Aquifer Thermal Energy Storage (ATES) systems at universities

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ABSTRACT

Even though most universities perform research in the field of renewable and sustainable energies, their own campuses are most often supplied by fossil-based technologies. However, several universities in particular in the Netherlands already successfully demonstrated the integration of Aquifer Thermal Energy Storage (ATES) into the heating and cooling system of a university. ATES at universities not only significantly minimized the carbon footprint of the campuses, but also reduced the expenses for heating and cooling. However, universities are usually characterized by a great diversity of building types with various requirements with respect to varying demand patterns. Thus, the design of an ATES in combination with a heating and cooling grid is often a challenging task. The financing, which often requires a higher investment, is in addition often impeded by a complex decision-making structure. Based on the experiences gained at several project sites, this study discusses hurdles and solutions for the successful implementation of ATES at universities considering technical, financial and political issues.

1. INTRODUCTION

Universities are amongst the buildings with the highest energy consumption with a large heating and cooling demand (Gul and Patidar, 2015). Hence, university campuses can be considered as small cities with regards to their impacts on the environment (Alshuwaikhat and Abubakar, 2008; Viebahn, 2002). Various building types with different load curves and changing energy demand seasons require a comprehensive energy planning (Chung and Rhee, 2014; Guan et al., 2016). Due to their wide range of knowledge and expertise, universities in particular should be obligated to serve as blueprints for the decarbonization of the heating and cooling sector. Since universities in moderate climates have a seasonal mismatch between the thermal and power demand curves, storage technologies have to be integrated into energy supply systems of campuses. Thus, the storage of heat and cold in groundwater also referred to as Aquifer Thermal Energy Storage (ATES) is becoming increasingly more attractive compared to common supply technologies. ATES stores sensible heat and cold seasonally in the subsurface using groundwater wells to reuse the thermal energy for the heating and cooling supply of buildings (Dickinson et al., 2008; Sommer et al., 2015). Worldwide, there are more than 2,800 ATES systems installed with more than 90 % operating in the Netherlands alone (Fleuchaus et al., 2018). Currently, low temperature ATES (LT-ATES) is mainly used for the heating and cooling supply of offices, hospitals, airports and shopping centres. Even though many ATES systems in the Netherlands have already demonstrated a technical and economic viability, until now only few systems are applied at university campuses. The implementation of ATES at universities has its own special issues mostly of technical, organisational, financial and planning nature. The present study therefore discusses the major issues and appropriate solutions to tackle these challenges in order to implement ATES on a larger scale. In addition, ATES systems already implemented at university campuses as well as past and ongoing research activities in the field of ATES are presented.

2. OVERVIEW OF EXISTING ATES SYSTEMS AT UNIVERSITIES

The first research activity in ATES can be traced back to the 1970s (Fleuchaus et al., 2018). During that time, several field experiments were designed and conducted at several universities such as Auburn University, Texas A&M University, or the University of Neuchâtel (Stottlemyre et al., 1979; Tsang, 1978; Saugy et al., 1984). However, the scope of these early storage projects was less to supply thermal energy for the university campus, but to investigate the storage of high temperatures in the subsurface. This changed in 1991, when the University of Utrecht started to store hot water from a cogeneration plant (CHP) for winter heating of the campus (van Loon und van der Heide, 1993). While the high temperature ATES (HT-ATES) in Utrecht stopped operating due to operational problems in 1998 (Sanner, 2000), other cities in the Netherlands such as Rotterdam or Eindhoven realized cold storages at their universities (van Mourik, 1993). With currently more than 2,800 ATES in operation worldwide, there are about 20 universities, where heat and cold is supplied by LT-ATES, most of them in the Netherlands.

The largest ATES system worldwide is operated at Eindhoven University of Technology (TU/e) (Fig. 1a). Here, 36 wells provide a cooling and heating capacity of about 20 MW (Snijders und van Aarssen, 2003). The supplied buildings are connected by a district heating and cooling grid with the ATES. With a CO_2 reduction of about 13,000 t of CO_2 per year, the invest of 15 million Euro amortized after 6-10 years (Worthington, 2011).

Figure 1: Eindhoven University of Technology (a), Utrecht University (b), Stockton University (c), and Leuphana University of Lüneburg. © Philipp Blum (a), Stockton University (b), Leuphana (c), Utrecht University (d).

