OPTIMIZATION OF CONTROL STRATEGIES – SWITCHING BETWEEN PASSIVE COOLING AND REVERSIBLE HEAT PUMP

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Abstract: So far analyzed geothermal systems in office buildings differ in their operation, so that a generalization of the results is restricted. Within the scope of the R&D project geo:build ground coupled supply systems for heating and cooling in the buildings are being analyzed both in theory and practice. The focus is to study an adjustment of the cooling modes and switching between passive cooling and chiller mode. Furthermore, a development of energetic and economical sensible combinations of these technologies is foreseen. In the project, four office buildings will be measured and analyzed. The planned targets for efficient combination of passive cooling and chiller mode are not yet sufficiently implemented, despite of implemented improvements.

Key Words: ground coupled reversible heat pump, energetic and economic efficiency, optimization, control strategies, monitoring

1 INTRODUCTION

In theory, it is planned to use primarily an efficient passive cooling for cooling the office buildings in the summer. However, in practice, it is determined, that buildings with integrated chiller use continuously mechanical cooling. This is partly due to an insufficiently coordinated control of passive cooling (PC) and chiller mode (CM) operation and, on the other hand, due to a raised soil temperature. As a result, a balance between heat injection and extraction can be disturbed and the possibility for using the passive cooling is often not guaranteed.

Within the scope of the ongoing R&D-project "Optimization of ground coupled heating and cooling supply systems in office buildings - reversible heat pump and passive cooling", control strategies of switching between passive and active cooling (rev. heat pump) are being analyzed both in theory and practice. The project is conducted by the IGS - Institute of Building Services and Energy Design at the Technical University of Braunschweig in cooperation with a scientific partner and the two industrial partners.

2 METHODOLOGY OF THE RESEARCH AND DEVELOPMENT PROJECT

At the beginning of the research project, a closer look is taken at coordination and switching between passive cooling and chiller mode. Subsequently, possible energy efficient and economically sensible combination of this technology will be developed.
The focus is on the monitoring of four office buildings (Table 1) with a reversible heat pump and passive cooling mode as well as the analysis of their operation strategies and operating system functions. Additionally building and plant simulations as well as simulations of heat extraction and heat injection into the soil and its thermal behavior will be carried out. The knowledge acquired from the simulations will be implemented and tested (see Figure 1).

The aim of the R&D-project is to optimize the implementation of geothermal heat and cold storages as well as to develop and test more efficient use of these storages. To achieve an improved storage efficiency ratio, optimized operation strategies and application-oriented storage concepts should be further developed and evaluated in particular with ground coupled chiller and the operation of switching between chiller and passive cooling mode.

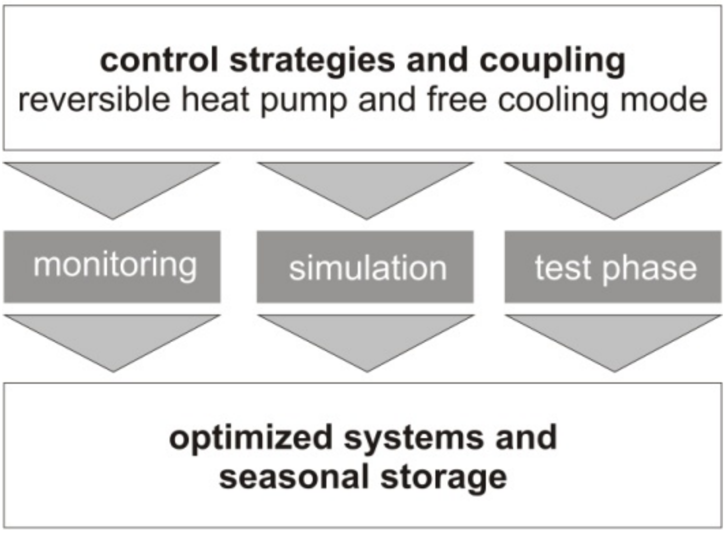

Figure 1: Proceedings

Approaches to design and control in terms of

- operation and control concepts enabling an immediate switching between chiller and passive cooling mode,
- potentials of an intermittent operation of the probe field,
- the regeneration phase between chillers operation and passive cooling mode,
- a constant thermal conditions in the soil as well as a realizable heat extraction and heat injection, the available load to the building and the correlation between heat extraction and heat injection

should be processed.

