Carnegie Mellon University
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A Presentation of Work in Progress
4 October 2006 in the Intelligent Workplace of CMU
Pittsburgh PA 15213

Carnegie Mellon's Intelligent Workplace Energy Supply System, IWESS: Power; Cooling, Heating, Ventilation from Solar Heat and Renewable Fuel

Abstracts

The Broad Two Stage, Steam Driven Absorption Chiller

Hongxi Yin

Developments in absorption cooling technology present an opportunity to achieve significant improvements in microscale building cooling, heating, and power (BCHP) systems for residential and light commercial buildings that are effective, energy efficient, and economic. However, model based design and performance analysis methods for micro scale absorption chillers and their applications have not been fully developed; particularly considering that thermal energy from a wide variety of sources might be used to drive the chiller in a residential or light commercial building. This work contributes important knowledge and methods for designing and integrating absorption chillers in BCHP systems that reduce energy consumption, decrease operational costs, and improve environmental benefits in residential and light commercial buildings.

To be more specific, this work contributes to the development and application of absorption chillers in the following areas:

- establishment of a unique experimental environment and procedures for absorption chiller tests under various conditions
- conduct of a comprehensive testing program on a microscale absorption chiller
- construction of a comprehensive chiller model based on the pertinent scientific and engineering principles adapted to the design of a chiller and to the analysis of extensive, detailed test data obtained from the test program
- analysis of the measured data, refinement of the model, and improvement of the chiller design on the basis of the data analysis process

The model is now being used as a tool to adapt the chiller to various heat sources and sinks and to carry out performance simulations of micro BCHP system.

The Broad Solar Receiver and Absorption Chiller System

Ming Qu, Sophie Masson

A solar driven absorption cooling and heating system has now been installed in the Intelligent Workplace, the IW. This 650 m^2 (7,000 square feet) space provides meeting rooms, offices, and laboratories for the faculty and graduate students in Carnegie Mellon's Center for Building Performance and Diagnostics.. The system consists primarily of 52 m^2 of single axis tracking parabolic trough solar receivers, PTSC's, and a 16kW two stage absorption chiller driven by either hot fluid from solar receivers or natural gas fuel. The system receives solar energy and converts it to thermal energy; the chiller then uses this energy in summer to generate chilled water. In winter, the thermal energy is directly used for heating. An performance analysis of the PTSC's was carried out based on mass and energy balances and heat transfer computations programmed as mathematical equations in the EES modeling system. The performance of the overall solar cooling and heating system for the IW has been programmed in the TRNSYS modeling system. Experimental data will been acquired and used for validating the solar model. The system model will be used in interpreting the data obtained on the system performance. This solar energy system has been estimated to provide up to 50% of the cooling and 20% of heating energy for the IW in Pittsburgh, PA.

A BioDiesel Fueled Engine Power Generation, Heat Recovery System

Fred Betz

The bioDiesel engine, generator, and heat recovery system is a renewable fuel based energy supply system providing both electrical and thermal energy to the Intelligent Workplace, the IW, and campus power, steam, and hot water grids.

A 32 kW bioDiesel fueled John Deere turbocharged diesel engine drives a 25 kWe grid connected Baldor generator. The engine exhaust, about 23 kWt, is utilized in a Vaporphase horizontally mounted steam generator to produce 30.4 kg/hr, 67.1 lb/hr, of steam at 7 bar absolute, 88 psig. This steam drives a Broad absorption chiller for space cooling in the IW during the summer months. During the winter months the steam is diverted to a converter to provide hot water for space heating in the IW. During the interim seasons the steam can be sent to the campus steam grid.

The energy in the engine coolant, about 20 kWt, is recovered in a heat exchanger producing hot water or is rejected to atmosphere in a remote air cooled radiator. The coolant energy can be utilized in the IW for space heating during the heating season or for desiccant regeneration in the Semco dehumidification ventilation unit in the cooling season. The Semco unit currently uses a heating natural gas heating to regenerate the solid desiccant.

The installation of this system is scheduled to begin on the December 2006 and startup is scheduled for April 2007. After two months of commissioning using petroleum based Diesel fuel the system will be operated with 100% bioDiesel fuels provided by CTI Biofuel of Pittsburgh, PA for extensive testing. Four different bioDiesel fuels will be tested at five load levels: maximum power and 100%, 75%, 50%, and 25% of the system design load, 25 kWe. The system fuel consumption and heat production will be measured. .