After the abandonment of the HT-ATES at Utrecht University in 1998, the university decided to continue using ATES, however, this time focusing on lower temperatures (Fig. 1d). Here, 16 groundwater wells are connected to a heating and cooling network. In addition, excess heat and cold is also transferred between allocated buildings directly. At Stockton University, New Jersey, 6 groundwater wells provide 2 MW of cooling capacity (Fig. 1b). Despite a high groundwater flow, about 70 % of the cold is recovered, which is injected from a cooling tower during wintertime (Stiles et al., 2009). In Germany, the Leuphana University in Lüneburg strives to realize a HT-ATES in order to increase the efficiency of a CHP (Fig. 1c). The HT-ATES installation perfectly matches the low-exergy heating demand of the campus building and bears the potential for high financial savings (Opel et al., 2017). However, due to organisational and regulatory issues, no permission has been given, yet. In addition, in the course of the research project Geospeicher.bw, the Karlsruhe Institute of Technology (KIT) strives to realise an ATES to provide 25 GWh of cold for the KIT Campus North. A technical and economic feasibility study indicated a recovery rate of more than 70 % and high financial savings compared to the existing compressions chillers.

3. TECHNICAL CHALLENGES

University campuses are continuously busy with their real estate, maintenance, replacement of old equipment, renovation and new constructions. Due to climate agreements, universities see a role for themselves to integrate renewable solutions in the real estate management. The challenge is not to implement some individual solutions for some buildings, but to come up with an overall vision for the long term. However, what is important and how should you start to develop an overall energy vision? Moreover, can ATES contribute to such a plan?

A campus can be considered as an energy system. The system borders of the energy system are the same as the borders of the campus. In summer, there might be a