Table 1: Data of building, geothermal systems and heating-/cooling concepts (NFA – net floor area)

Gelsenwasser AG, Gelsenkirchen		
	building data	office building NFA 6.189 m² year of construction 2004
	geothermal system	36 borehole heat exchanger à 150 m
	design heating load	total building 207 kW / 43,6 W/m^2_{NFA} heat pump 326 kW
	design cooling load	total building 305 kW / 9,3 W/m^2_{NFA} passive cooling 200 kW rev. heat pump 320 kW
VGH Regionaldirektion, Lüneburg		
	building data	office building NFA 3.957 m² year of construction 2002
	geothermal system	101 energy piles à 20 m
	design heating load	total building 350 kW / 88,5 W/m^2_{NFA} heat pump 85 kW
	design cooling load	total building 120 kW/ 30,3 W/m^2_{NFA} passive cooling 80 kW rev. heat pump 89 kW
Office Freundlieb am See, Dortmund		
	building data	office building NFA 2.930 m² year of construction 2010 / 2011
	geothermal system	12 borehole heat exchanger à 144 m
	design heating load	total building 125 kW / 42,7 W/m^2_{NFA} heat pump 87,6 kW
	design cooling load	total building 95 kW / 32,5 W/m^2_{NFA} passive cooling 60 kW rev. heat pump 68,4 kW
Lecture Hall, Salzgitter		
	building data	lecture hall building NFA 3.296 m² year of construction 2012 / 2013
	geothermal system	15 borehole heat exchanger à 95 m
	design heating load	total building 92 kW / 28 W/m^2_{NFA} heat pump 60 kW
	design cooling load	total building 152 W / 46 W/m^2_{NFA} passive cooling 60 kW rev. heat pump 45 kW

3 CONTROL STRATEGIES FOR SWITCHING BETWEEN THE MODES

Already at the beginning of the project, it could be determined how large and variable implementation and integration of passive and active cooling in a geothermal plant can be. Moreover how important it is to implement and coordinate this combination in the right way to operate buildings efficiently and to protect the ground.
A literature review as well as a survey of the heat pump manufacturers show that the previous and common rules for the combination of passive cooling and chiller is based on simple comparisons. According to it, four main control strategies can be defined:

1. set-point regulation: as soon as a defined temperature is exceeded or undercut, the operation mode changes from PC to CM and vice versa. Parameters such as supply temperature or return temperature (distributor, CCA, HVAC, etc.), outlet or inlet temperature from / into the soil, room temperature or ambient air temperature are considered.

2. difference-regulation: change between the two modes is done in response to a predefined temperature difference. To form the differences, the parameters supply and return temperature at the distributor, the inlet and outlet temperatures of soil, primary and secondary side or extraction and undisturbed soil temperature are being used.

3. duration scheme: this strategy is based on, for example a certain time program which defines switching between the PC and CM or it is based on running in intervals

4. algorithms: lately, the algorithms are being implemented to draw up efficient control strategy including a holistic attitude to building. The factors considered: balanced soil temperature, energy / primary energy consumption, energy cost, comfort, weather forecasts, etc.

In addition, all combinations of the presented control strategies are possible and implemented.
Already on basis of the examined buildings in the project, it becomes clear how different the implementation of the scheme of passive cooling and chiller mode can be. It can be seen that primarily the focus is laid to the set-point regulation – due to diversity of variants - based on the primary or secondary side of the system.

