

ECBCS Annex 49

news Low Exergy Systems for High-Performance Buildings and Communities

Newsletter No. 4 September 2008

LOW-EXERGY BUILDING TECHNOLOGIES AND COMMUNITIES

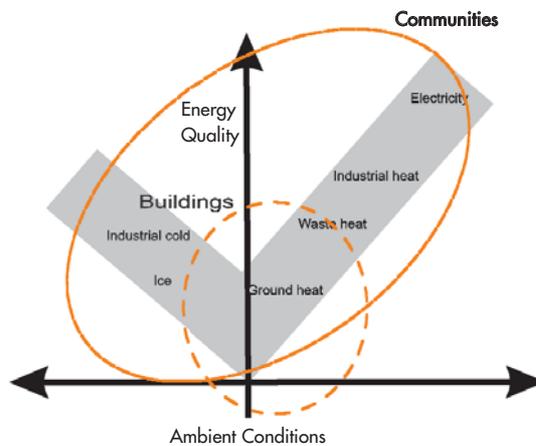
Herena Torío¹

The work and focus of IEA ECBCS Annex 49 are based on an integral approach which includes the analysis and optimisation of the exergy demand in the heating and cooling systems and all other processes where energy/exergy is used within the building stock. In addition to building related technologies, optimization of community energy supply structures is also pursued.

temperature heat might be used for electricity production and industrial processes. For managing supply and demand together, generation, storage and distribution structures in the community play a major role. Thus, the development of advanced concepts for generation, storage and distribution systems on a community scale is a key objective of the research activities.

In Figure 2 an assessment of the exergy flows through the building energy supply chain are shown for different building systems. In the "energy transformation" and "generation" subsystems, the transformation of energy sources into end energy for covering a specific use is assessed. Thus, energy supply structures and systems such as district heating, power plants, boilers, CHP units, etc. are regarded here. In turn, in the emission system, building technologies for supplying the space heating or cooling demands on buildings are addressed. These are the steps where greater exergy losses arise (see Figure 2). Thus, assessing both building and community energy supply structures research is focused on the steps of the energy supply chain where major exergy losses occur, i.e. where greater improving potential is found.

Figure 1: Scope of energy sources investigated within the scope of Annex 49 to provide demands with different quality levels on building and community scales.



For this aim, different energy uses such as lighting, electricity demand for appliances, process heat, etc. need to be regarded and managed. Available energy resources on the community area need to be assessed and classified according to their potential or quality, giving special regards to possible local renewable energy sources. In this sense, the work from Annex 49 enhances results from earlier research activities, widening the scope to different energy uses and community structures.

Following the LowEx approach means to organize the available energy sources according to the demanded uses: environmental heat/coolness or process waste heat might be used for supplying low-exergy demands such as space heating or cooling, whereas high exergy resources such as wind power or high

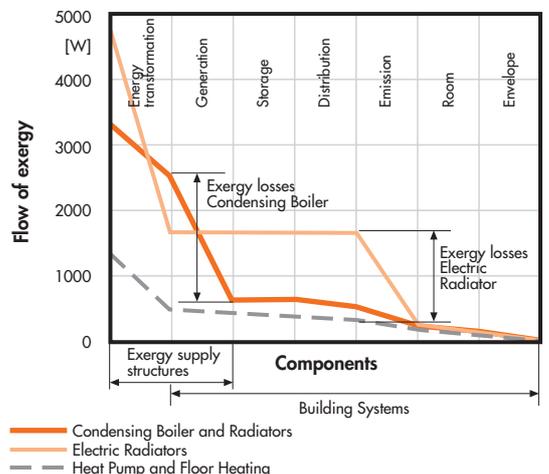


Figure 2: Exergy flow through subsystems of the energy supply chain.



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Energy Conservation in
Buildings and Community
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LOW-EXERGY INNOVATIVE TECHNOLOGIES

Marco Molinari²

In the last decades significant efforts have been made to reduce the energy use in buildings: they range from the demand side, with the improvement of the building envelope, the control of air flows and the reduction of air leakages, to the supply side, mainly with the improvement of the appliances energy efficiencies, the use of renewable energy supplies and the exploitation of the energy cascade, providing a more rational energy use. All these single approaches are summarized in the so-called best building practices, examples of buildings with a much lower energy use than the average new buildings.