Engine emissions will be monitored throughout this test program by a six gas NOVA gas analyzer and a TSI Dusttrak to measure particulates in the 0.1 to 1.0 micron size range. Detailed particulate emissions monitoring will be carried out by the Center for Atmospheric Particulate Studies, CAPS, at CMU.

The LTG Fan Coil with Siemens Control Sytem

Yun Gu, Viraj Srivastava

Fan coils of three distinct types have been specified and ordered from LTG for delivery in early December 2006. These fan coils will be installed in 8 office and 2 meeting room spaces of the southern half of the Intelligent Workplace, the IW_s. Mounted below the floor level, the units will meet the space cooling and heating loads of the IW_s by circulating room air through heat exchangers supplied with chilled or heated water from the building grids. They will also distribute conditioned fresh air from the Semco ventilation unit to the space.

Preliminary engineering for the installation of these fan coils with their chilled and heated water and electrical power supplies has been completed. An advanced control system is now being designed for this overall system. Siemens Building Technologies will supply instrumentation and control hardware and software and installation. This control system will set the fan speed, the flow and temperature of the chilled and heated water, and the flow of ventilation air to each fan coil in the various room spaces of the IW_s based on measurement of temperatures, humidity, and occupancy. And it will also evaluate the overall effectiveness and efficiency of the overall system in providing a building environment that promotes the health, productivity, and comfort of the occupants at a minimal expenditure of energy.

A description of the functioning of the system and a listing of the sensor and control hardware and the software required has bee prepared and submitted to Siemens. Preliminary plans for the installation of the overall control system have been drawn up including room controllers interconnected by a wireless net with an overall system controller for data processing, equipment monitoring, system evaluation, and integration with other building systems in the IW_s. The fan coils and their control system will be installed and operational by the end of December 2006. Various operational and control strategies will be programmed and evaluated in the following year.

Radiant Cooling/Heating Devices in the IW

Gary Gong

Radiant cooling and heating have the potential to greatly reduce the energy consumption in buildings as an alternative to the currently overwhelming use of cooled/heated air convection systems. Two types of radiant heating and cooling are used in IW. They are radiant mullions and overhead panels. Our study enhances the understanding of the heat transport physics of radiant heating and cooling, and the effect of infiltration on indoor humidity and moisture condensation control of a radiantly heated or cooled office. The following aspects have been studied:

- the impact of the position of radiators and ventilation rate on energy consumption and thermal comfort in a hybrid HVAC system.
- a heat transfer model for mullion heating and cooling.
- s heat transfer models for overhead radiant panels.
- the effect of moisture condensation on a radiantly cooled office integrated with a passive desiccant system.

Continuing work will investigate air infiltration in the IW. Infiltration will be measured, and ways to reduce it will be recommended. The effects of infiltration on indoor humidity and moisture condensation on radiant cooling in the IW with its desiccant based ventilation system will be modeled.

The SEMCO Enthalpy Recovery, Solid Desiccant Dehumidification, Heat Pump Ventilation System

Chaoqin Zhai

A Semco heat pump and solid desiccant based ventilation unit, the REV 2250, together with an enthalpy recovery module, the FVR 2000, has been installed and is now being tested in the Intelligent Workplace, the IW.. The unit has been operated in two different modes: as an air conditioning system, which provides ventilation and a portion of heating/cooling for the IW through recirculation air; and as a dedicated outdoor air system, a DOAS, which delivers ventilation air at a user selected temperature and humidity while heating/cooling is provided by other systems such as radiant panels and mullion pipes supplied with chilled or heated water. The winter performance of the enthalpy recovery module has been tested and reported; a finite-difference heat transfer model has been developed to relate the enthalpy wheel performance to its design parameters and operating conditions. The winter performance of the active desiccant wheel functioning as a sensible heating device and the heat pump section of the unit has also been tested. The heat and moisture recovery performance of the enthalpy wheel, the dehumidification performance of the active desiccant wheel, and the cooling performance of the refrigeration system is now being tested and results will be reported in September 2006. A combined heat and mass transfer model will be constructed to relate the enthalpy and active desiccant wheel performance to their design parameters and operating conditions. This model will be used to explore the sensitivity of certain design parameters and operating variables and the possibility of performance improvement of the ventilation system. The experimental data and the computational model will also be used to investigate the potential to integrate the ventilation system with other components in IWESS, such as the engine generator and solar thermal receivers.