The currently defined control strategies and switching parameters between passive cooling and chiller operation provide that:

- Building GEW: approval for chiller operation, if the outlet temperature from the soil exceeds 18 C.
- Building VGH: passive cooling ends as soon as the supply temperature to the emission systems exceeds the set value.
- Building FAS: approval for the chiller operation, if the term

  $(T_{outlet\ BHE} + 2K) > (T_{set\ emission\ system} + 1K)$ is satisfied.
- Building HSS: passive cooling in operation until the supply temperature to the distributor exceeds the 16 °C.

4 FIRST MONITORING RESULTS - FUNDAMENTALS

The collected experiences from the preceding project “WKSP - heat and cold storage in the foundation area of office buildings” (BMWi, FKZ 0327364A) are the basis for carried out monitoring and further optimizations in the research project geo:build.
First optimizations and bug fixes are implemented in the buildings VGH and Gelsenwasser AG as well as in the Lecture Hall regarding the performance of the systems, heat injection and heat extraction to achieve an even balance in the soil as well as the implementation of the designed operation.
The design goals concerning more efficient use of the passive cooling mode compared to the chiller operation was still not yet been adequately implemented. This is where geo:build starts.

4.1 VGH Regionaldirektion, Lüneburg

Based on the heat injection and heat extraction (Figure 2) it becomes clear that until 2007 no planned heating or cooling operation of the geothermal system has been scheduled.
To increase the extraction of heat from the soil and to establish a systematic heating and cooling mode, the following measures and optimizations have been implemented as part of the first monitoring:

- Elimination of design errors in the concrete core activation system (e.g. improperly installed valve)
- Elimination of control errors in the building management system (BMS)
    - Modification of the calculation of the mean ambient temperature
    - Adaption of heating and cooling boundary set point temperatures
    - Adjustment of the heating and cooling curves of concrete core activation and ventilation systems
- Localization of errors in the internal controller of the geothermal heat system.
- Implementation of the heating operation in spring 2007.
- Partial realization of the cooling operation in summer 2009.

Through the carried out optimization measures and the implementation of the designed cooling operation the ratio of cooling supply by chiller to passive cooling in the year 2007 was 89% to 11% and will be reduced in 2009 to 55% to 45%. There is no information on the designed proportion of compression chiller/ passive cooling.
Due to the high heat extraction and in result disturbed energy balance in the soil (Figure 2), the temperature in the soil is very low. Thus, a further reduction of the chiller operation and implementation of the efficient passive cooling mode should be possible.

