Energy Autarky of the Monte Rosa Cabin – A Challenge for the Building Services Engineering Concept

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SUMMARY

Close to Zermatt (Switzerland) the new Monte Rosa mountain cabin is going to be built in 2008 at 2810 metres above sea level. This hut is designed to accommodate 120 mountaineers. Furthermore, it is going to mark a milestone in high alpine building presenting an attractive, unconventional architecture combined with both a surpassing comfort and a high degree of energy autarky of over 90%.

Of course several measures have to be taken to achieve such a high degree of autarky while always keeping a limited budget in mind. Apart from the technical systems, which are based on existing technology (combined heat and power unit, photovoltaics, thermal collectors), there will be an innovative wastewater treatment and, first and foremost, an ingenious energy management. Only an optimised operation taking into account external conditions such as weather forecast and anticipated occupancy schedules is likely to achieve the demanding goal of the high degree of autarky. Detailed thermal simulation is used on the one hand to dimension the building services engineering systems and on the other hand to develop the best energy management strategies.

This is a joint project of the Swiss Alpine Club (SAC) together with the Swiss Federal Institute of Technology in Zurich (ETH), while the energy strategy and building services technology concepts are worked out by the Centre for Integral Building Technology (ZIG) at the University of Applied Sciences of Central Switzerland, Lucerne (HTA).

Figure 1. The new Monte Rosa cabin amidst impressive glaciers showing the Matterhorn in the background (computer visualisation by ETH).

INTRODUCTION

The new Monte Rosa cabin is planned in the context of the 150-year anniversary of the ETH in a joint project with the SAC. The hut is situated 2810 metres above sea level amidst pure nature, surrounded by the Gorner, Grenz, and Monte Rosa glaciers and about 10 kilometres away from the world-known health resort Zermatt. The Monte Rosa cabin is one of the best-known and most visited alpine huts of Switzerland and the starting point for several mountain hikes.

For this new building the engineers aim high. The mountain cabin shall offer an unheard of comfort for such a mountain shelter. Rooms will be heated and mechanically ventilated, the hut will be supplied with enough fresh water such that the visitors can enjoy a hot shower and the wastewater is going to be purified on-site to be reused as greywater. All of the above-average comfort shall be provided without negative effects on the hut's required energy supply. Indeed the hut will feature an energy autarky of 90% meaning that 90% of needed energy is obtained locally from renewable sources.

The concept worked out in detail by HTA incorporates technologies and procedures by which the high requirements concerning comfort, energy demand, and autarky can be achieved – all the time bearing in mind that the budget is limited. Thermal simulations turned out to be of crucial importance to both reach the high planning confidence and permit to establish that the set goals can be achieved.

This paper offers an overview of the aims, the approaches, and the proposed solutions to building services engineering.

METHODS

The simulation package IDA ICE 3.0 [1] is used to set up a very detailed simulation model both of the building and the energy and building services system based on the formulation of the energy strategy and building services engineering concept described below. This model takes into account the climate data, the geometry, the physical properties of the building envelope, all components of energy supply and building services, as well as the thermal loads of persons, equipment, and lighting. The entire system, room temperatures and conditions, as well as the energy flows are being calculated dynamically using hourly steps over a whole year.

These simulations pursue three main aims:

- Represent the actual project status,
- Identify the important factors and system sensitivity on these,
- Optimise the building envelope, the building services, as well as the operation (energy management).

At the same time the investment costs are calculated in a second computing model since the cost is a dominant factor for project realization. This second computing model integrates the investment costs and finds how the energetic aim of 90% autarky are reached at the lowest cost.

Starting from the first design solution, different scenarios with varying exterior conditions are calculated to analyse the stability and robustness of the technical solution examining:

- How does the system react to changed climate conditions (e.g. fewer sunny days than expected)?
- How does the system react if the number of visitors exceeds expectations?
- How does the system react to the failure of single components (system redundancy)?

The following chapter comments on the results of the first phase of the project "Definition, dimensioning, and optimisation of both energy and building services technology". The second phase of the project "Energy management" is currently subject to ongoing work at the HTA.

RESULTS

Water

Water supply and wastewater treatment are top-ranking questions considering the hut's location far away from any infrastructure [4]. On top, the water demand surpasses the average demand of mountain shelters due to the elevated comfort requirements of the cabin (hot water showers, toilets with water flushing).