In the design of sustainable buildings we look with interest to the energy efficiency and to the use of renewable sources. In this context, exergy analysis aims both at improving thermodynamic efficiencies and at using more efficiently all the different sources, including the renewable ones, based on a further insight into the different processes in the buildings. Here, two different technologies at different research stages are presented and discussed.

The first case is a wastewater heat recovery system. While the practice of recovering HEAT from exhaust air in building is common, very few examples in domestic hot water (DHW) are seen: pre-heating the water before it enters the heat pump yields thermodynamic benefits from both the first law of thermodynamics (heat recovery) and the second law of thermodynamics (higher COP).

The project is carried out in Switzerland in cooperation between ETH-Swiss Federal Institute of Technology and the company Geberit AG also with the participation of the Technical University of Lucerne and the construction of a monitoring building is scheduled for 2010.

The second one is a new approach, still at the early stages of investigation, to use the ground below the house as thermal storage system, for both heating and cooling, with relative initial low investments cost and suitable both for cool and for warm heat storage.

CASE STUDIES ON INNOVATIVE TECHNOLOGIES

Building Case I: Wastewater recovery technology

Forrest Meggers³

Main features of the concept

In order to create a truly low exergy building the sources of exergy destruction must be eliminated. These include the exergy destroyed by warm air being released to the external environment, as well as the warm water. Recovery systems for exhaust air are already common, but wastewater is overlooked. Most well insulated high performance buildings now have nearly half of their heat demand coming from hot water production. In this project a recovery system is being analyzed to maximize the potential of warm wastewater to augment the performance of a heat pump.

The heat from showers and other hot water demands is captured at the highest possible temperature and used to reduce the temperature lift needed for the heat pump to produce hot water. Thereby a low-lift compressor can be used in the production of both low temperature space heating as well as for hot water production that requires a higher production temperature, but now receives a higher source temperature. The concept is diagrammed below and the potential change in COP is demonstrated in the T-S diagram (Figure 4).

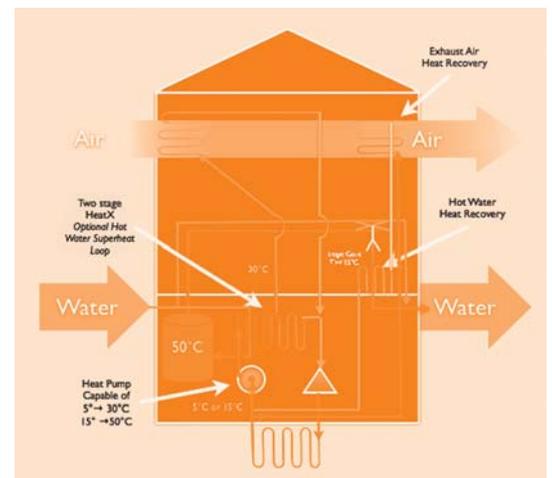


Figure 3: Schematic view of the recovery system.

Competitiveness

A public-private partnership is under development through the Swiss Office for Innovation between the ETH Zurich and Geberit AG. Geberit is the largest sanitary product manufacturer in Europe, and will be able to bring the concept into fruition as an actual product that will be widely available through Geberit's extensive market share. The concept is also

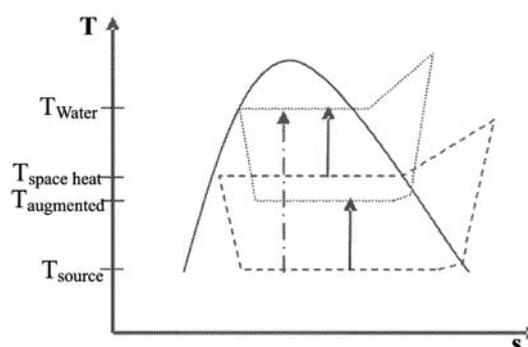


Figure 4: Thermodynamic T-S diagram of the heat recovery process.

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unique in that there are very few products for domestic wastewater heat recovery readily available at the scale being studied. The use of exergy also provides an advantage as this provides a way to optimize the system such that the maximum quality energy is recovered, providing the most benefit to an integrated heat pump system.