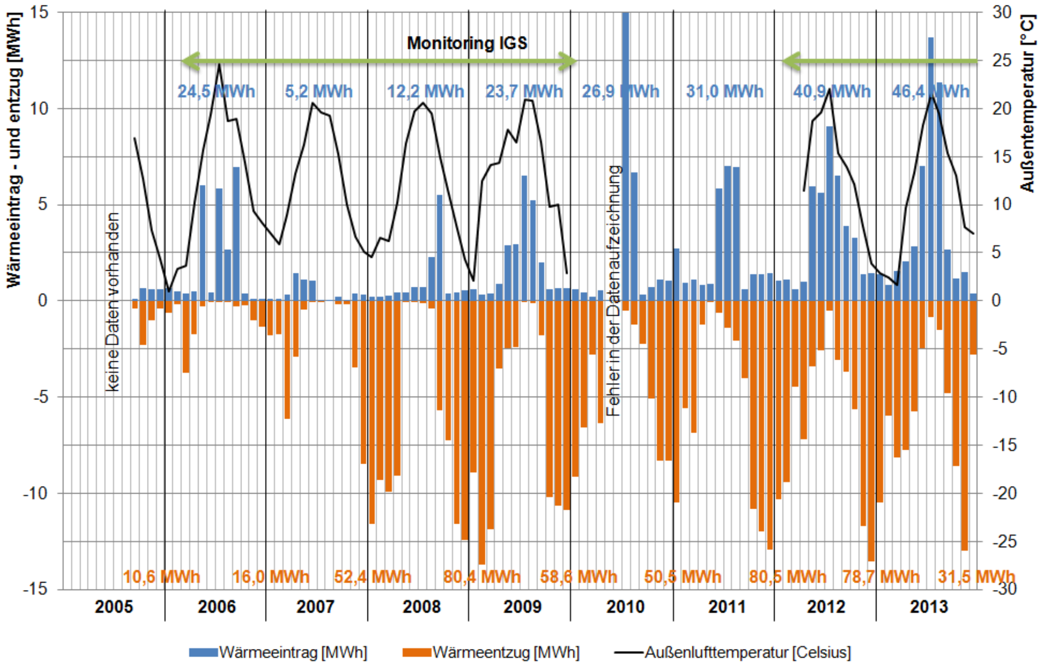

Figure 2: Monthly heat injection and heat extraction (2005 – 2013), VGH

4.2 Gelsenwasser AG, Gelsenkirchen

During 2006 to 2009 significantly more heat was injected into the soil than extracted (about two to three times). The heat came e.g. from the building itself (combined operation mode) and the high fraction of the chiller. The result is a warming of the soil to an unfavorable temperature level for passive cooling mode, so that during the cooling mode mainly the chiller was operated.
According to the planning documents for the Gelsenwasser AG, a ratio for cooling supply by the passive cooling mode to chiller was designed 68% to 32%. However, to date, it was only possible to achieve a ratio of 49% to 51% (see Figure 3).
As a part of the existing monitoring, measures and optimization were carried out to minimize the heat injection, in particular the combined heating and cooling mode and to reduce the high fraction of chiller operation.

Measures and optimization:

- Optimized ventilation strategy:
    - No cold supply during office hours at low outside temperatures.
- Use of self cooling through the building envelope and the supply air flaps
    - No space cooling during the night when the outside temperatures are less than the room temperature.
- Priority for the free night cooling.
- Changing the control strategy of the geothermal system:
    - Increasing the temperature limit (outlet temperature from the ground heat storage) for approval of operating chillers.

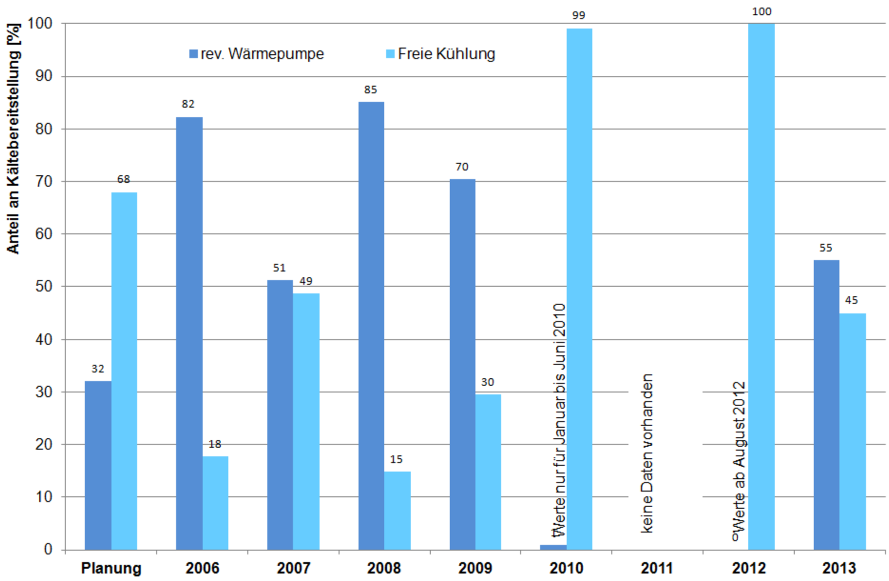

Figure 3: Percentage distribution of refrigeration by passive cooling and chiller operation (GEW), 2006 - 2013

4.3 Lecture Hall, Salzgitter

Since March 2013 the full monitoring of the Lecture Hall building in Salzgitter has been added with the start of using. In planning, a ratio of 54% operation of the reversible heat pump to 10% passive cooling was defined based on thermal simulations. In order to cover peak loads, two additional compression chillers are integrated to cover the remaining 36% of the total cooling energy demand.