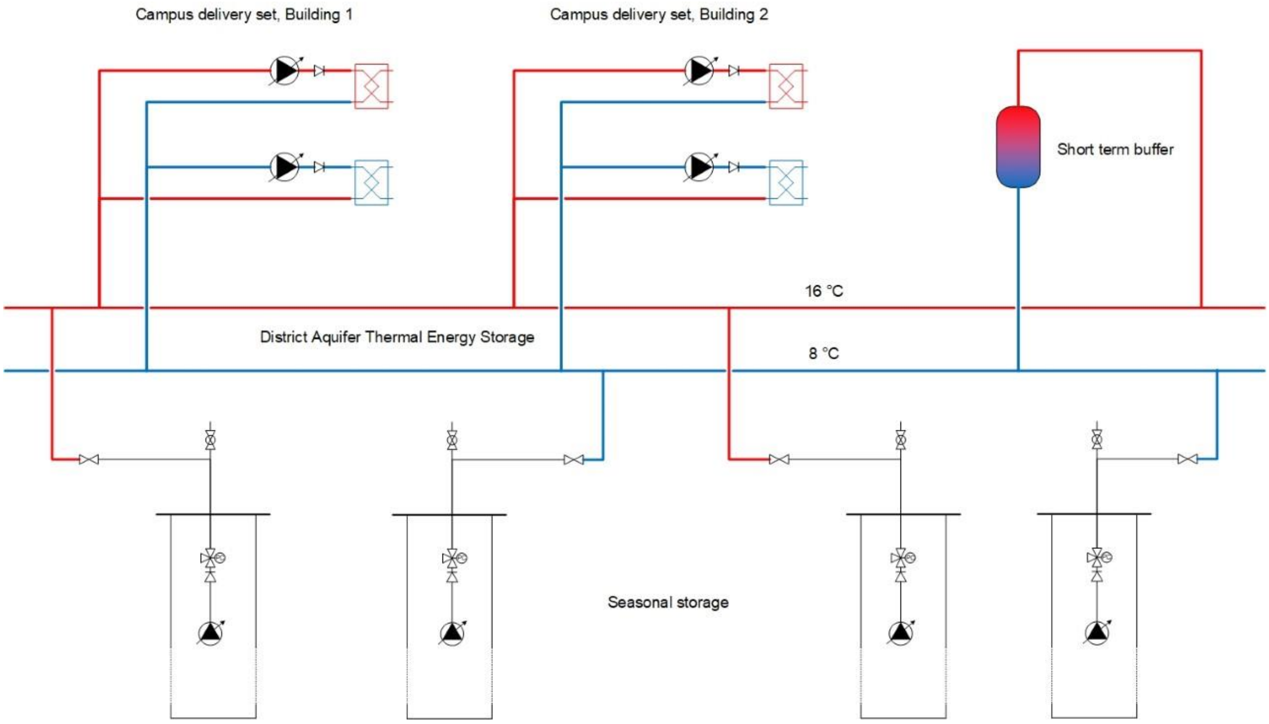

Figure 2: District ATES system (DATES) showing a low temperature grid connected to ATES. ATES wells are shown below, the district system in the middle and the connection to the buildings on top. Source: IF Technology BV.

large surplus of heating and in winter a large shortage of heating. Thus, the key challenge for this type of energy systems is to connect the surplus of one season with the shortage of the other season. In an optimized energy system, the borders are closed to avoid energy exchange over the borders (losses or primary energy consumption). Energy can be interchanged between buildings and between seasons. Only the imbalance has to be produced in the most sustainable way at the most ideal moment. Hence, a district ATES system (DATES) would be ideal to balance the heat and cold demands of buildings and seasons (Velvis and Buunk, 2017, Fig. 2).

3.1. Qualitative energy assessment

University campuses are often historical places with a long history. Many present buildings are designed based on ancient standards and outdated energy visions, which were sufficient in the past, however need adaptions to future needs. One example is the high temperature heating concept, which needs high supply temperatures. Heat is typically generated by burning fossil fuels at very high temperatures > 1,000 °C. The heat is then transported at temperatures of over 100 °C to be finally used for space heating at 20 °C. This concept would be useful for buildings with a steam demand, but not for all the other buildings on a campus with a heating demand only for space heating and/or tap water production. It is an ineffective way of using energy (exergy), because a lot of energy is lost due to transportation and temperature decrease before usage.

A first step in modernising the energy concept of a whole campus is to make an inventory of all the existing buildings and its characteristics. This includes:

- Year of construction;
- Building type;
- Heating and cooling demand:
- Periods of heating and cooling;
- Required peak loads;
- Proportion of heat used for steam, tap water and space heating.

The buildings are divided into old buildings (high energy demands, badly isolated, old energy infrastructure), standard buildings (modern buildings with relative low energy demands, low temperature HVAC systems and well isolated) and high-efficient buildings (very low energy consumption, very well isolated, low temperature HVAC system). This classification is crucial in order to develop a specific plan of action in the process of designing the new heating and cooling strategy. In order to optimize the use of energy, it is essential to combine buildings with a similar heating and cooling strategy and look separately to buildings with an extreme peak load or energy use. A low temperature heating (< 45 °C) and a high temperature cooling (> 10 °C) concept is more energy efficient compared to high temperature heating (oil, gas fired boilers) and low temperature cooling systems (air conditioning and chillers). Energy intensive buildings such as data centers or steam users should be considered separately.

In addition, it is also important to keep in mind that future energy networks may work at much lower temperatures in order to match the low heating temperatures and to optimize the exergy. Thus, HVAC installations also has to be adapted to low temperature heating and high temperature cooling systems.

A promising solution to optimize the exergy is to create synergies by cascading the energy use to maximize the utilisation of energy. For instance, excess thermal energy of steam can be used for low temperature heating purposes.

3.2. Quantitative energy assessment

Even though energy cascading bears a certain potential for exergy optimization, it is still indispensable to reduce the thermal energy demand of the campus. However, a first important step is the thermal refurbishment of the old building stock by optimizing insulation, replacing old windows by HR+ glass, or the installation of solar screens. In addition, HVAC designer often estimate the thermal energy consumption of a building very imprecisely. Holidays, vacation, or the absence due to illness is often not considered. Thus, a detection of presence can be an easy first measure to adjust the thermal supply to the heating and cooling demand.

A high optimization potential is also attributed to the creation of synergies from the simultaneous supply and demand of both heat and cold. Often heat and cold is required at the same time and in the same building. Considering the simultaneous needs, heat and cold can be exchanged and technologies producing cold can directly be used as heat generators. This is mostly done with complex controlling software and adaptations. Inside a building heat pumps can be used for producing heat and cold at the same time.