Overall System Performance Modeling: Solar Thermal Cooling/Heating of the IW

Sophie Masson, Ming Qu

A model has been programmed in Trnsys to calculate the performance of solar thermal energy supply in providing annually cooling and heating for Carnegie Mellon's Intelligent Workplace, the IW. The model includes the Broad parabolic trough high temperature solar receivers installed in August 2006, a Broad hot water driven absorption chiller, chilled water thermal storage, LTG fan coil, and the southern section of the IW, the IW_s. This model predicts the energy required for cooling and heating the IW_s and the fraction of that energy that can be provided by solar energy from the receivers. The effects of significant system parameters – the orientation of the receivers, the capacity of the thermal storage tank and the insulation thicknesses on the piping and tank – on the fraction of solar provided energy have been calculated by the model. This Trnsys study has proved helpful in the design of the solar based cooling and heating system now installed in the IW_s.

The base case system (without storage tank) is able to provide 37.8% of the cooling loads and 8.4% of the heating load from solar energy. The same system with north-south axis, east-west tracking solar troughs is able to provide 61.4% of the cooling loads and 7.5% of the heating loads. The north-south axis installation of the solar troughs on the IW_s was not possible due to the roof configuration.

Adding a storage tank without insulation to the base case cooling system increases the system energy performance, the solar ratio, from 37.8 % to 40 % - 47.6 % for tank volumes from 1 to 5 m^3. The solar cooling system can reach up a solar ratio of 49.2% with a 5 m^3 storage tank and 5 inches of thermal insulation. Adding a storage tank even without insulation to the base case heating system leads to a significant increase in the energy performance from 8.4 % to 20.9 % for a tank volume of 5 m^3. The solar heating system can reach up a solar ratio of 27% with 5 inches of thermal insulation.

A second TRNSYS model has been developed to simulate the Broad solar thermal receivers an independently variable load to measure the thermal output of the system. The solar system testing will enable us to adjust and validate both TRNSYS models based on experimental data.

Overall System Performance Modeling: The Effect of Window Opening on Cooling in the IW

Elisabeth Aslanian, Sophie Masson, Berangere Lartigue

This project extends the previous studies of the impact of the natural ventilation in a bay of the IW on cooling and ventilation energy requirements for a typical summer in Pittsburgh.
The Trnsys-Comis model has been extended to calculate, for any given control strategy, the effect of window opening on the cooling and ventilation energy requirements and on the thermal comfort achieved for the space. Different strategies have studied based on temperature or temperature and humidity criteria to meet the space requirements and to improve the thermal comfort in the bay.

The climate in Pittsburgh and the situation in the IW is not ideal for natural ventilation with complimentary nighttime cooling due primarily to the low thermal mass of the IW. Nevertheless, hybrid ventilation in the IW can reduce sensible and latent loads for the building and for its ventilation while maintaining the indoor conditions in the comfort zone. Energy saving of 14 %, about 1,000 kWh per bay, each summer can be achieved by the system while maintaining the thermal comfort during 84% of the occupied time.

Further research will exercise the current model (impact of the thermal mass and the control time step on the system performance) and then extend it (implementation of predictive control, shading control, fan assisted natural ventilation). Experiments and CFD modeling will be considered to improve the accuracy of calculation of air flow through the windows of the façade and the effects of partial window opening and air flow in the space.

IWESS from Here to Where, How?

David Archer

The IWESS components described in the previous presentations will be integrated in an overall system that will provide power, cooling, heating, and ventilation to the IW_s. The objective is an integrated system that

- provides for the safety, health, productivity, and comfort of the occupants. It is effective.
- reduces the energy requirements of space operation by a factor > 2. It is efficient.
- reduces the overall life cycle costs of space operation. It is economic..
- reduces the environmental impact of building operation, It is environmental.

Integration involves components, the space, and the various supply grids for power, steam, chilled and heated water. The steps involved in realizing, characterizing, and integrating each of these components are outlined and the status of the overall project is described.

The direction of future work on the IWESS and on the dissemination of its principles and lessons learned will be suggested.