The calculations show that even using water saving devices, 219 m^3 of fresh water are needed annually. This amount can only be won by catching the melt water around the hut. At the same time it is essential to take into account that melt water accumulates primarily during the summer months (typically during two months only). Therefore the melt water needs to be collected and stored until the next summer. Should the water tank not be built high enough above the hut, a booster pump is necessary. Although the quality of this water is quite good in general, it cannot be directly used as drinking water.

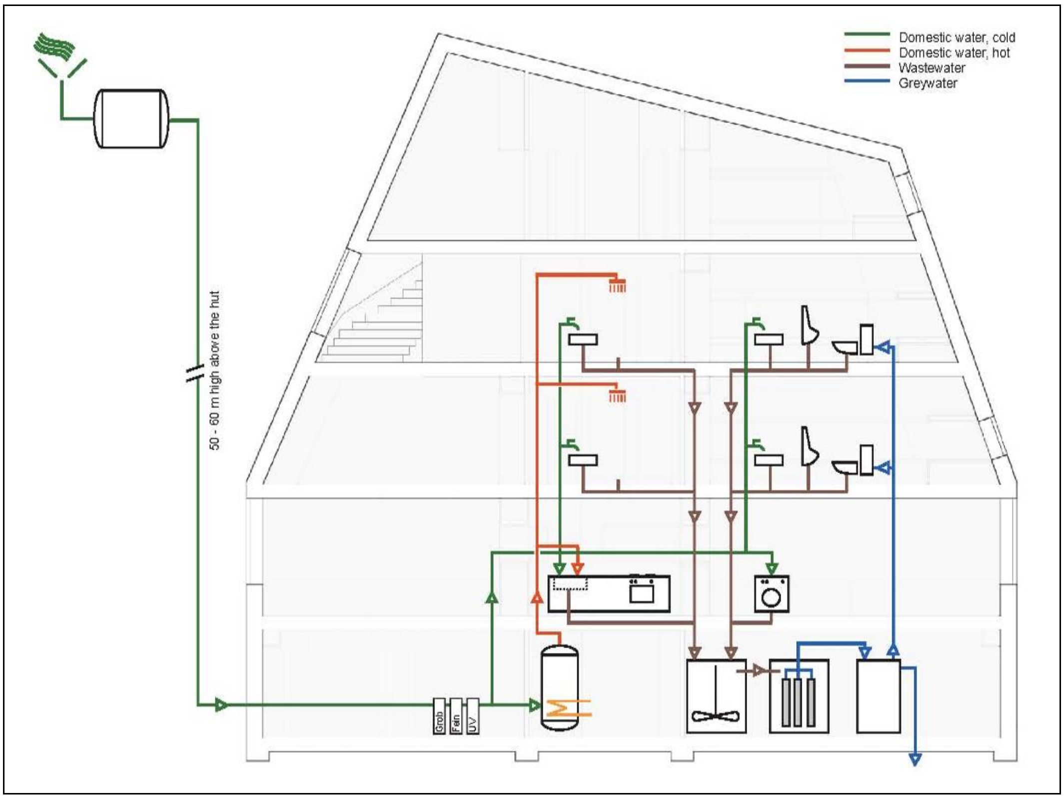

Figure 2. Concept of water supply and wastewater treatment.

After suitable treatment the melt water is used for showers, for cooking, for personal hygiene, and laundry. The toilets are flushed with greywater that originates from the wastewater treatment system. This system is new for such sites and based on the principle of microbiological sewage plants [2]. Tests on the nearby mountain *Hohtälli* show very promising results.

The water balance presents itself as follows:

Supply water:	219 m^3/a, thereof 120 m^3/a hot water
Greywater:	100 m^3/a
Wastewater:	320 m^3/a

Figure 3 shows the water demand prediction over the year, the expected melt water volume, and the resulting water level at the water tank. Clearly recognisable are the weekends with high water demand and the peak weekends with the maximum demand (about 3500 l/d which equals 30 litres per guest). Well recognisable is the fact that the critical phase of storage is reached in early summer just before the melting begins. Depending on the effective water level at the water tank it is generally necessary to save water in spring, which is easily and most effectively done by shutting off the showers.