The same accounts on campus-scale: laboratories, offices, data centres often require cooling, while the student dormitories, animal stays, lectures halls require heating. Exchange of heat and cold between the buildings reduces the final thermal energy demand significantly. To facilitate the transfer of energy, a smart energy grid is required. This can be realized by a low temperature heating and cooling grid, which can also be used to connect the buildings to the ATES. An example of such a grid is given in Figure 2 and the installation of a grid is shown in Figure 3. By using a district ATES (DATES), the surplus of heat or cold can be shared by the connected buildings. Less energy has to be stored in the subsurface reducing both capital and running costs of the ATES. The grid itself functions partly as buffer. In particular in spring and autumn, the energy demand of the buildings is relatively small. Thus, the circulation within the grid is enough to provide enough heat and cold for the buildings. When the demand become larger, which results in a larger ΔT in the grid, extra heat or cold is supplied by the ATES wells to the grid.

Another important advantage of an energy grid is the ability to combine different thermal energy storage techniques. Artificial storage techniques such as tank thermal energy storage (TTES) and/or pit thermal energy storage (PTES) create a certain flexibility of the system (Fleuchaus et al., 2018). PTES and TTES are not only able to balance short-term (day-night) demand and supply peaks, but also to store high temperature heat from steam applications. In contrast, ATES provides the base loads by the long-term (summer-winter) storage of heat and cold.

Figure 3: Construction of low temperature grid at the University of Utrecht. Source: IF Technology.

Finally, the assessment of the thermal energy system should also include the local environment of the campus. Hence, it is recommended to analyse the energy potential of surface waters, the sewage system, the solar potential as well as allocated industrial areas or nearby house settlements.

4. ORGANISATIONAL ISSUES

4.1. External stakeholders and cooperation

To implement sustainable technical solutions on a campus, it is important to consider the organisational aspects. Often the entire campus belongs to the university, which makes it less complex compared to other developments. However, it is not said that if the university owns the buildings and that they own the property. In addition, external stakeholders are often present at a campus.

It is recommended to make an inventory of all stakeholders to analyse their position, potential role and involvement in the energy transition. Involvement of the external stakeholders should be done from the beginning, which makes it possible to cooperate and to find combined and shared solutions. In fact, they also can become a potential risk of failure of the entire plan, if they can address their influence or property position to block sustainable plans. Showing the combined advantages may pull them to join the plan.

In addition, the role of the authorities should not be underestimated. Especially in areas, where ATES is not well known yet, the large abstraction and also the injection is often a major concern (Drijver and Godschalk, 2018). Authorities are responsible for the protection of groundwater, but often the same authority is also willing to reach energy goals. This dual interest may open the discussion to look for opportunities to protect the groundwater interest and to support in the energy savings goals.

This issue is an important role, when ATES is used as buffer and energy source for the heating and cooling grid. Individual ATES solutions for specific buildings, takes a lot of underground space, which is often limited on campuses. Initiatives from external stakeholder would treat the overall ATES plan. Cooperation increases the effective usage of the subsurface (Godschalk and Bakema, 2009).

4.2. Internal stakeholders and reliable energy needs

Of course, also the internal stakeholders have to be involved in the development of the energy strategy for the university campus. An inventory of the end-users and/or buildings is a good starting point as well as the involvement of technical staff. Their experience is extremely useful to be adopted in the energy strategy.

Another aspect in the energy vision is the reliability of the energy supply in the various buildings. Often the energy systems in buildings are over dimensioned to fulfil high peak load demands or for redundant energy supply. Analysing the importance of the reliability of the energy supply destresses the energy concept. Offices, college rooms, canteens are less challenging with regard to their heating and/or cooling demand, while data centres are extremely depending on a reliable energy supply. Libraries and test set ups are between both examples.

Connecting the buildings with a high reliability demand to a grid, provides a huge step to mitigate such as energy risks. Additional back up equipment can be designed, however using the low temperature energy grid results in a base load use of the grid and therefore in an energy reduction. Only in case of emergency, the backup units have to be used.

The input of the technical staffs is crucial to improve the energy system of the campus. Inputs from end-users is also valuable and helps to create a support and a cycle of improvements. This is important, because the way how new energy systems work is somewhat different from the existing high temperature heating system. Finally, the end-user is determining the success of the energy concept, while it is important for the management to implement and integrate the low temperature grid with ATES smoothly and without annoyance of the end-users.

