IEA ECBCS ANNEX 49

LOW EXERGY SYSTEMS FOR HIGH PERFORMANCE BUILDINGS AND COMMUNITIES

Jahresbericht 2008

Autor und Koautoren	Forrest Meggers (ETH) Petra Benz-Karlström (Basler & Hofmann)	
beauftragte Institution	ETH Zürich	Basler & Hofmann AG Ingenieure und Planer
Adresse	HIL E 15.1, Wolfgang-Pauli-Str. 15, 8093 Zürich	Forchstrasse 395 8032 Zürich
Telefon, E-mail, Internetadresse	044 633 28 60, meggers@hbt.arch.ethz.ch	
BFE Projekt-/Vertrag-Nummer	102532 / 153233	
BFE-Projektleiter	Charles Filleux	
Dauer des Projekts (von – bis)	von 11.02.2008 bis 28.02.2010	
Datum	01.12.2008	

ZUSAMMENFASSUNG

It was a very productive year for the Swiss participation in the IEA ECBCS Annex 49. This was the first year of official Swiss participation, but initial work and preparation had already been done back in 2007. The projects were initially defined and relationships were developed with the international participants in the Annex 49. This was expanded over the summer into an official application for the support of the BFE for participation in the project. The project was accepted and officially began in February 2008. It included support for three research areas: HVAC modeling, wastewater heat recovery, and retrofit cooling.

There were two working phase meetings of the Annex 49 in 2008 where the international participants gathered. At the 3rd working phase meeting of the Annex 49 in Vienna in March, 2008, the Swiss participation was accepted and the projects were placed into Subtask A and C. Forrest Meggers, Petra Benz-Karlström, and Luca Baldini represented Switzerland at this meeting and gave 4 different presentations on low exergy research being carried out in Switzerland. The other participants provided valuable feedback at the Vienna meeting on how best to proceed with the Swiss projects. The projects were integrated into the framework of the Annex and collaborations and networks were developed within the subtasks. At the 4th working phase meeting in Iceland, the progress in the wastewater project was presented, and important frameworks were setup with the other collaborators in the Annex on the design tool and on the retrofit cooling projects.

Over the course of 2008 Forrest Meggers created initial models and analyzed the methods of applying exergy analysis to wastewater heat recovery. Initial results were submitted in abstracts for presentation in three conferences. The abstracts were accepted and full papers were developed discussing the initial models and results. The papers were presented as posters at conferences and were included in the conference proceedings.

The retrofit cooling subproject was delayed due to organizational changes for the Swedish collaboration partners. The development of the tool could start in autumn and results are expected in the first months of 2009.

Projektziele

The application of exergy analysis to building systems has been shown to have a large potential impact on reducing the primary energy demand of buildings, and thus the subsequent greenhouse gas emissions related to energy production. In the initial year of this project the relationship with the international community was further developed, and the scientific framework and initial methods and models for the projects was setup. The projects being contributed by Switzerland have been integrated into the Annex 49 and represent new and important aspects of exergy analysis and buildings. These projects along with the contributions of the other Annex 49 members will result in a substantial step towards not just more efficient buildings with reduced energy demand, but more importantly, appropriate and more effective building technologies that minimize CO_2 emissions.

On a broad scale, the goals of the Annex 49 as a whole are progressing well. The 3rd and 4th working phase meetings were held, and the subtasks are moving forward, and still some new ideas and exciting concepts are being added. Many of the subtask deliverables are already undergoing internal review. This includes some new modeling tools in Subtask A, extensions into the community level in Subtask B, many new specific technologies and applications in Subtask C, and of course the dissemination and organizational preparations in Subtask D. There is already a wealth of material that needs only to be organized to be included in the guidebook that will be a result of the Annex 49.

On the specific contributions from the Swiss participation being supported by the BFE, progress was also made. The initial models of wastewater heat recovery have shown a large potential for energy recovery. They also indicate the potential for an optimization based on exergy that would not be possible on an energy basis alone. The work on HVAC modeling has been extended to better examine the building systems. This provides a more extensive look at the exergy consumption of a building, and it provides important information that might be missed by an energy-based calculation.