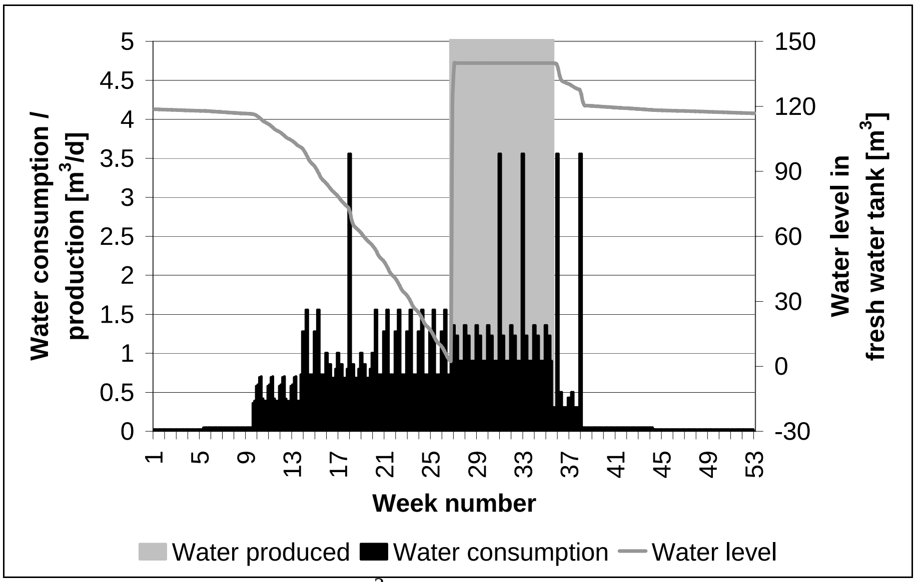

Figure 3. Water supply (20m^3/d during summer) and use, water level at the water tank.

Another point of importance concerns frost protection of the water tank since it will be placed outside the hut. Using good insulation and covering the water tank several metres high with soil solves this problem. In addition, the water tank will be heated during winter by the excess electricity from photovoltaics so that the water temperature will never fall below 5 °C.

Energy

For the needed electricity and heat energy there are photovoltaics (about 84 m^2) and thermal collectors (about 56 m^2) available, respectively. Optionally, a wind generator could supplement those facilities. Although no manufacturer could be found to date who would guarantee its operation at this exposed site. Solar energy can cover 90% of the energy demand not counting cooking, which in a later phase could be covered by solar energy as well. A combined heat and power unit (CHP) powered by gas or rapeseed oil serves as a backup and to cover the demand during peak hours. Both a hot water storage tank of 6000 litres (4500 litres for heating and 1500 litres for sanitary hot water) and batteries having 184 kWh capacity buffer the occurring differences between heat supply and heat demand.