Side effects

As a part of the system design, new technologies are being implemented simultaneously at Geberit. This includes new flushing mechanisms for rapid operation of the system. Also systems to help very low flow flushing systems have proper drainage are helped by the batch flushing process in this system, along with ideal integration with new grey water separation and efficiency improvements.

The heat exchanger used to extract heat also allows Geberit to expand into simple systems for heat recovery, such as those that simply preheat incoming water before it is heated in the hot water system instead of a complete integrated low-exergy system. This allows for more simple retrofits to become an option as well as well.

This research is also being done in collaboration with the Technical University of Lucerne in Horw. There the creation of new low-temperature-lift heat pumps with innovative compressor technologies is being researched.

Performance analysis tools and simulations

Initial results from the model for a hot water usage profile based on statistics from the USA for a four person home are shown in Figure 5. This shows the exergy extracted over the course of the year in orange and the energy extracted versus the flow rate through the heat exchanger.

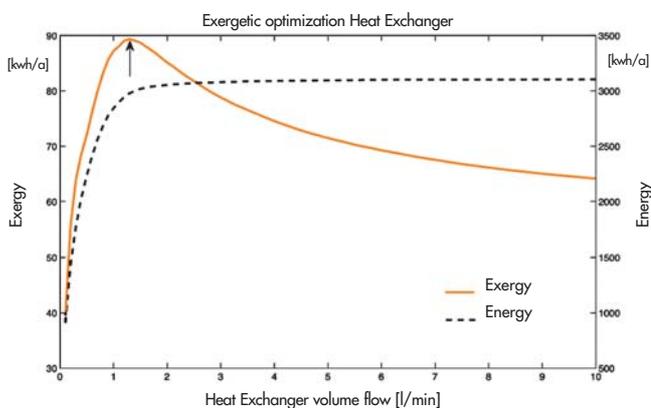


Figure 5: Energy and exergy based optimization of the heat exchanger

Demonstration projects

The first system will be built into the project at Bollystrasse 35 in Zurich, Switzerland. This project is managed by Prof. Dr. Hansjürg Leibundgut who leads the Buildings Systems group at the ETH Zurich where this research is being carried out. The project will contain other low exergy systems that are being researched and optimized in the group [1]. The build-

ing, rendered in the Figure 6, will be a four floor apartment complex with an office on the first floor. It will be built over an existing old water storage tank from the city, providing an interesting 4m high space to do further experiments on building systems. The project will begin construction in 2010 and be finished in 2011.



Figure 6: Rendering of the monitoring building.

The above pilot project will be actively monitored for performance of the system, as it will be one of the first implementations. This will include the monitoring of the borehole heat pump system, the low exergy heating, the decentralized ventilation and centralized exhaust recovery, as well as the wastewater heat recovery. This will also serve the purpose of giving Geberit data to finalize and upgrade their product specifications.

The implementation and evaluation in the Bollystrasse 35 building in Zurich will take place as stated above. The theoretical approach and analysis will be expanded and the model improved. The analysis will be evaluated in conjunction with Geberit to design a product or product line. The theoretical research will be presented at conferences in the fall of 2008 in to gather input from experts and to discuss future work [2, 3, 4]. The final design and analysis will be submitted for publication in a relevant peer reviewed journal and used as a part of the PhD thesis of the author.

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- [3] F. Meggers. Integrated Wastewater Heat Recovery in a High Performance Low Exergy Building System Design. ICEBO 2008. Berlin, Germany. Oct. 2008.
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Building Case II: Shallow ground heat storage with surface insulation

Marco Molinari⁴

Main features of the concept

The idea presented here is part of an ongoing research project at the department of Building Technology at KTH: by coupling solar panels and a heat pump with a pipe system merged into the ground under the building, either warm or cool exergy can be stored and then be released to the building itself (see Figure 7).

By covering large ground surface areas with insulation of sufficient thermal resistance the heat loss from the storage will be closer to the solution for a semi-infinite solid heated on the surface. Such a storage will be favourable compared to a single borehole, especially when heat is supplied and extracted by the heat carrier in an annual cycle. The aim is to combine such an annual storage with solar collector and a low-exergy heating system in order to minimize the use of high quality energy for heating and/or cooling. The energy carrier can be, for example, air in ducts or in a gravel bed or a fluid in pipes with high conductivity flanges.

