback Situations with Residential GeoExchange Systems" on November 13th, 1997, was very helpful.
8. A good assessment of this issue is given by Alliant Energy, which, in partnership with the Electrical Power Research Institute of the United States, created a web page (http://www.alliantenergygeothermal.com/howitworks/index.htm) with relevant information for contractors, engineers or building managers.

9. For an overview of these publications, see Fördergemeinschaft Wärmepumpen Schweiz (FWS) http://www.fws.ch/. In this context, it is interesting to notice how “Energie Schweiz”, a program of the Swiss government for the promotion of an efficient use of energy and renewable resources, uses these publications for advising customers: http://www.energie-schweiz.ch/imperia/md/content/gebudeanlagen/produkteplattform/leistungsgarantien/7.pdf.

10. As an example, the Standards issued by the Air-Conditioning and Refrigeration Institute of the United States include, among others, specific procedures and documentation about a wide range of uses of geothermal heat pumps and their interaction between the overall heating or cooling system within a house. http://www.ari.org/std/standards.html

11. See, for example, Wirtschaftsministerium Baden-Württemberg, Referat 44: Lebenswissenschaft, erneuerbare Energien und rationelle Energieanwendung: „Wärmepumpen-Technologien“, Stuttgart, 28. Februar 2005, which also contains information about the environmental permits which are required for (vertical) drilling systems. Retrieved http://www.wirtschaf tsinformationen-bw.de/Energie/Download s/Erneuerbare_Energien/WP-Technologie.pdf.

12. See, for example: Thomas M. Fehlmann: Linear Algebra for QFD Combinators – A Tutorial for QFD Practitioners how to Combine Measurements with Deployments, October 2003, available at www.e-p-o.com.

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