OAK RIDGE NATIONAL LABORATORY
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FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2012/143

Light Commercial Building Flexible Research Platforms

April 2012

Prepared by

Patrick Hughes
Energy and Transportation Science Division

Sponsored by

Building Technologies Program
U.S. Department of Energy

UT-BATTELLE
ORNL-27 (4-00)

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ORNL/TM-2012/143

Energy and Transportation Science Division

LIGHT COMMERCIAL BUILDING FLEXIBLE RESEARCH PLATFORMS

Patrick Hughes

Date Published: April 2012

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACKNOWLEDGMENTS

This report and the work described were sponsored by the Building Technologies Program of the US Department of Energy's Office of Energy Efficiency and Renewable Energy. Oak Ridge National Laboratory (ORNL) was competitively awarded the MAXLAB project under the buildings topic of the American Recovery and Reinvestment Act (ARRA) Lab Call #09-002. The MAXLAB project funded the design and construction of the permanent portions of the light commercial building flexible research platforms (FRPs). As of this writing, the design and erection of the first baseline test buildings on the FRPs is under way. The author wishes to acknowledge the contributions of ORNL's entire FRP team:

- Project Manager—Heather Buckberry
- Data Acquisition and Process Control Systems—Chris Halford
- Envelope Principal Investigators—Andre Desjarlais (lead), Diana Hun, Therese Stovall
- Equipment Principal Investigators—Ed Vineyard (lead), Chris Halford
- Commissioning, Fault Detection and Diagnostics, Controls Principal Investigators—Teja Kuruganti (lead), David Fugate, Charles Castello
- Building Information Modeling (BIM), Building Energy Modeling (BEM), and Visual Analytics (VA) Principal Investigators—Joshua New (lead), Mahabir Bhandari, Piljae Im

ABBREVIATIONS, ACRONYMS, AND INITIALISMS

ADN	Autodesk Developer Network
AOP	annual operating plan
ARMA	Asphalt Roofing Manufacturers Association
ARRA	American Recovery and Reinvestment Act
BACnet	Building Automation and Control Networks
BEE	Building Energy Efficiency
BEM	building energy modeling
BIM	Building Information Modeling
BMS	Bayer Material Science
BTP	Building Technologies Program
BTRIC	Building Technologies Research and Integration Center
CBEA	Commercial Building Energy Alliance
CBECS	Commercial Buildings Energy Consumption Survey
CD	critical decision
CDR	conceptual design report
COTS	commercially available, off-the-shelf
CRADA	Cooperative Research and Development Agreement
DAS	data acquisition system
DoD	Department of Defense
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EIFS	exterior insulation and finish system
EMCS	energy management and control system
EPS	expanded polystyrene
ESC	Energy Services Coalition
ESCO	energy service company
ESPC	energy savings performance contract
FDD	fault detection and diagnostics
FEMP	Federal Energy Management Program
FRP	flexible research platform
GE	General Electric
GPIC/HUB	Greater Philadelphia Innovation Cluster for Energy Efficient Buildings
HVAC	heating, ventilation and air-conditioning
IDIQ	indefinite-delivery, indefinite quantity
JCI	Johnson Controls, Inc.
LEED®	Leadership in Energy and Environmental Design
MAXLAB	Maximum Building Energy Efficiency Research Laboratory
MBMA	Metal Building Manufacturers Association
MOA	memorandum of agreement
ORNL	Oak Ridge National Laboratory
R&D	research and development
REA	Retailer Energy Alliance

RTU	rooftop unit
SMDS	smart monitoring diagnostic system
SPRI	Single Ply Roofing Institute
UC	University of California
SON	statement of needs
VAV	variable air volume
VRF	variable refrigerant flow
WFO	Work for Others
WLHP	water loop heat pump

EXECUTIVE SUMMARY

Oak Ridge National Laboratory (ORNL) was competitively awarded the MAXLAB (Maximum Building Energy Efficiency Research Laboratory) project under the buildings topic of the American Recovery and Reinvestment Act (ARRA) Lab Call #09-002. Among other things, the MAXLAB project funded the permanent portions of two research apparatus known as the light commercial building flexible research platforms (FRPs).

