A Final Report to the U. S. DOE/EERE/NETL

**Advanced Building Efficiency Testbed Initiative/Intelligent Workplace Energy Supply System; ABETI/IWESS**

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IINTRODUCTION

ABETI/IWESS is a project carried out by Carnegie Mellon’s Center for Building Performance and Diagnostics, the CBPD, supported by the U.S. Department of Energy/EERE, to design, procure, install, operate, and evaluate an energy supply system, an ESS, that will provide power, cooling, heating and ventilation for CBPD’s Intelligent Workplace, the IW. The energy sources for this system, the IWESS, are solar radiation and bioDiesel fuel. The components of this overall system are

- a solar driven cooling and heating system for the IW comprising solar receivers, an absorption chiller, heat recovery exchanger, and circulation pump.

- a bioDiesel fueled engine generator with heat recovery exchangers, one on the exhaust to provide steam and the other on the engine coolant to provide heated water.

- a ventilation system including an enthalpy recovery wheel, an air based heat pump, an active desicant wheel, and an air circulation fan.

- various convective and radiant cooling/heating units and ventilation air diffusers distributed throughout the IW.

PROJECT GOAL

The goal of the ABETI/IWESS project is to demonstrate an energy supply system for a building space that will provide a healthy, comfortable environment for the occupants and that will reduce the quantity of energy consumed in the operation of a building space by a factor of 2 less than that of a conventional energy supply for power, cooling, heating, and ventilation based on utility power and natural gas fuel for heating.
PROJECT ACCOMPLISHMENTS, STATUS

This project has installed and has successfully operated all of the components of the IWESS. It has completed also the test and evaluation of all of the components, except the cooling/heating units with their advanced control system. Mathematical performance models have been programmed for each of the IWESS components based on their fundamental scientific and engineering principles. These models have been used in analyzing performance data obtained in testing of the components. Systems performance models that include the IW, the IWESS components, the building operation schedules, the outdoor ambient conditions, and the system operating algorithms have also been programmed and used in the design of system components, the test of operating algorithms, and the evaluation of the performance of the IWESS in reducing the energy demands for operating the IW throughout the course of a typical year in Pittsburgh.

The ABETI/IWESS project has been carried out over three years with $2.7 million in funds from the U. S. Department of Energy responding to a Congressional directive sponsored Congressman Mike Doyle of Pennsylvania. It has also received support from the Pennsylvania Department of Environmental Protection, the U. S. Department of Defense, and a number of industrial sponsors. Paul Giles has ably served as the DOE Project Officer.

The project has received significant technical contributions from the Milwaukee School of Engineering/Sierra Nevada College, the Texas A&M University, and the University of Maryland.

PROJECT FUTURE

The IWESS equipment has been installed, operated, and tested, but funding from the U. S. DOE has been interrupted. Further work on the ABETI/IWESS is required to achieve the full energy conservation, economic, and environmental benefits of this work on ABETI/IWESS. Three significant tasks still remain.

Control automation, operation integration and optimization.

Up to now PhD graduate students have been responsible for operating independently the solar thermal cooling/heating and the bioDiesel fueled power supply/heat recovery systems. The operation of these two systems must now be automated to provide for start up, load follow, and shut down of the systems. Systems diagnostics will be required to provide for emergency shut down and for maintenance advisories. The operation of these two systems must be integrated with the IWESS and with the campus power, chilled water, and steam grids to provide reliably and efficiently the power and cooling/heating energies needed by occupants and by the ventilation system of the IW.
In parallel, the operation of the ventilation system and the cooling/heating units needs to be examined and optimized. The development of advanced controls must be continued to consider a variety of features in their operation: the measurement and consideration of occupancy, CO₂ levels, humidity, and multiple temperatures; the adoption of set back temperatures; the coordination with operable windows, blinds, and solar reflectors; the use of weather predictions and night cooling.

It is expected that these efforts in control automation, integration, and optimization will result in a further reduction of energy consumption in the IW by a factor of 1.5.

Economics: reduction of equipment, installation and operating costs.