Durchgeführte Arbeiten und erreichte Ergebnisse

Admin

First of all, the work done in support of the project organization included the finalization of the project application and description, as well as communication with the Annex operating agent for the inclusion of the Swiss projects in the Annex. There were several meetings held between the Swiss participants from the ETH Zurich and from Basler and Hofmann. This included mostly the preparation and post-discussions for the two international meetings. Also the financing setup between the two participating institutes has been made and organized within the two partner institutions.

Wastewater Heat Recovery

The work on the wastewater heat recovery project was focused on creating an initial model of the system to demonstrate the potential exergy savings. The first obstacle that was overcome was the problem of how water is used and wastewater is generated. This is a very discontinuous system. A method was developed based on a statistical analysis tool [1] and using the input designed for a 2, 3 and 4 person residential building from recent data collected by the National Renewable Energy Laboratories in the USA [2]. This provided the input data for basis to build a model of potential heat recovery. A hot water usage profile was generated from the above tool and statistics for one year. Events were described in 6-minute time intervals for showers, bathes, sinks, clothes washing, and dish washing. Both the raw hot water usage and the total mixed usage were described.

The model uses the flow of hot water over time along with its temperature from the data mentioned above, but is flexible to use newly acquired data. The simulation sends hot water to a modeled recovery tank containing a heat exchanger. At each time step the simulation checks if a hot water event occurred and the amount of water going into the tank. The temperature of the incoming water is according to [2] and the losses from usage and transport are subtracted.

If an event has occurred, the new volume of the tank is calculated. A valve is simulated that activates if the tank fills to capacity making space for new inputs. These new events are combined using an energy balance with the current volume in the tank. This calculates the new temperature of the tank assuming it is completely mixed. The heat extraction by the heat exchanger is modeled as a laminar flow through a pipe with constant surface temperature equal to the tank temperature [3]. The model calculates the heat extracted from the tank and the heat losses at each step using an energy balance. These heat exchanges determine the temperature of the tank for the next time step. If the temperature has dropped below a set temperature, the tank is flushed completely and waits for the next event.

A second model was derived that allowed for an approximation of a tank with stratified conditions, eliminating the assumption of a completely mixed system. The same setup for the input of data was used in the mixed model. In this case the wastewater volume is broken up into discrete layers within the tank. The heat exchanger is modeled using the same equations except the heat is removed separately from each layer during each time-step. Because the heat exchanger flows in from the bottom, the heat is removed at the bottom first creating a stratified state. Thus the temperature at the top stays warmer (augmented by buoyancy) and the output temperature of the heat exchanger at the top is higher (more exergy). The conduction between each layer is included as the stratification develops, and the temperature differences are monitored such that unrealistic extreme cases can be avoided. In this case a valve is simulated that would be at the bottom of the tank and empties the bottom layers if they drop below a set temperature at each time step. The tank is also emptied if it is overfilled as done in the mixed model.

Using the annual input data the amount of exergy available from the wastewater is calculated from exergy equations [4] and the amount of heat extracted by the heat exchanger at each step. The optimal heat exchanger flow rate and tank size were probed to see if there is a potential to optimize the system based on exergy. Also the potential improvement in the performance of a heat pump was considered based on exergetic heat pump performance data from a BFE project at HSLU in Horw [5].

The output of the model for a dynamic filling and emptying of the 400 L recovery tank for each 6-minute time step over the model year is shown in Figure 1. The variations shown are due to complete emptying of the cooled tank, while the overflow happens only while the tank is completely full. January is highlighted in Figure 1, and is shown in Figure 2.

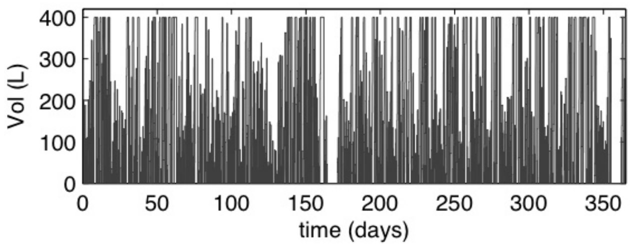

Fig 1. Volume in the recovery tank over the course of the modeled year with the month of January highlighted

In Figure 2 the top plot shows the total volume given in Figure 1 with better resolution. The bottom plot is the tank temperature. The temperature decreases quickly after each fresh input to the tank, and then decreases slowly until it is emptied. A normal fill and recovery cycle appear to take about one to two hours.