On March 22–24, 2010, ORNL hosted the workshop "Shaping the Future of the BTRIC User Facilities." The workshop was held to gather input from industry and university "users" on desired new Building Technologies Research and Integration Center (BTRIC) user facility research capabilities. More than 100 people from all over the country participated. The input received influenced the capabilities provided for the FRP research apparatus, which are summarized as follows:

- Perimeter and interior space-conditioning zones
- Active foundations (adiabatic when "on")
- Use of process control to simulate occupant effects on energy use
- Individual active load components separately metered
- Downloading of modified controls software into the active load components
- Testing and validation of advanced controllers, control algorithms, and fault detection and diagnostic algorithms for active load components
- Use of process control to force common active load component faults in order to stress-test features claimed by emerging system/building-level technologies (e.g., fault detection and diagnostics, retro/continuous commissioning, model-based controls)
- High-capacity data link for process control, data acquisition, and secure web-accessible data analytics and visualization for remote users

On August 4, 2011, ORNL and the University of California–Davis co-hosted the "Light Commercial Building Technology Roadmap Workshop" at University of California–Davis. The purpose of the workshop was to identify challenges or problems facing building energy efficiency product suppliers, or owners and operators of light commercial buildings, which could potentially be addressed by applied research and development and deployment actions that overcome the challenges (problems). More than 90 people from all over the country participated, and workshop results were documented in the form of a roadmap.

As the name "flexible research platforms" implies, just about any feature of a temporary "test building" applied to the FRPs can be changed for research purposes. Input received during the 2010 and 2011 workshops was used to select, from among the infinite possibilities, a few specific research directions for the first test building cycles on the two FRPs.

As the two workshops unfolded, a group of industry leaders stepped forward and began to suggest energy efficiency solutions they were interested in accelerating to market through collaborative research with ORNL using the FRPs. ORNL organized these industry leaders into one-story FRP and two-story FRP groups and worked with them to define the first baseline test buildings.

In general, the FRP research process involves the following chronological steps:

1. A group of industry partners is found in which (1) at least one industry partner exists for each major building system (walls; roof; and heating, ventilation, and air-conditioning, at a minimum); (2) the industry partners desire to improve the energy efficiency of their offerings and are willing to invest in cost-shared collaborative research to accelerate the availability of improved offerings; and (3) industry partner agendas are compatible enough with one another that an integrated test building adequately satisfying all partner needs can be conceptualized.

2. ORNL develops an integrated whole-building design for the test building to be erected on the FRP.

3. Each industry partner erects its building system on the FRP in accordance with the integrated design. Any test building gaps (i.e., required features having no donors) must be provided by ORNL.

4. ORNL characterizes baseline test building performance under natural weather exposure over a period of time.

5. ORNL and industry partners collaborate on the development of tune-up and/or retrofit solutions (multiple alternatives may be evaluated on other research apparatus for down-selection).

6. Industry partners implement their tune-up and/or retrofit solutions onto the test building.

7. ORNL characterizes modified test building performance under natural weather exposure over a period of time.

8. Items 5 through 7 may be repeated several times during a test building research cycle.

9. ORNL removes the test building and repeats the process for the next test building research cycle.

ORNL expects that industry partners will provide (1) effort to help develop test building research plans, (2) effort to develop specifications for industry-provided building systems, (3) effort to review ORNL's integrated test building design, (4) outlays for donated materials and equipment and related shipping, (5) travel and labor outlays for industry-provided construction superintendents and crews to erect building systems on the FRPs, (6) outlays and training to local contractors in cases where "active" building systems may require after-installation service, (7) self-funded participation in collaborative research with ORNL to develop better tune-up and/or retrofit solutions, (8) effort to revisit test building research plans annually and, most important, (9) aggressive investments to commercialize energy efficiency solutions emerging from the program.

The report documents the business model for using the FRP research apparatus and explains how sponsors and industry partners engage with ORNL to conduct test building research cycles on the FRPs. The Department of Energy's Building Technologies Program (BTP) would select FRP-related projects for funding following its standard processes and decision making, leading to a directed-research annual operating plan (e.g., statement of needs, statements of work, review, selection). Industry partners have access to a form of user's agreement whereby they are allowed to come on site at ORNL and erect their building systems on an FRP. The installation will be done in accordance with the integrated whole-

building design for the test building for that FRP. For FRP-related projects in which true collaboration is to occur between ORNL and an individual industry partner, the agreement form is likely to be a Cooperative Research and Development Agreement under which BTP covers ORNL's effort and the industry partner is self-funded.

The first test building research cycle on the FRPs is a special challenge for BTP, ORNL, and ORNL's industry partners. BTP's expectation was that the ARRA-funded MAXLAB project would provide the funding for the first baseline test buildings on the FRPs. However, in reality, ORNL needed to maintain a "bright line" separating "construction" of the permanent portions of the FRPs, and "research" using the FRPs (e.g., implementing baseline test buildings on the FRPs in collaboration with industry partners, taking measurements to characterize their performance). As a result of the "bright line" separation, ORNL has been granted a Davis-Bacon waiver on the research work so it can be conducted more cost-effectively than would otherwise be the case.

BTP directed ORNL to overcome the special challenge without BTP funding until after the first baseline test buildings are erected on the FRPs. ORNL is currently in the process of implementing this directive using leftover MAXLAB construction contingency and cost sharing from industry partners.