Competitiveness

The cost of 120 m borehole is in the order of magnitude of 10,000 €. The cost for 200 m² of 400 mm EPS insulation is of the order of magnitude of 4,000 €. Under a new building some insulation is anyhow needed for the ground floor and such a thick insulation can also be used to provide forms for casting the ground plate in a most rational way. When the pipes are laid into the ground there is also the possibility to introduce elements for enhanced transversal heat flow from the pipes to the surrounding masses.

The possibility to store energy on an annual basis is also not realistic for a single borehole. However, in the case that energy is only extracted without any recharging, the borehole could be preferable.

Side effects

Positive side effects are the possibility of providing heating and cooling with a low exergy demand, the reduced heat loss to the ground and a lower risk for frost while on the other side special care will probably be needed for moisture from the ground.

Still to be accurately evaluated are the environmental feasibility, with particular concern to global climate, local climate, health and comfort, as well as the effects of the changed conditions for vegetation on top of insulation and the costs of the increased use of insulating material compared to normal foundation and a drilled borehole.

Another important issue to take into account for this solution is the auxiliary power for the transport of the energy carrier.

Performance analysis tools and simulations

Applications for linear systems with constant flow and for non-linear systems where the magnitude and direction of the flow of the energy carrier can be varied with time have been developed in the FEM environment COMSOL Multiphysics.

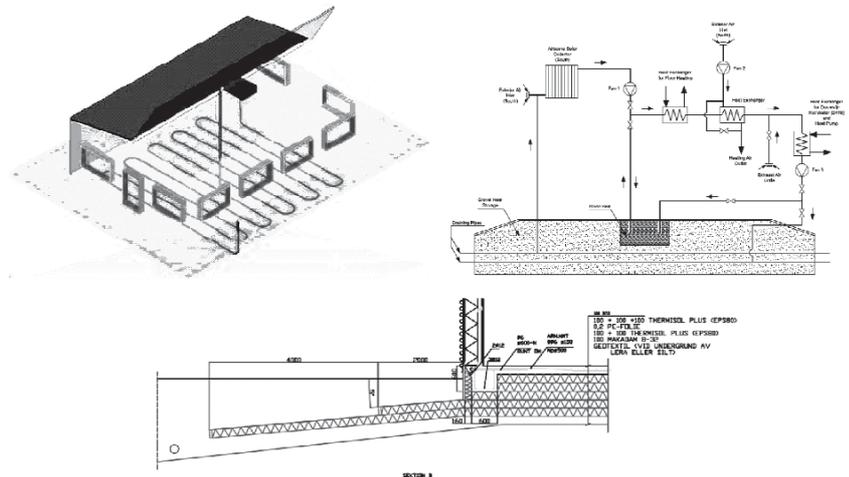


Figure 7: General view of the system

Studies have been carried out for a constant flow system and a system with variable flow of the energy carrier [2]. Simulations with air born solar heaters connected to a 60 m air duct have been conducted. After the duct, heat is extracted to provide a source for space heating and DHW in a one family house. The flow has been varied in time and recirculated in the duct when feasible. The minimum outlet from the duct is 15-20°C in winter.

A two year project for field testing has been granted to KTH Building Technology and in another project the plan is to use such a storage to provide low-exergy heating to cultural buildings where additional insulation or other refurbishment measures are not an option.

Simulations of a ground storage coupled to a solar collector system and a house heating system have indicated that the storage temperatures can be kept above 20 °C in the coldest month [1], [2], even in Nordic climates (Stockholm). The system could provide direct heating for a large part of the year and then be combined with a heat pump working under favourable conditions for supplying heating for the coldest month and the additional heat for the domestic hot water.

References

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⁴KTH-The Royal Institute of Technology, Stockholm, Sweden

THE LOW-EXERGY APPROACH ON A COMMUNITY LEVEL

Ken Church⁵

Managing energy supply and costs within a community requires that the community has a vision of where its future lies. Plans and strategies for developing energy supply structures for communities would incorporate the development of programs and projects that create resilience within the community and thereby a resistance to the impact of energy market fluctuations.