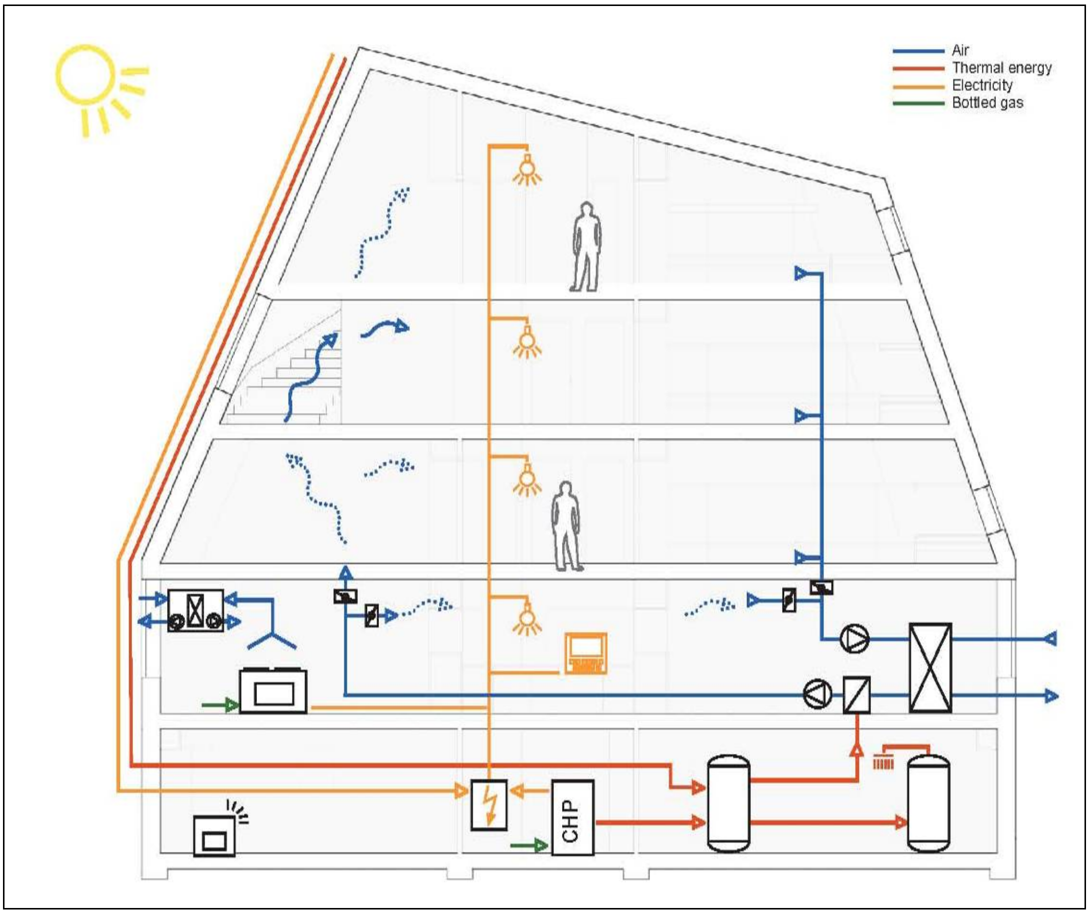

Figure 4. Basic scheme of energy and building services technology.

Building services technology

The cabin will be mechanically ventilated, which is a novelty for mountain shelters. The mechanical ventilation serves two purposes: First it helps to avoid structural damage mainly by mould (the risk is quite high since the building envelope is designed to be extremely airtight) and second, it ensures a basic thermal comfort for the occupants. At the same time the building will be heated by air. The supply air is blown into the open staircase and the exhaust air is drawn off the rooms. After heat recovery, the air is blown outdoors. During the operation of the hut (beginning of March till end of September) the internal heat loads (i.e., persons, equipment, and lighting) together with passive solar gains suffice to ensure the required air temperature of 5 - 20 °C, whereas the target value lies at 15 °C.

The dynamic simulations of the building services technology show that with the chosen concept it is necessary that especially during winter time, in the absence of the warden, the combined heat and power unit, is switched on to ensure the temperature of 5 °C to avoid freezing of piping. The buffers will be charged to 100% while they get uncharged during the few peak weekends when the CHP is used for the production of electricity.

The above described dimensioning of different parts of the facility is based upon elaborate dynamic simulations. Those simulations served to optimise, amongst others, the following parameters:

- Size of batteries and hot water storage tank,
- Optimal division of the available area into photovoltaics and thermal collectors,
- Clarification of whether an improvement of the building envelope or the augmentation of the area of thermal collectors (or the hot water tank) is more cost-effective.

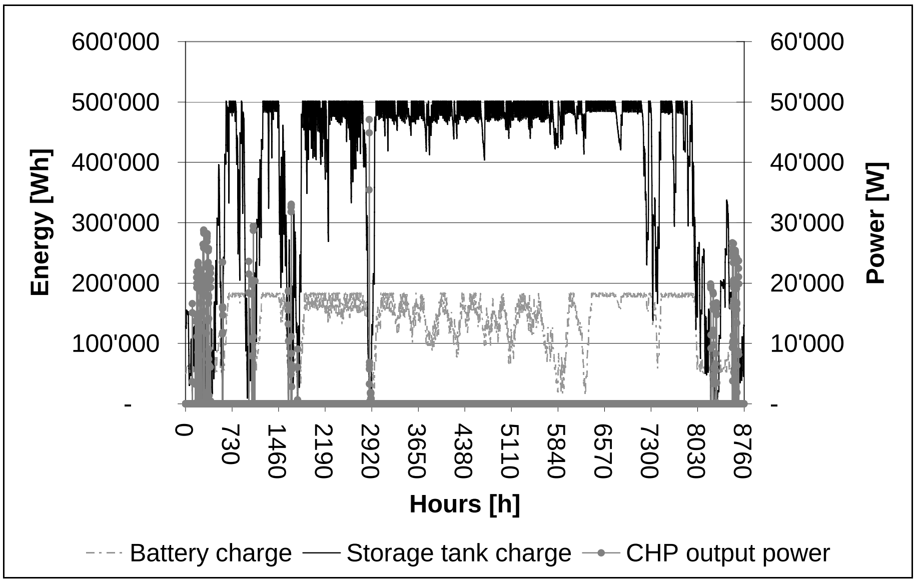

Figure 5. Results of simulations: State of charge of batteries and hot water storage tank, net total power production (heat and electricity) of CHP.