Figure 4 shows the first ratio for the period from August until December 2013, after the commissioning phase of the operation of building and measurement equipment. In essence, the cold is provided by the heat pump in the chilling mode. The potential of the passive cooling is generally limited at the end of the cooling period due to rising temperature in the soil. An optimization is necessary to raise the proportion of passive cooling at the end of the cooling period 2014.

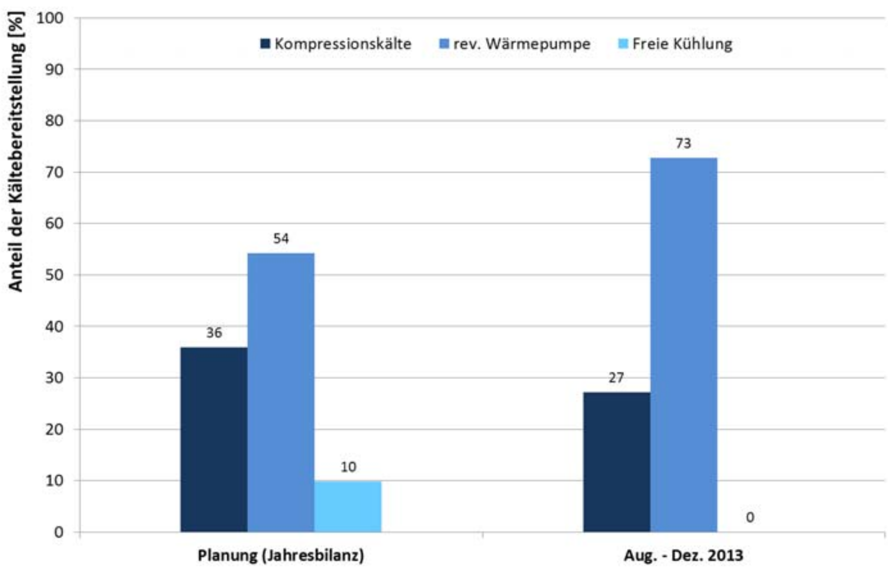

Figure 4: Percentage distribution of refrigeration by passive cooling and chiller operation (HSS), 2013

5 TRNSYS SIMULATION

Using the simulation software TRNSYS, the lecture hall in Salzgitter and the VGH Lüneburg are created in a holistic building and plant model. The model is imaged with all building-specific configurations. The rooms in the buildings will combined in zones according to their thermal boundary conditions (Figure 5 and Figure 6) and their physical properties. Important boundaries to heating, cooling, ventilation and internal loads, etc. are also determined for each zone.