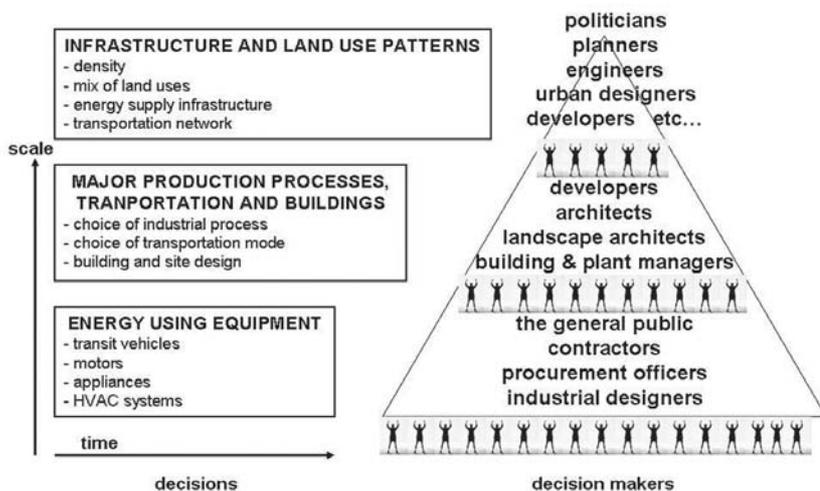


Figure 8: hierarchy of energy-related decisions

The Community

It is an interesting fact that the term “community” is used by all with apparent disregard for a consensus on its meaning. Here, the term community refers to a predetermined study area over which the decision-makers have authority or influence. For City Hall this may be an entire municipality, although the evaluation of an entire city might be complex or unwieldy; it could also be a more modest development such as a downtown rejuvenation project. To enable categorisation of demands the study area should be heterogeneous in its design, containing a variety of building types with a variety of energy uses and demand profiles. Such mixtures could include such properties as residential, commercial, retail, institutional, and even industrial.

The planning and decision making process

Changes in energy use patterns may be made within a community at a variety of levels (see Figure 8). At each level the decision-maker may be different. The simplest change is often at the level of the end-user. For example a manufacturer might improve the efficiency of his refrigerator; his car, or his light bulbs. Each end-user would purchase this new product based upon anticipated cost savings but for significant savings to be made, the number of end-users purchasing this new product must be large.

In turn, a change in energy type at the system level would involve fewer stakeholders and should be (theoretically) easier to initiate but would require increased investment. For example, a simple cycle plant might decide to recover its rejected heat and employ this within a district energy system, displacing oil heating in community buildings. At the community level, this change would likely be the expensive but also environmentally the most far reaching of the alternatives. It is at this level of change that a community planning tool is under development within Annex 49, making it essential that there be a rigorous approach established to its decision-making process.

If exergy is a comprehensive measure of the potential for an energy supply to do work [1] then it offers the ability for the user or users to organise activities to manage the availability of energy. By knowing the characteristics of the task to be undertaken (demand), one can select the most appropriate energy stream with which to undertake this task (supply). Energy sources within the community must be separated and categorised according to their quality (i.e. exergy content) before being aggregated to form specific energy supply groups. Similarly, categories for energy demand types can be defined.

With an understanding of the capacity and capability of each category, supply and demand, integration would follow, linking energy supplies and demands in the most effective manner and where possible, using local resources to generate that energy.

Within reason, it should also be possible to align the tasks in such a manner that the output energy stream from one task becomes the input energy stream for another thereby cascading through the activities, maximising the effectiveness of the supply. This line of thinking is similar in some respects to Pinch Technology [2] as used within an industrial process where the cooling and heating requirements are coordinated to minimise the need for imported energy. The fundamental difference though between the use of exergy and energy in Pinch Technology is that for the latter i.e. energy, a satisfactory solution is obtained when the supply and demand is balanced or the difference is minimised. A satisfactory exergy solution however is only obtained when the supply and demand is not only balanced, as before, but also anchored at its lower conditions to the ambient temperature – a much more demanding condition.