The significant reduction of energy consumption and the associated environmental emissions resulting from the adoption of an ESS for operating a building seems clear. But a critical questions remain concerning the cost of designing, procuring, installing, and operating such systems and the pay back for such costs based on reduced energy requirements. An effort that must be made to calculate such costs and to consider carefully and in detail how they might be reduced in both new and retrofit ESS installations. Such considerations need to include not only the ESS itself but also the building in which it is installed in order how costs might be minimized.

Dissemination, commercialization, deployment

In order to realize the full benefits of this ABET/IWESS project in significantly reducing the energy consumed in U. S. buildings and in providing enhanced economic activity, the knowledge gained and the lesson learned must be disseminated. The technical advances achieved must be commercialized. And the technology represented in IWESS – distributed power generation and combined cooling, heating, and power, CHP, production for buildings – must be deployed.

To date, dissemination has been fostered through presentations, publications, and the IWESS website. Seven graduate students have been or are being trained. This effort will be continued. But further work must be explored and planned for dissemination through education – students, professionals, and the public.

Eight commercial firms have donated substantial equipment items and/or services to the IWESS project. Six additional firms have been involved in a substantial way. These firms have continued to work closely with the program so that there are existing channels for commercializing the advances made in the work. Further work in commercialization must be considered and planned.

Deployment, first addressed through proposed building projects at Carnegie Mellon and at Texas A&M University needs to be pursued and facilitated through a number of efforts: the preparation of design guides, procedures, and tools for ESS components and
systems; contacts in architects, builders, and developers; efforts with legislators, regulators, and code writers regarding provisions for increased effectiveness and efficiency of buildings.

ABET/IWESS TECHNOLOGY HALVES THE ENERGY REQUIRED FOR BUILDING OPERATION

A primary objective of the Advanced Building Efficiency Testbed/Intelligent Workplace Energy Supply System, ABET/IWESS, Project is to develop and demonstrate measures that

- reduce by half the energy required to provide power, cooling, heating, ventilation, and domestic hot water to a commercial building
- provide an environment in a building that promotes the health, productivity, and comfort of its occupants.

The specific measures for energy consumption reduction being employed in the IWESS are

- separation of ventilation air supply and space cooling/heating; control of ventilation air temperature and humidity for health, comfort, and effective operation of cooling/heating units, avoiding condensation.
- enthalpy recovery: heat and moisture exchange between ventilation air supply and air exhaust. Enthalpy recovery reduces by 70-80% the energy required to cool/heat and dehumidify/humidify the ventilation air.
- hydronic space and ventilation air cooling/heating, replacing air based cooling/heating distribution: chilled/heated water supply to radiant and/or convective units distributed in the building space. Hydronic cooling/heating eliminates the fan energy required to circulate air in an air based distribution system and reduces the air duct size in the building by a factor of 5 to 10.
- distributed power supply from a renewable liquid or natural gas fueled engine generator with heat recovery from the exhaust gas and engine coolant
  - in summer for chilled water production in a two stage absorption chiller and desiccant regeneration in a ventilation air dehumidifier.
  - in winter for heated water production for space heating.
  - year around for domestic hot water supply.

The reduction in the energy required for operating a building from these measures obviously depends upon the specifics of the building, its location, and its operation. But some indication of the possible savings can be obtained by considering the following
Table 1 presents statistical data from the U. S. EIA 1995 on the current average delivered energy intensity, kWh/m²yr, of commercial buildings in the U. S. for space and ventilation air heating and cooling, electrical energy for lighting, equipment, pumps, and fans; and water heating. These building energy requirements are summed in the left section of the table in terms of total thermal and electrical delivered site energy intensities after each of the IWESS energy savings measures is successively adopted. The total reduction of delivered site energy is 60.1%, a factor of 2.5. If it is assumed that utility power is delivered to the building at an overall efficiency of 30%; that the efficiency of an engine generator located at the site is 35%; and that heat is delivered as natural gas, used at an efficiency of 80%, then the reduction of primary energy is 50.7%, a factor of 2.0.

The table thus shows that IWESS technologies result in a 50% reduction in the total primary energy required for building operation; and a 60.1% reduction is delivered site energy, if solar thermal energy is available to supply the heat not available from power generation. It also shows that because of the balance between the building power and heat requirements that a slightly less efficient power generation system could be employed in the building energy supply system without compromising the overall efficiency of the system.

