

Building As Power Plant – BAPP/Invention Works Project at Carnegie Mellon University, Pittsburgh PA, USA Dr. Volker Hartkopf¹, Dr. David Archer², Professor Vivian Loftness³

A NATIONAL NEED

About 40% of the energy in the United States of America is being consumed to heat, light, ventilate and cool buildings (EIA 2003). Adding to this figure, the energy required to fabricate, transport and assemble the materials, components and systems of buildings, conservatively estimated, results in an additional 10% of the annual US national energy budget.

Substandard building performance, such as buildings that sicken their inhabitants (sick building syndrome), can lead to a reduction of as much as 20% of the productivity of the workforce (Loftness 2002). The Environmental Protection Agency has estimated the cost to the US economy to amount to about \$60 billion annually. During 1993 \$508 Billion for new construction and \$339 Billion for the renovation of existing facilities was spent in the US. This total of \$847 Billion amounted to 12.5% of the US GNP. Considered long-term, 5/8 of the nation's reproducible wealth is invested in constructed facilities. Collectively the US construction industry only expends 0.5% of sales on R&D. The industrial average for the US is 3.5% (Construction Industry Whitepaper, 1994). In summary, commercial buildings in the US require significant resources to be constructed, operated and adapted and are judged by the occupants to fail principal tests. Research and development expenditures are inadequate.

BAPP - BUILDING AS POWER PLANT

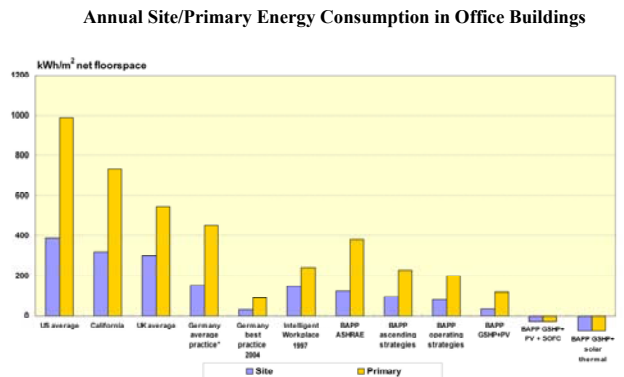
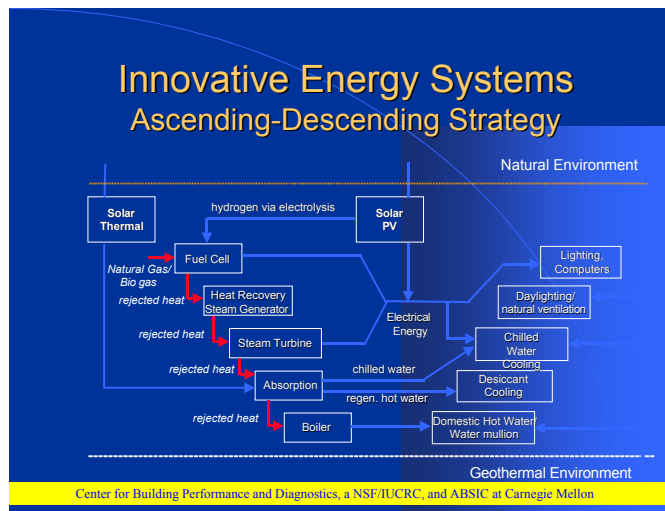
Building on the concepts of and experiences with the Intelligent Workplace™, a living (always adapted and updated) and lived-in laboratory at Carnegie Mellon University (Hartkopf and Loftness 1999, Napoli 1998), a research, development and demonstration effort is directed at the “Building as Power Plant – BAPP”. This project seeks to integrate advanced energy-effective enclosure, Heating, Ventilation, and Air-Conditioning (HVAC) and lighting technologies with innovative distributed energy generation systems, such that all of the building's energy needs for heating, cooling, ventilating lighting and equipment are met on-site, maximizing the use of renewable energies. Figure 3 schematically illustrates this idea.

BAPP is designed as a 6-story extension of the existing Margaret Morrison Carnegie Hall Building with total area of about 6000 m², which houses classrooms, studios, laboratories and administrative offices for the College of Fine Arts. The building will be equipped with a decentralized energy generation system in the form of a combined heat and power plant. This will include a 250 kW Siemens Westinghouse Solid Oxide Fuel Cell (SOFC), heat recovery steam generator, steam turbine and absorption chiller/boiler technologies. In addition, advanced photovoltaic, solar thermal, and geo-thermal systems are being considered for integration.