5. FINANCIAL AND PLANNING ISSUES

5.1. Financial challenges

Money is making or breaking good solutions. A smart financial strategy is important to be able to implement the energy plan. The total costs for the renovation of the total energy supply on a campus include millions. The capital costs of an ATES are often twice the price compared to a common supply technology. Additionally, standard technologies neither necessarily require the retrofitting of the old building stock nor the connection of the buildings to a low temperature heating or cooling grid. While the operating costs are often neglected, energy planners often decide against a long-term investment: even though the technical and financial feasibility was already proofed, the Leuphana University still hesitates to provide the required financial means for a high temperature ATES for the new Campus building (Opel, 2019). The same accounts for the Karlsruhe Institute of Technology (KIT). A feasibility study showed the great finical potential of replacing the existing compression chillers by a district cooling system supplied by ATES. Despite prospective financial savings of up to 2 million euros per year, no further actions are currently initiated.

Even though many ATES projects already showed fast payback times and high financial savings (Andersson et al. 2013; Vanhoudt et al. 2011; Stiles et al. 2009), the high initial investment is still a great hurdle in the decision-making process at universities. One way to reduce the high upfront investment is to connect in a first step only the new building stock to a small thermal grid. The remaining buildings can be retrofitted and connected to the system stepwise over time by extending the heating and cooling grid.

5.2. Planning challenges

The planning of the implementation contributes to the success of the plan and the final efficiency of the energy system. As described above, many choices have to be made, because a campus involves many buildings, which cannot be improved in one run. Improvement of one building can be planned and tuned with the relevant stakeholders. However, the strength of the integrated design is that various energy sources and buildings are connected to each other and buffered by ATES wells. Investment in the low temperature heating and cooling grid is a large threshold for a smooth implementation. A chick and egg problem pears up, because what should be invested first, the grid or the energy system in a building, which is depending on the grid?

The solution might be to do both, but often this is not the preferred solution, due to availability of the financial resources. One suggestion is to design the energy concept of a single building on a low temperature supply profile and to connect the building to an individual ATES system. During the construction of the wells and the connection to the building, further connections are prepared, which makes it possible to reconnect the building when the grid is prepared. The wells of the buildings are also reconnected to the grid.

The advantages of a low temperature grid are the relative low installation costs and that the grid can already operate at a small scale. It can easily be expanded, which makes it possible to plan the grid over years and extend it step by step. The diameter of the grid does not have to be as large as in a traditional heating grid (Figure 3), because energy is not transported from the source to the end-user only. At low temperature grids, energy is only locally transported in the grid and buffered by ATES wells. When other buildings are connected to the grid, it can be extended and additional doublets of ATES systems can keep up the storage capacity of the grid. Investment costs can therefore be spread over time and the planning of the installation can be managed more easily.

6. CONCLUSIONS

An increasing number of university campuses are evaluating their energy system considering how to implement a future proof and a sustainable energy system for the whole campus. Individual solutions are often still considered, however integrated campus solutions result in a more efficient and reliable energy supply. Technical solutions as optimizing the exergy and reducing the energy demand are the basis for a future proof energy system. Involvement of external stakeholders is essential for the success and involvement of internal stakeholders provide valuable and important information to improve the implementations and to distinguish the needs for redundancy and reliability of energy supplies.

Smart planning strategies help to reduce the initial investment costs of new heating and cooling grids and to manage the workload for the implementation. The integration of all involved parties such as stakeholders, facility managers, end users, research institutes and decision makers is essential to overcome especially financial and institutional barriers.

REFERENCES

Alshuwaikhat HM, Abubakar I (2008) An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices. Journal of Cleaner Production 16:1777–1785. doi: 10.1016/j.jclepro.2007.12.002

Andersson, O.; Ekkestubbe, Jonas; Ekdahl, Anna (2013): UTES (Underground Thermal Energy Storage) -Applications and Market Development in Sweden. In: J Energy and Power Eng 7, S. 669–678.

Chung MH, Rhee EK (2014) Potential opportunities for energy conservation in existing buildings on university campus: A field survey in Korea. Energy and Buildings:176–182. doi: 10.1016/j.enbuild.2014.04.018

Dickinson J, Matthews M, Snijders A (2008) Aquifer thermal energy storage: theoretical and operational analysis. Géotechnique:1–12. doi: 10.1680/geot.2008.58.00.1

Drijver, B., Godschalk, B. (2018), Important criteria for ATES legislation. 14th International Conference on Energy Storage EnerSTOCK2018, Adana Turkey.