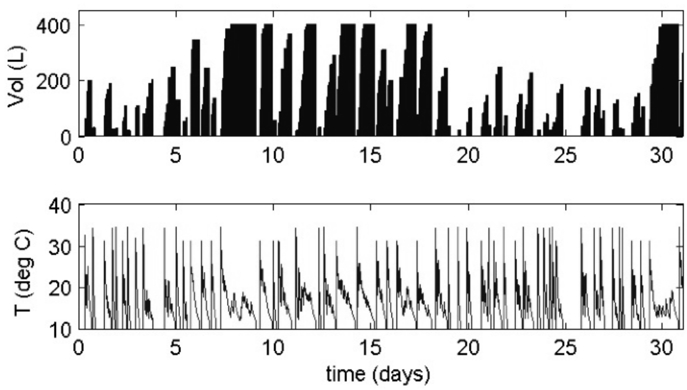

Fig 2. January data for the recovery tank total volume (grey) and overflow volume (black) on top, tank temperature in the middle, and exergy recovered on the bottom.

When the characteristics of the tank were varied, an exergetic optimum was indeed found. This is shown in Figure 3 for the flow rate through the heat exchanger and for the tank volume. These plots also show the energy recovered for the various tank parameters, which demonstrates how the exergy analysis shows an optimal point that would not be clear from an energy analysis alone. The values are the annual recovery of energy and exergy at the different system configurations. The exergy analysis captures not just the raw quantity of energy, which of course increases with a larger tank and faster flowrate, but it also captures the quality of the energy recovered. In this case, the higher temperature recovery is more valuable so the bigger tank and faster flow rates actually result in the total quality of the energy recovered (i.e. the exergy) to be reduced. This is especially important when considering the impact on the performance of a potentially integrated heat pump.

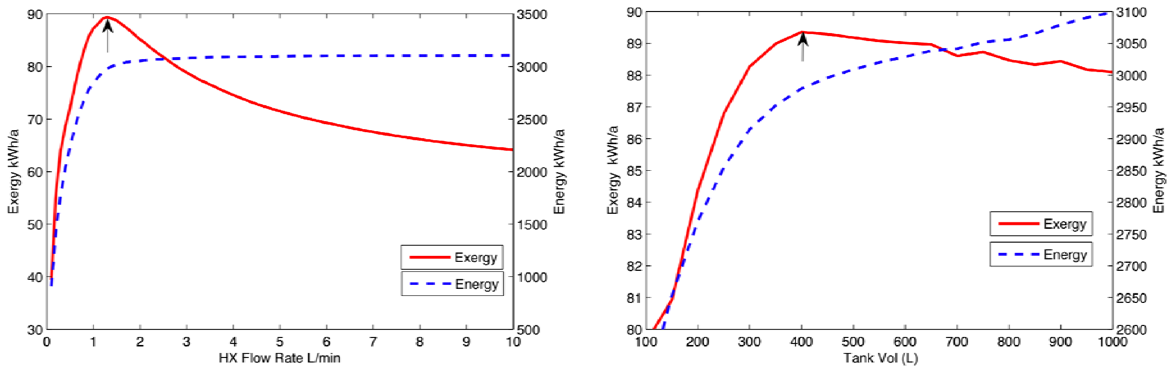

Fig 3. Total exergy recovered over the year versus the heat exchanger flow rate.

At this state the model system recovers 85 kWh of exergy. The energy demand reported by NREL [17] for this annual hot water usage was 4800 kWh and the tank model simulation gave a similar demand of 4400 kWh for the year. The simulation produced exergy consumption for the annual hot water production of 350 kWh. On an energy basis 3000 kWh are brought out with the heat exchanger, which is 68% of the demand supplied. From an exergy perspective 85 kWh are recovered compared to the 350 kWh supplied. This is only 25% because the temperature recovered is lower than the temperature supplied, thus this is another example where exergy shows a loss in quality that would is not captured by energy analysis alone.