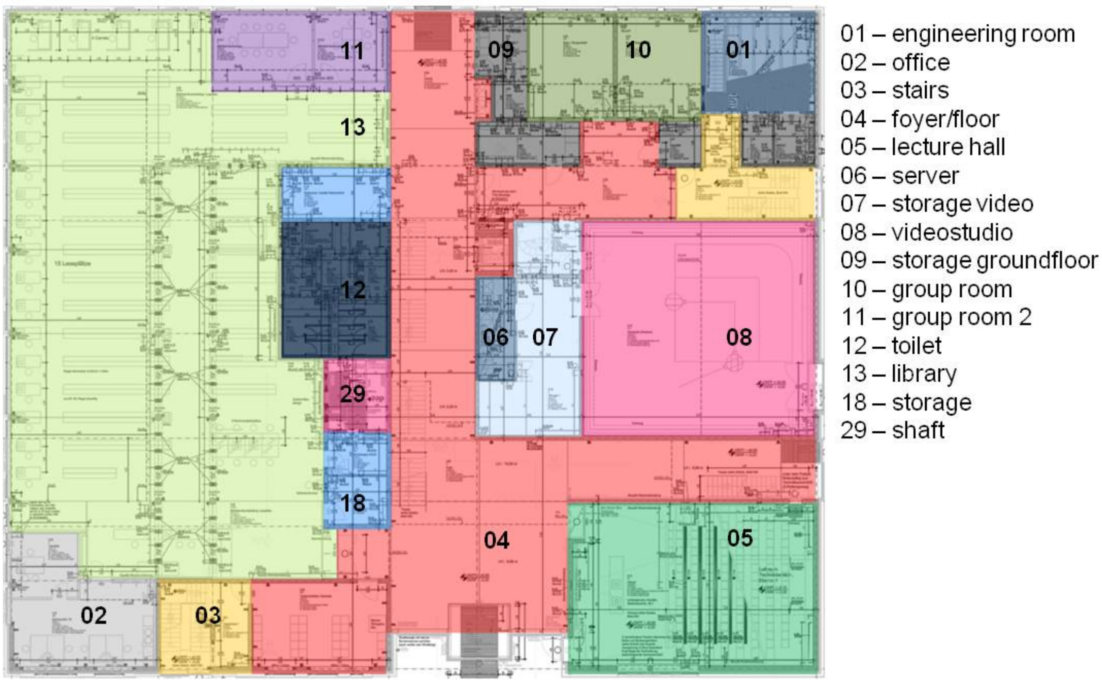

Figure 5: Zoning lecture hall Salzgitter, ground floor (total 29 zone)

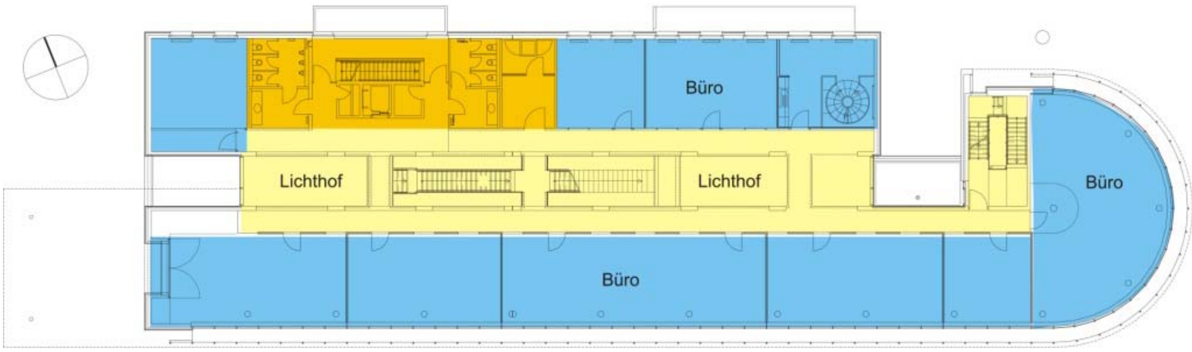

Figure 6: Zoning VGH, 1. floor (blue: office, separated in north and south; orange: toilet and kitchen, yellow: floor (areaway))

A universal base simulation model is created for the buildings, including the plant technology. The model used general data interfaces for input parameters, such as weather data, and data outputs such as load curves (Figure 7). The building models, created for each project, are linked with pre-defined transfer interfaces on the load profiles for heating and cooling with the plant technology. Due to the general structure of the simulation model, the effort will be reduced to simulate the various buildings and equipment designs. So only the different performing systems for each building will be supplemented and adjusted in the standard deck. The simulation data are stored in output files and can be used for further processing, graphic processing and for direct comparison with measured data from the real operation.