Fleuchaus, Paul; Godschalk, Bas; Stober, Ingrid; Blum, Philipp (2018): Worldwide application of aquifer thermal energy storage – A review. In: *Renewable and Sustainable Energy Reviews* 94, S. 861–876. DOI: 10.1016/j.rser.2018.06.057.

Godschalk, M.S., Bakema, G., 20,000 ATES systems in the Netherlands in 2020 – major step towards a sustainable energy supply, Proceedings Effstock. 11th International Conference on Thermal Energy Storage for Energy Efficiency and Sustainability, Stockholm, Sweden.

Guan J, Nord N, Chen S (2016) Energy planning of university campus building complex: Energy usage and coincidental analysis of individual buildings with a case study. Energy and Buildings 124:99–111. doi: 10.1016/j.enbuild.2016.04.051

Gul MS, Patidar S (2015) Understanding the energy consumption and occupancy of a multi-purpose academic building. Energy and Buildings 87:155–165. doi: 10.1016/j.enbuild.2014.11.027

Opel, O.: Personal communication (2019).

Opel, O.; Strodel, N.; Werner, K. F.; Geffken, J.; Tribel, A.; Ruck, W.K.L. (2017): Climate-neutral and sustainable campus Leuphana University of Lueneburg. In: *Energy. DOI:* 10.1016/j.energy.2017.08.039.

Sanner, Burkhard (2000): ECES Annex 12: “High Temperature Underground Thermal Energy Storage”. Fifth report to the Executive Committee.

Saugy, B.; Doy, R.; Mathey, Bernard; Aragno, M.; Geister, M.; Rieben, C. et al. (1984): Accumulateur de chaleur en nappe souterraine SPEOS - Bilan de deux ans d’exploitation.

Snijders, A. L.; van Aarssen, Martijn M. (2003): Big is beautiful? Application of large-scale energy storage in the Netherlands. In:. Proceedings Futurestock. 9th International Conference on Thermal Energy Storage, Warsaw, Poland, September 1-4, 2003.

Stiles, L.; Snijders, A. L.; Paksoy, H. (2009): Aquifer Thermal Energy Cold Storage System at Richard Stockton College. In:. Proceedings Effstock. 11th International Conference on Thermal Energy Storage for Energy Efficiency and Sustainability, Stockholm, Sweden, June 14-17, 2009.

Stottlemyre, J. A.; Smith, R. P.; Erikson, R. L. (1979): Geochemical equilibrium modeling of the Auburn Thermal Energy Storage Field Test.

Tsang, C. F. (1978): Ates Newsletters. A bimonthly review of Aquifer Thermal Energy Storage. In: *Berkeley, Earth Sciences Division, Lawrence Berkeley Laboratory, PUB-294* 1 (1).

Van Loon, L.M.J.; van der Heide, K. (1993): High Temperature ATES at the University of Utrecht, the Netherlands. In: E. A. Jenne (Hg.): Aquifer Thermal Energy (Heat and Chill) Storage. Proceedings of the 27th Intersociety Energy Conversion Engineering Conference, San Diego, CA. IECEC-92. San Diego, CA, 3-7 August 1992, S. 47–50.

Vanhoudt, D.; Desmedt, J.; van Bael, J.; Robeyn, N.; Hoes, H. (2011): An aquifer thermal storage system in a Belgian hospital. Long-term experimental evaluation of energy and cost savings. In: Energy and Buildings 43 (12), S. 3657–3665. DOI: 10.1016/j.enbuild.2011.09.040.

Velvis, H. and Buunk, R.J.: District Aquifer Thermal Energy Storage (DATES), Proceedings of the 12th IEA Heat Pump Conference 2017, Stichting HPC 2017.

Viebahn P (2002) An environmental management model for universities: from environmental guidelines to staff involvement. Journal of Cleaner Production:3–12

Worthington, Mark A. (2011): Aquifer Thermal Energy Storage: An Enabling Green Technology for Campus District Energy Systems. IDEA 24th Annual Campus Energy Conference. Miami, US, 21.02.2011.