The stratified tank model was developed more recently and requires much more computation time, and due to small variations in the filling of the top layer, the long simulations were not always stable. Therefore the month of January was used to explore various flow rates for the optimal heat exchanger setting, instead of using an entire year. This is shown in Figure 4.

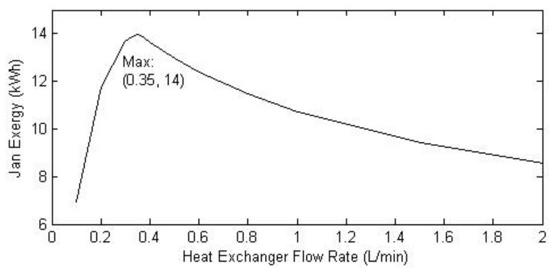

Fig 4. Exergy recovered over the month of January versus the heat exchanger flow rate for a stratified model of a wastewater heat recovery tank.

Compared to the mixed tank model this is a much lower flow rate. However, this should be expected as the stratified model allows higher temperatures to be present and remain longer in the top of the tank. The heat exchanger flow gained more exergy from the high temperature fluid at the top using a lower flow rate. As for the quantity of energy recovered in the stratified tank, it is the same as the mixed tank at 3000 kWh hours of energy, or 68% of the hot water energy recovered. This agreement helps to verify accuracy of the independent models. As expected, the exergy recovery is higher because a higher temperature is maintained at the top of the tank. By routing the heat exchanger from the bottom of the tank to the top, a stratified system is setup that increases the exergy extracted. In this case 145 kWh of exergy are recovered of the 350 kWh, nearly double that of the mixed model.

The potential impact on the heat pump was considered. The integration of a heat pump operating in conjunction with the recovery system was not included in the model, but an estimate on how the characteristics of the heat recovery described by the model would impact a heat pump was determined. Based on the recovery temperatures and the heat pump performance (COP) related to input temperatures [5], a rough estimate was made that the COP of the heat pump could be increased. Based on the average output of the heat exchanger at 15 degrees, the COP can be increased by 15-20% on average. If one considers that the water heating may be able to take place only during the initial phase after when the highest temperatures are recovered from the tank, then the COP has the potential to increase by nearly 100%. A flow chart of the system and its integration with a heat pump was developed and is shown in Figure 5.

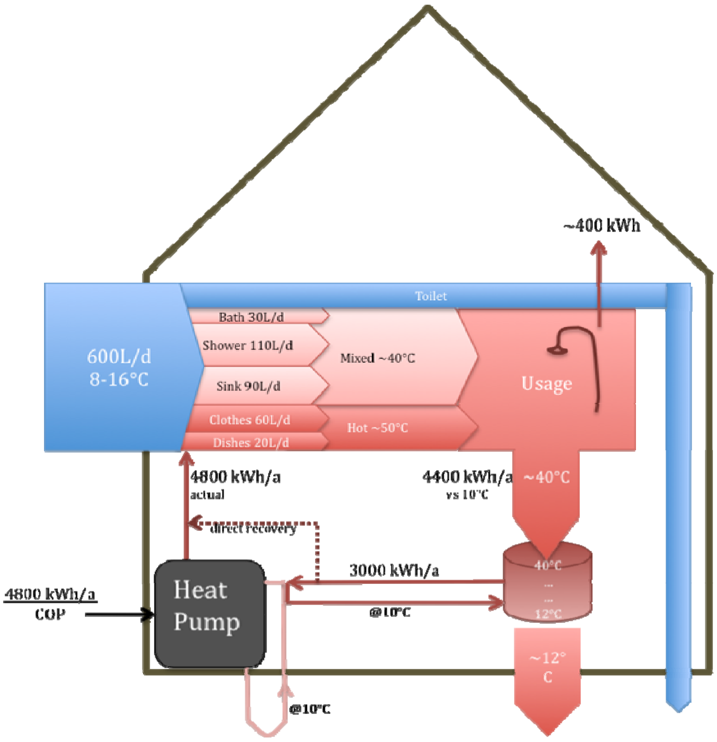

Fig 5. Flow diagram of the water usage in a typical 4 person residential home with a separate grey water system with heat recovery integrated with a ground source heat pump to augment the source temperature.