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- [2] Göran Wall, Mei Gong. Exergy Analysis Versus Pinch Technology. ECOS'96

⁵Natural Resources Canada, Canada

CASE STUDIES ON LOW-EX COMMUNITIES

Community Case I: Parma City, Italy

Paola Caputo⁶

The city of Parma is located in Northern Italy, in the Emilia-Romagna region, with approximately 178.000 people living and a balanced presence of tertiary, industrial and agricultural sector, a mild climate and a notable historical buildings stock and cultural heritage. Because of these characteristics, Parma represents a typical city of the Pianura Padana.

During last years the city has undergone many initiatives related to energy efficiency measures for its community, with two energy plans (the last date back to 2006), local regulations for mobility, and the current project of a local mandatory buildings energy regulation with advanced quality certification tools and incentives for low energy and renewable energy technologies implementation.



Figure 9: Overview of the city of Parma

The project starts with a detailed energy use analysis for residential, tertiary, industrial and agricultural sector. The consumption of electricity, fuels for heating and water were given by the local utility and implemented in a GIS, in addition to thermal plants data. This tool allows to easily localize energy consumptions and to match with buildings features, location, type of activity in a comprehensive database.

Energy efficiency improvements, renewable energy potential and emission reductions strategies will be assessed to find a realistic path to reach the 2020 European goals, introducing mandatory regulatory issues on local energy planning. The end of the project will be an assessment on the futuristic hypothesis of transforming Parma in a 100% renewable city by the year 2050 adopting as a benchmark today best available technologies.

Yearly energy use data for each building and activity will be split into monthly values, using statistical cor-

relation given by the utility. After that, thermal energy demand will be disaggregated into three main categories, heating, domestic hot water and cooking. Then electric energy consumption will be subdivided into categories related to the different activities (using statistical data collected in other similar case studies), thus allowing us to compute possible efficiency improvements by the use of low energy appliances.

In particular the approach adopted in calculation will be bottom-up engineering oriented, in order to suggest practical and readily available solutions for the customer (the end-user has to be aware of the possible economic advantages of energy saving strategies, and how to implement them).

Three scenarios will be evaluated for Parma: business as usual, 2020 European goals (the path for reaching renewable energy integration, primary energy consumption reduction and carbon emission reduction goals) and Best Practice (best available technologies adoption). Then an assessment on how to transform Parma in a 100% renewable energy city by the year 2050 will be conducted. To that end, also low exergy technologies will be proposed.

Community Case II: Okotoks Solar Demonstration Project, Canada

Ken Church⁷

The community of Okotoks, Alberta (Canada) lies more than 1,000 m above sea level, but because of its position it has an average summertime temperature that exceeds 20°C. This has allowed the development of North America's first solar demonstration project that incorporates the principles of low-exergy in its design. Not only low exergy thermal collection, but the project also includes the concepts of short term storage and long term season borehole thermal energy storage (BTES).



Figure 10: Okotoks solar demonstration project

The bank of thermal collectors collectors, facing South at an angle of 45°C, are designed to collect up to 1.5 MW of thermal energy, enough to supply heat to the buildings at 55°C.

⁶ Politecnico di Milano, Italy

⁷ Natural Resources Canada, Canada

The solar water heating system using 2,293 m² of commercially available flat plate solar collectors was designed to provide 90% of the annual space heating and 60% of domestic hot water (DHW) for the 52 individual dwellings located within this north American subdivision; this, despite winter temperatures as low as -33°C. To provide consistency of collection and security of mounting, the array was mounted on garages that were located to the rear of the detached houses. The system uses a propylene glycol/water solution that is pumped through an underground pipe network to a main collection heat exchanger and a high temperature but short-term thermal store (STTS) located within the neighbourhood's 'Energy Centre'.