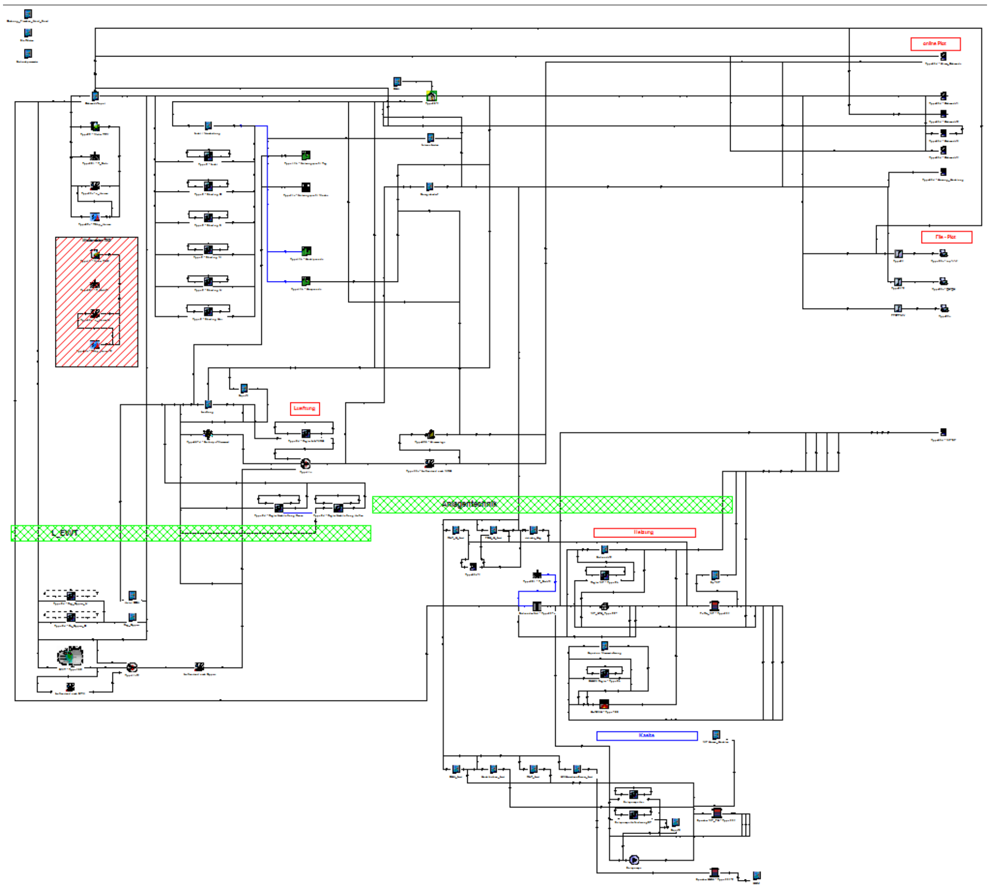

Figure 7: current „universal deck“

The validation of the model with existing data is currently being proceeded, so that the building and the control strategies can be tested.
The validation can achieve a very good result. For example the borehole heat exchanger (used Type 557): according to Figure 16 it can be seen that the deviation between simulation and measured values amount to ~ 7% (Figure 8). All settings and parameters from the planning data and the TRT (thermal response test) can be applied to lecture hall Salzgitter.