The analysis of the system performance was submitted to three conferences for presentation and discussion. Initially the simple model was submitted to the AIVC conference on ventilation where the performance was compared directly with ventilation heat recovery. Ventilation heat recovery is very common, but the potential for recovery from wastewater was shown to be nearly the same. This is demonstrated in Figure 6. It shows how hot water is becoming a more and more important part of the building energy demand as space heating and ventilation systems are made more efficient. In the most efficient residential buildings hot water can be over 50% of the demand.

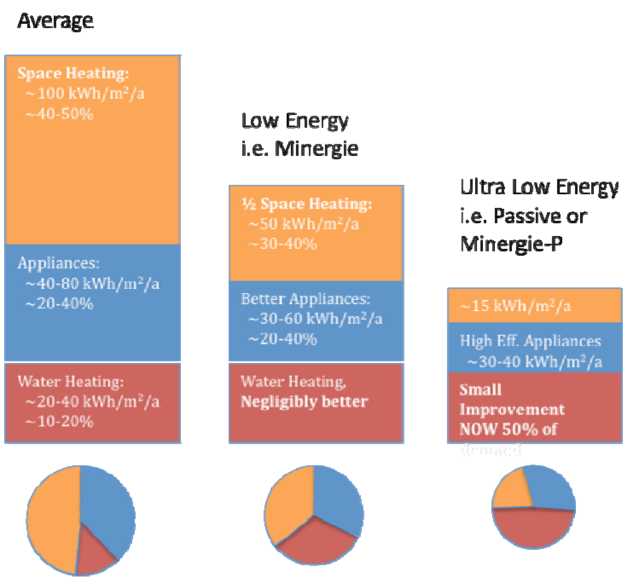

Fig 6. Energy demand in residential buildings for Space Heating (and ventilation), Appliances, and Water Heating for buildings with different performance levels from typical to very low energy. With new efficient buildings, water heating is becoming a much more important part of building energy demand.

The model was also presented at the ICEBO (Intenational Conference on Enhanced Building Operations) where the impact on total building performance was discussed. Finally, the extended model including the stratified tank model was presented at the PLEA (Passive and Low Energy Architecture) conference. There were many passive house designs presented, and in one concept an architect became very interested in implementing this concept in his project, and the may prove to be a very preliminary and rough pilot if he carries out the idea.

Retrofit Cooling

This subproject is an extension of another BFE project being worked on by Petra Benz-Karlström, “Hocheffiziente Kühlsysteme für Gebäudesanierungen.”

The work within the Annex 49 was initially hindered by the change in location of one of the principal collaborators and head of Subtask C, Prof. Gudni Jóhannesson. He moved from the KTH in Sweden to a position as Director General of the Icelandic National Energy Authority. In connection with the 4th working phase meeting a separate meeting was held, and the development of the tool could start.

The outlay of the tool was defined. The models for calculation have to some extent been defined, but the work is still ongoing. Unfortunately it is not possible to show any results at this time. At present the stability of the calculations are being tested.

The decision tool from the project “Hocheffiziente Kühlsysteme für Gebäudesanierungen.” will be integrated in the Annex deliverables.

Nationale Zusammenarbeit

The main collaboration is between the two principal investigators, Petra Benz-Karlström at Basler and Hofmann and Forrest Meggers at the ETH Zürich. Regular meetings and discussions take place on the status of the Annex project and the individual Swiss contributions. It is a good combination with the perspective from the industry in combination with the academic view.

At the ETH there is a wide range of potential collaboration. Through the connection with the Annex, architects Frank Thesseling and Arno Schlueter were able to take the exergy tool and extend their Design Performance Viewer tool to peform exergy analysis. This tool is now being further developed within another BFE project on planning tools, and exergy is still playing an important role.