Figure 6 shows an example diagram for this optimising process. For different fractions of a certain total area covered by thermal collectors one can read off the possible degree of autarky on the ordinate. The abscissa hereby displays the total area covered by both photovoltaics and thermal collectors.

The figure shows that to reach a degree of autarky of 90% and using the best ratio of photovoltaics and thermal collectors one would need at least 125 m^2 total covered area. The concept of HTA proposes to cover up 140 m^2, taking into account the local situation.

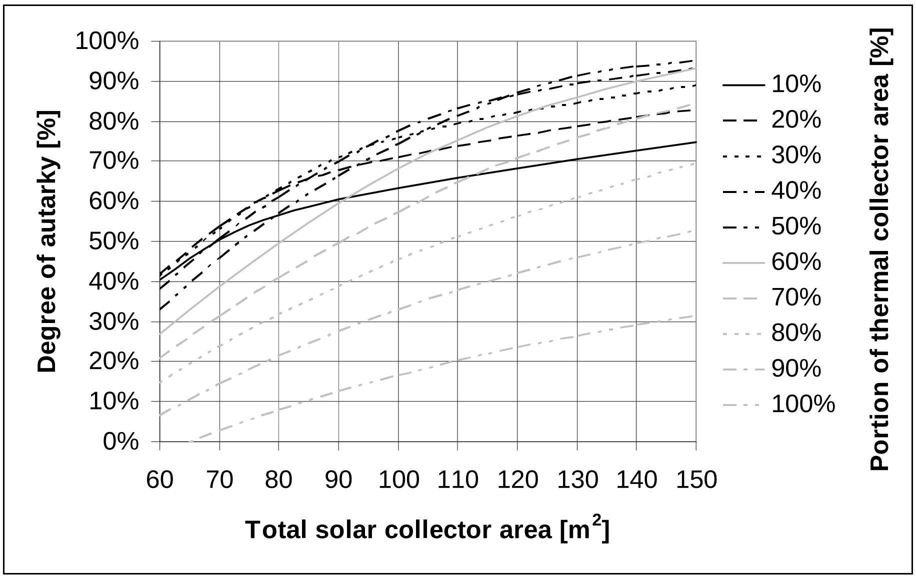

Figure 6. Optimisation of the total area covered with collectors and the resulting degree of autarky. The different curves represent the portion of thermal collectors to the total collector area.

Another optimising process concerns the building envelope (U-value of opaque parts and windows) and the area covered by thermal collectors taking into account the investment cost (see Fig. 7). The figure shows clearly the interrelationship of the area covered by thermal collectors and four different qualities of U-values of the façades. The right figure shows distinctively that even using a comparatively bad building envelope (U-value opaque 0.19 W/m^{2}K, U-value windows 1.2 W/m^{2}K, code 'H019_F120') the investment cost for the building services would not increase much. In contrast, building a good façade (U-value opaque 0.13 W/m^{2}K, U-value windows 1.0 W/m^{2}K, code 'H013_F100') would increase primarily the building envelope cost. Therefore one reaches a better cost-benefit ratio planning a "poor" building envelope and increasing the area covered by thermal collectors.