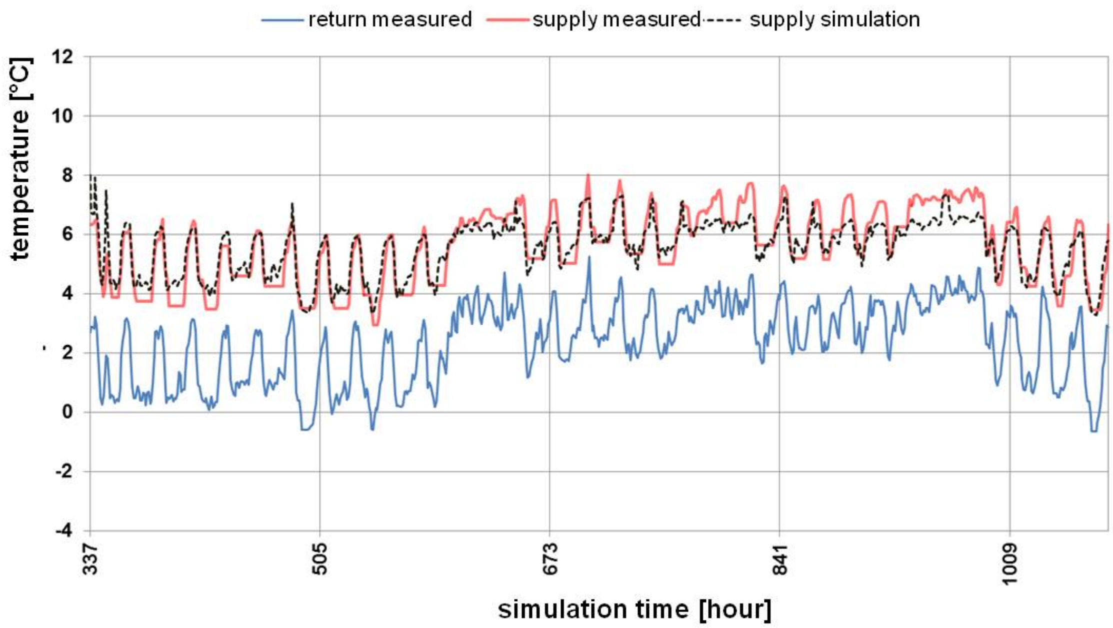

Figure 8: Result of validation of the borehole heat exchanger

Due to the comparison of the results from simulation, design and measured values from monitoring, it is possible to analyze optimization approaches prior to field studies.

6 FIRST ESTIMATIONS

Based on the measured cooling consumption and the soil temperatures (both 15-minute values) of the VGH, a first rough estimation of the different control strategies is made. The assessment does not consider the actual response of the soil or the building. It is only compared to the duration of passive cooling vs. mechanical cooling with reference to the existing measured data and the varied control strategies. To select and preliminary analyze the strategies, the ambient air temperature, supply and return temperature in the building as well as the inlet and outlet temperatures of the energy piles were used.

Strategies:

Actual / current strategy: Passive cooling ends as soon as the supply temperature to the emission systems exceeds the set value of the cooling curve.

A – set value soil: Passive cooling ends as soon as the outlet temperature from the energy piles (ground) exceeds 17,5 °C or the ambient air temperature exceeds 24,5°C.

B – temperature difference energy piles: Passive cooling starts when the temperature difference exceeds 2K. The chiller operation works between 0 – 2K.

C – temperature difference emission system: If the difference is smaller than 0,6 K, the passive cooling starts.

D – program + set value: passive cooling between 8 pm and 2 am as well as between 6 am and 10.30 am and if set value for emission system is > 20°C. Otherwise active cooling.

E – program + set value 2: passive cooling between 8 pm und 6 am and if set value for emission system is > 20°C. Otherwise active cooling.

Table 2 shows the comparison of the tested control strategies in terms of the potential of passive cooling. Based on the results, an initial assessment can be done, which control strategies are suitable for increasing the passive cooling operation and which cannot.

Using the first rough results it should be highlighted that it is a great potential in the change of control strategies, to use the more efficient passive cooling and thus to conserve the soil. The potentials also show that it is crucial to look not only to the predetermined cooling curve of the building by creating a control strategy. The strategies should be implemented considering mutual interactions between the building and the soil.

Table 2: Results of first estimations concerning variation of strategies

<table>
<tr><th>Strategie</th><th>Operation time passive cooling simulation</th><th>Operation passive cooling reality</th><th>Potential</th></tr>
<tr><td>A – set value soil</td><td>1.252 h</td><td rowspan="5">305 h</td><td>947 h</td></tr>
<tr><td>B – temperature difference energy piles</td><td>1.099 h</td><td>794 h</td></tr>
<tr><td>C - temperature difference emission system</td><td>405 h</td><td>100 h</td></tr>
<tr><td>D - program + set value</td><td>1.257 h</td><td>952 h</td></tr>
<tr><td>E - program + set value 2</td><td>1.133 h</td><td>828 h</td></tr>
</table>

7 CONCLUSION

The monitoring results show that the post commissioning monitoring of operation is important in order to identify and resolve problems at an early stage.
With the completion and validation of the shown models of buildings and plants, the foundation is laid, to identify further optimization potential and to develop valuable control strategies for planning. Before an implementation in field installations such a simulation allows the testing of new control strategies for building cooling with geothermal systems in theory.

8 ACKNOWLEDGEMENTS

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