Collaboration has also been further developed between the ETH and the HSLU in Horw where research is being done on exergy and heat pumps led by Dr. Beat Wellig. A new test rig has been developed to test the performance of heat pumps, and a report on exergy consumption of air/water heat pumps [5] prepared in Horw as part of the WEXA project has been very useful. F. Meggers also met with the group at the IEA Heat Pump conference in Zurich along with other researchers working on heat pumps and low exergy or recovery systems.

Finally, the application of the concepts that have been modeled in a real project was considered in the development of a potential KTI project together with Geberit AG. The project was accepted at the end of the year, and the final details will be worked out with Geberit in January 2009. Idealy Geberit will develop this concept initially into a product that can recovery heat and simply preheat hot water. The pilot project for the integration with a heat pump system will take place in 2009/10 with the B35 building project of Prof. Dr. Hansjürg Leibundgut.

Internationale Zusammenarbeit

The IEA Annex 49 project consists of many international participants from industry, university, and research institutes around the world. Members come from the following countries:

Austria • Canada • Denmark • Finland • Germany • Italy • Japan • Poland • Sweden • Switzerland • The Netherlands • USA

There were representatives from each of the countries attending at least one of the two working phase meetings in 2008. There were also members of the Annex at the AIVC conference in Kyoto, Japan and F. Meggers had a one on one meeting with Prof. Shukuya, a pioneer of exergy analysis applied to buildings, at his university in Yokohama. One of the main topics in the international discussion and debate is the determination of a reference state for exergy analysis of buildings. Usually the outside conditions are selected, but this is best applied to steady state analysis. When the conditions change it becomes more difficult to compare results. The work done on the reference state is of importance to the exergy analysis being worked on in the Swiss projects because dynamic systems are being studied, and using an appropriate reference state is important.

Bewertung 2008 und Ausblick 2009

The 2008-year was productive. There were many developments and outcomes to consider. The most important success was the completion of administrative aspects to get the project officially underway. The working phase meetings were also a success as the Swiss projects were accepted officially into the Annex and a good relationship with the other members of the Annex was developed. The presentation of the initial analysis of the wastewater system at three conferences was a success and valuable feedback was received, along with potential contacts for future extension of the work. Overall, most of the work described above could be considered a success. Although the retrofit project was delayed, the work is now underway and results are expected during the first quarter of 2009.

In 2009 there will be two more working phase meetings as part of the Annex 49. One in Heerlen, Netherlands in April 2009 and one in Helsinki, Finland in the fall. The final deliverables for the Swiss projects will be completed and the final deliverable of the Annex 49 will be completed. In the spring of 2010 there has been plans made to have an international conference on buildings and exergy to present the outcomes of the Annex 49 research to the international community, as well as to learn about other current developments. In the next year the goal will be to maintain a better awareness of the developments and progress in the different aspects of the Swiss participation, as well as a better awareness of the changes happening within the other research projects in the various subtasks of the Annex. Also, ideally the KTI project will officially begin and it will build off of the results that have been obtained from the Annex 49 work. It will be important to make sure that both projects meet their goals, and they should be mutually beneficial.

Referenzen

[1] Jordan, U. and Vajen, K. **Influence Of The DHW Load Profile On The Fractional Energy Savings: A Case Study Of A Solar Combi-System With TRNSYS Simulations**. *Solar Energy*: pp. 197-208, 2001.

[2] Hendron, R. ***Building America Research Benchmark Definition****.* Golden: National Renewable Energy Laboratory, 2007.

[3] Incropera, F. P. and DeWitt D. P. ***Fundamentals of Heat and Mass Transfer***. New York: Wiley, 2002.

[4] Schmidt D. Design of Low Exergy Buildings Method and Pre-Design Tool. ***International Journal of Low Energy and Sustainable Buildings***, 3: pp. 1-47, 2004.

[5] Gasser, Lukas. **WEXA:** ***Exergy analysis for increasing the efficiency of air/water heat pumps****.* Lucerne: Lucerne Univ. of Applied Science and Arts, 2008.