Again it can be emphasized that these considerations are based on an averaged situation. Specific buildings in specific locations

- having various power generation components with their heat recovery systems
- coupled with different thermal based cooling systems and heating systems
- supplying chilled/heated water to various radiant/convective cooling/heating units and a ventilation air cooling/heating/circulation unit with humidity control
- incorporating also a solar photovoltaic or thermal energy recovery unit

can operate with source energy reductions greater or smaller than 50%. The important factors are the integrated design and operation of building and its energy supply system.

Automation, integrated operation, and advanced control of the various components of the IWESS are the factors that will be investigated in the next phase of ABET/IWESS project as funding is provided. It is projected the energy intensities can be further reduced, by a factor of 1.5 or more.
### Table 1. Effect of ABETI/IWESS Technologies on Reducing the Energy Required to Operate a Commercial Building

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Energy Intensity</th>
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<tbody>
<tr>
<td>1) Average consumption for a standard VAV commercial installation using natural gas and electricity. Other includes elevators and pumps.</td>
<td>Total Energy</td>
</tr>
<tr>
<td>2) Load: Average boiler, burner efficiency is 80%, therefore the actual load for space heating, water heating and cooking is 20% lower than the consumption [2].</td>
<td>Low Temp. Thermal</td>
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<tr>
<td>4) Separation: Space heating, burner efficiency is 80%, therefore the actual load for space heating, water heating and cooking is 20% lower than the consumption [2].</td>
<td>Electrical</td>
</tr>
<tr>
<td>5) Hydronic: Applying a hydronic heating and cooling distribution system rather than a ducted system reduces ventilation fan power by 85% as stated in step 3. Further, the energy consumed by the fans is for heating and cooling is reduced by 95% and added to other [5,6]</td>
<td>Notes</td>
</tr>
<tr>
<td>6) Enthalpy: Use of an enthalpy recovery wheel on the ventilation air reduces the heating and cooling loads by 70% [7]</td>
<td>Assumptions</td>
</tr>
<tr>
<td>7) Absorption: Absorption Chillers are used to cover the cooling load, which changes the electrical input for the chillers to a thermal input using a COP of 1.1 [8]</td>
<td>Assumption 1</td>
</tr>
<tr>
<td>8) DG+CHP: A combined heat and power system is applied to cover the electrical load of 127.4 kWh/m2-year, which will yield 88.4 kWh/m2-year in high temperature heat and 101.1 kWh/m2-year in low temperature heat [9]. Fuel is added in site total, with an efficiency of 80%.</td>
<td>Assumption 2</td>
</tr>
<tr>
<td>9) Solar: Assuming 1 kW/m2 and an efficiency of 0.4 at 6 hours of sunshine per day yields 216 kW of thermal energy. Therefore the balance of the thermal load can be covered by a solar thermal system operating in parallel with the CHP system. [8]</td>
<td>Assumption 3</td>
</tr>
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</table>

### References:


Figure 1: Carnegie Mellon’s Intelligent Workplace with Solar Receivers on the Roof

Figure 2: Installed Components of the Energy Supply System of the Intelligent Workplace, the IWESS
Figure 3. BioDiesel fueled engine generator

Figure 4. Heat recovery steam generator

Figure 5. Parabolic trough solar thermal receiver

Figure 6. Two stage absorption chiller
This Final Report for ABETI/IWESS project is comprised of the following:

- the brief project summary presented above concluding with the section that presents how the technologies incorporated in the IWESS reduce the energy consumption of a commercial building, both site and source, by a factor of 2 or more.

- a .ppt presentation following describing the current status of the project.

- this reference to the website of the project: <http://www.cmu.edu/iwess>

- a collection of eight Appendices: one for each of the four IWESS components; two for modeling studies, one for systems’ performance and the other for air flow and temperature in the IW; and one for each of two collaborators, Texas A&M University and the University of Maryland. The work of Sierra Nevada College/Milwaukee School of Engineering is incorporated in the Appendix 2, dealing with the bioDiesel engine generator and its heat recovery exchangers. These Appendices include theses, publications, reports, and computer program files of component and systems models.