A conceptual scheme for an “ascending-descending energy scheme” that integrates energy generation and building HVAC and lighting technologies is shown below. In an ‘ascending strategy’, fenestration, shading, and building mass will be configured to minimize the lighting, cooling and heating loads and maximize the number of months for which no cooling or heating will be needed. Then, passive strategies such as cross ventilation; stack ventilation,

fan-assisted ventilation and night ventilation will be employed. Passive cooling will be followed by desiccant cooling when humidity levels exceed the effective comfort zone. Ground-Source Heat-Exchange will be used to activate the building mass for cooling and heating. As outdoor temperatures or indoor heat loads exceed the capability of these systems, then absorption and finally refrigerant cooling will be introduced, first at a task comfort level. Only the last stage of this ascending conditioning system will be a task-ambient central-system refrigerant cooling system.

Complementing these ‘ascending’ energy strategies is a ‘cascading’ energy strategy designed to make maximum use of limited natural resources. In a cascading system, a fuel cell and photovoltaic panels might be bundled for the building’s power generation; reject heat from the fuel cell can be converted into steam which can be used to first drive desiccant, absorption and refrigerant systems; and finally the resulting reject heat can be used for space heating and hot water.



Data source: EIA, Commercial Building Energy Consumption Survey 1995; PG&E, Commercial Building Survey Report 1999; UK National Statistics
 * Germany average practice is calculated based on the energy consumption measurements of 15 German office buildings built between 1990 and 2002 (with primary energy consumption ranging from 180kWh/m² to 1,000kWh/m²).

SHP Means Ground Source Heat Pump, PV means Photovoltaic, SOFC means Solid-Oxide Fuel Cell
Energy Consumptions Compared to BAPP

CONCLUSION:

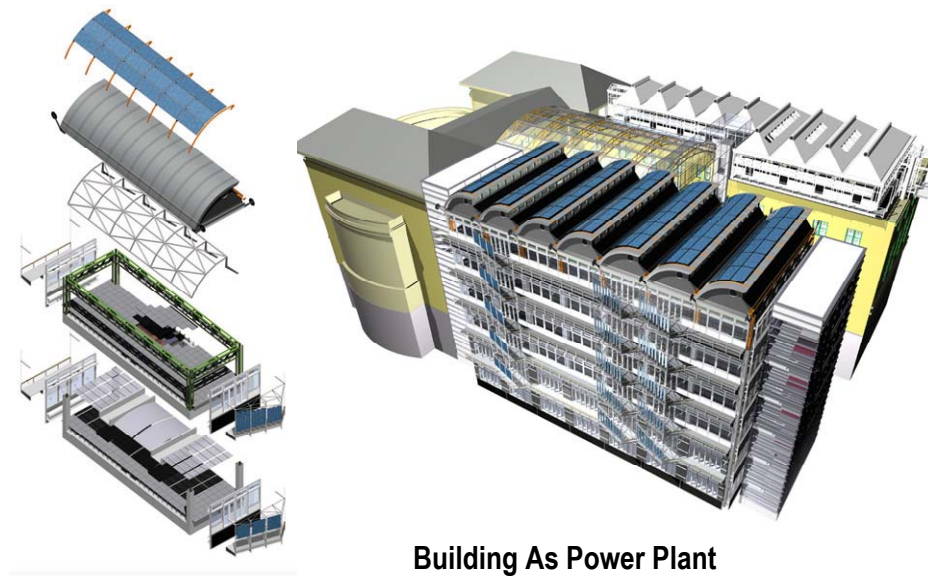
The Building as Power Plant addresses significant national needs in terms of energy effectiveness, energy quality, reliability and security, as well as environmental performance. Consequently, the U.S. Congress has designated the BAPP as National Test-bed for advanced technology. This enables the team at Carnegie Mellon University to work with key researchers at Texas A&M University, University of Maryland, Sierra Nevada College NV, and the West Virginia Institute for Scientific Research.

Preparation for the BAPP and its ESS:

For the fiscal years 2005-2006 the National Test-bed Congressional Support is focused on the design, engineering, installation, commissioning, operation and evaluation of the Intelligent Workplace Energy Supply System (IWESS). This includes on the supply-side the integration of solar/thermal, two-stage absorption chiller, desiccant dehumidification ventilation, and

ultimately either high temperature fuel-cell, or engine generator technologies. These efforts will clearly identify which scientific and technical advances in materials and processes dealing with distributed electric energy generation, solar conversion, energy from non-renewable resources conversion, as well as storage and transfer are required, particularly fuel-to-power, heat-to-power, waste-to-fuel/power challenges will be addressed. These are key challenges before energy consumption can be further reduced and the release of pollutants, including CO₂ emissions can be averted. Of equal importance is a full understanding of the economic impact these new technologies will have. This effort must include, beyond investment and energy operating costs, the impacts on public health, the health of individuals, organizational effectiveness and productivity.

Therefore we propose a 3-stage effort: First the building and its integrated technologies will be realized, commissioned, monitored and evaluated; Second key scientific and technical challenges mentioned above will be identified, to be addressed by the scientific and technical experts of the proposed ERC team; Third the results of the investigations and scientific/technical breakthroughs will be shared with the industrial community in order to advance the technology and manufacturing processes, design, engineering and systems integration practices.



**Building As Power Plant
BAPP**

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