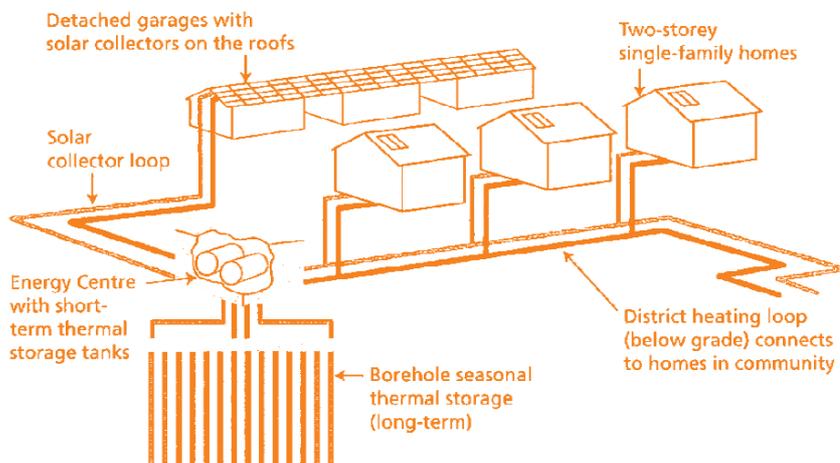


Figure 11: Solar seasonal storage and district heating loop

Two 120 m³ un-pressurised epoxy-lined cylindrical steel water tanks, pumps and controls comprise the STTS which, through the use of internal baffles encourage stratified thermal storage that manage the peaks and troughs of daily thermal demand. To extend this capacity and ensure minimal demand for higher exergy fossil fuel consumption, there has been designed a long-term Borehole Thermal Energy Storage (BTES) underneath what is now the local park and children's play area.

This storage facility comprises 144 boreholes, each 35 m deep and 150 mm in diameter. Each borehole contains a U-tube grouted in place to transfer heat between the system fluid and the earth. To maintain thermal efficiency, the borehole storage is topped by layers of sand and insulation and a waterproof membrane, with clay and attractive landscaping. The BTES is connected in strings of six boreholes and in four circuits to prevent any one string or circuit, if damaged, to impact storage capacity.

Even though the buildings are supplied with heat at 55°C, by the end of a typical summer, temperature in the earth surrounding the boreholes will reach more than 80°C. The two storage systems operate in series in that when the short-term system temperatu-

re exceeds that of the long term system then pumps circulate the hot water from the short term tank through the boreholes.

The plant was designed and built by a consortium of federal and municipal governments and utilities and started operation in June 2007. It is estimated that it will take three years to fully charge the underground storage to the design temperature of 80°C. Performance indications from May 2008 suggest that the solar energy system is performing as designed and that the 90% solar fraction will be achieved by year 5.

The 52 single detached homes included in the design were typically 142 m² in heated area and included a number of key energy efficiency features, specific to the use of low temperature heating systems. These included an innovative design of fan-coil unit to accommodate the heating supply temperature of 55°C and a return temperature of 35°C. The unit was designed according to the specifications of Natural Resources Canada, the federal government's research office. Despite a premium price attached to the development, all properties sold quickly and post occupancy reviews have been favourable.

Low exergy supply systems such as this must consider the seasonal variations in temperature and other problematic events. The failure of the electrical power for example may overheat the glycol loop and thus an additional 3.6 kW photovoltaic (PV) array and battery bank was incorporated in the Energy Centre to power the pumps in this situation. Likewise in winter with low ambient temperatures, if there was no glycol circulation, the loop may cool to below freezing and cause damage to the equipment. On start-up therefore, the glycol solution is circulated through a bypass loop until its temperature exceeds that of the short term storage tank. This protects the heat exchanger in the Energy Centre. As an additional security measure, whenever the temperature in the short term storage tank is lower than in the longer term storage, the system reverses and heat is transferred from the BTES to the STTS and to a heat exchanger and thence to the EN253 standard district heating loop. This supplies heated water to individual houses and the specially designed low temperature air-handler units in the basements. Warmed air is distributed through the house via internal ductwork.

Annex 49

Low Exergy Systems for High-Performance
Buildings and Communities

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ECBCS ANNEX 49

Annex 49 is a task-shared international research project initiated within the framework of the International Energy Agency (IEA) programme on Energy Conservation in Buildings and Community Systems (ECBCS).

Annex 49 is a three year project starting in November 2006, following a preparation phase of one year. About 12 countries are currently participating.

For up-to-date date information see:

www.annex49.com

Announcements

- **Joint Annex 49 - COSTeXergy Conference:**
The Future for Sustainable Built Environments
- Integrating the Low Exergy Approach
21st April 2009
Heerlen / The Netherlands
- **5th Expert Meeting: Spring 2009**
April 22nd - 23rd, 2009
Maastricht/Heerlen
The Netherlands
- **Final (6th) Annex 49 expert meeting**
2nd - 4th September 2009
Espoo, Finland



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