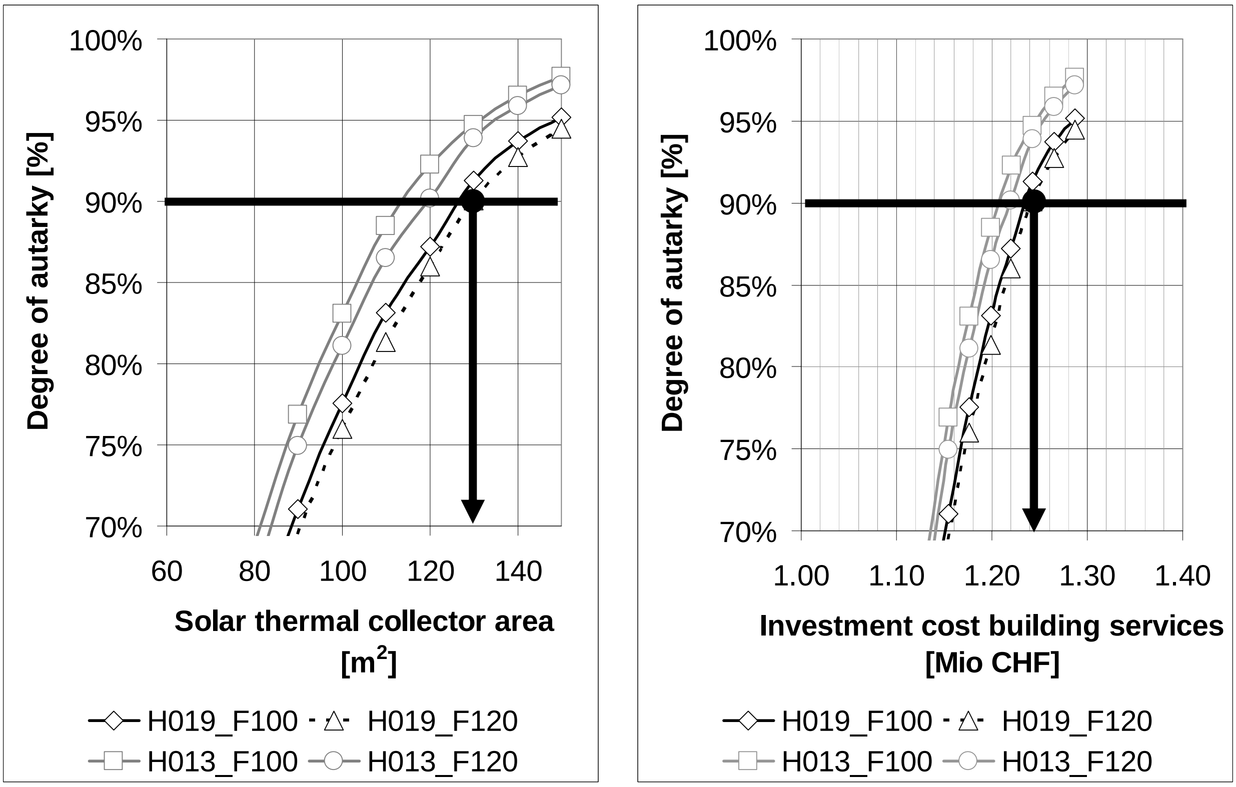

Figure 7. Optimisation among total area covered by collectors, the quality of building envelope ("H019_F100" etc.), investment cost for building services, and degree of autarky.

DISCUSSION

The part "energy and building services technology" for the new Monte Rosa cabin shows that it is certainly possible to reach an extraordinarily high degree of autarky at absolutely affordable investment costs. It is vital that because of the remote location only proven and robust systems are employed. No unproved equipment or sophisticated gadgets will be installed because one cannot take any chances at a hard-to-reach, remote location as an alpine cabin in the middle of the mountains. Despite the reliability of the employed systems (photovoltaics, thermal collectors) it is paramount to provide redundancy and therefore plan a backup system to ensure full security of supply. Furthermore, the paper shows that energy is just the second largest challenge in the conceptual design of such a building. Much more demanding is the supply and recycling of water since, after all, wastewater cannot be disposed of untreated as is quite common nowadays [3, 4].

One important insight will affect the next steps of the project: The presented concept will reach the desired degree of autarky with a clever optimised energy management. This energy management system incorporates the weather forecast and expected occupancy schedules to allow an optimal management of both batteries and hot water storage tank. This is also important to guarantee an optimal operation of the wastewater treatment system. The wastewater tank should be emptied before the peak weekends so that the energy-intensive treatment system can be operated at off-peak times when free electricity is available. Further dynamic simulations will focus on the development of such algorithms for the building automation system and the energy management as well as their validation. Another crucial element is going to be the investigation of sensitivities and the analytical testing of different scenarios to determine the robustness of the planned energy strategy and building technology concept.

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