1. BACKGROUND

1.1 ARRA COMPETITIVE SOLICITATION AND PATH FORWARD

Oak Ridge National Laboratory (ORNL) was competitively awarded the MAXLAB project under the buildings topic of the American Recovery and Reinvestment Act (ARRA) Lab Call #09-002. The solicitation objective was to strengthen the research and development (R&D) capabilities of the national laboratories. The August 10, 2009, proposal requested $25M and ORNL received notification of a $20.2M award on November 18, 2009. Funding arrived at ORNL on March 19, 2010. The project was de-scoped from $25M to $20.2M under the direction of the Department of Energy (DOE) Building Technologies Program (BTP).

Lab Call #09-002 required that the construction portion of the MAXLAB project be implemented in accordance with DOE Order 413.3A and its critical decision (CD) approval process. Further, BTP directed that the MAXLAB project schedule be accelerated from what was originally proposed so the ARRA spending plan could be more aggressive. In response, on April 12, 2010, ORNL provided a revised accelerated plan whereby (1) the conceptual design report (CDR) is completed and the procurement for a design/build firm issued by the end of May 2010, (2) the design/build firm is selected by the end of June 2010, and (3) prompt DOE signoff of design/build firm selection (CD-1) occurs so actual detailed design begins in early July 2010. The accelerated plan was contingent on (1) BTP's following best practices for small projects and delegating Acquisition Executive authority to the DOE site office physically located at ORNL so reviews and approvals could be timely and in-person oversight practical; (2) BTP's following DOE Order 413.3A, which does not require External Independent Review for projects under $100M; and (3) BTP's following DOE Order 413.3A, which does not delay research equipment upgrade expenditures in existing buildings until CD-1 signoff on a new building construction project.

BTP concurred with these conditions; the project has been accelerated; and the official DOE CD approval history is as follows: CD-0 Mission Need approved December 2009; CD-1 Alternative and Cost Range approved July 16, 2010; CD-2 Performance Baseline approved January 31, 2011; CD-3A Early Construction approved May 31, 2011; and CD-3B Construction approved September 2011. The current forecast for CD-4 Construction Completion is December 2012, which is 6 months ahead of the original schedule.

The $20.2M MAXLAB project budget provides $16M for construction of the new MAXLAB building and the permanent portions of two research apparatus known as the light commercial building flexible research platforms (FRPs). The remaining $4.2M was used to upgrade existing research apparatus in existing Building Technologies Research and Integration Center (BTRIC) labs and to acquire the proposed and awarded new research apparatus. The new MAXLAB building is located on the ORNL main campus at the corner of Bethel Valley Road and 5th Street, just east of BTRIC, whose staff will use the new facilities. MAXLAB houses a high-bay lab with an overhead crane for envelope systems research; a low-bay lab for heating, ventilation, and air-conditioning (HVAC) systems research; a data center, and offices. The project is targeting LEED® Gold certification through the United States Green Building Council. New research apparatus include a large clamshell for wall moisture penetration and air leakage research to be located in the high-bay area of MAXLAB, and the environmental chambers for multi-zone HVAC system development and performance characterization to be located in the low-bay area. A full list of new and upgraded research apparatus can be provided upon request.

1.2 USERS WORKSHOP FOR INPUT ON CAPABILITIES

On March 22–24, 2010, ORNL hosted the workshop "Shaping the Future of the BTRIC User Facilities" to gather input from industry and university "users" on desired new BTRIC user facility research capabilities. More than 100 people from all over the country participated (see Appendix A for participant list). The event, facilitated by Energetics Inc., had seven breakout sessions:

- Building Envelope (Including Renewable Energy Supply Integration)
- Active Building Loads Integration, Intelligence, and Control
- Building Construction and Retrofit Processes
- Residential Whole-Building Integration (New/Retro)
- Commercial Whole-Building Integration (New/Retro)
- Building-to-Grid Integration, Intelligence and Control
- Advanced Building Computing and Simulation

The workshop was designed to receive input from users on the desired capabilities across all of the BTRIC user facilities. The raw notes from this workshop influenced decisions concerning upgrades to existing research apparatus and need for new research apparatus. The raw notes also influenced the MAXLAB final CDR and design criteria and the CD-1 Alternative and Cost Range that was approved in July 2010. The following items summarize the capabilities that users wanted the FRPs to provide:

- Perimeter and interior space-conditioning zones
- Active foundations (adiabatic when "on")
- Use of process control to simulate occupant effects on energy use
- Individual active load components separately metered
- Downloading of modified controls software into the active load components
- Testing and validation of advanced controllers, control algorithms, and fault detection and diagnostic (FDD) algorithms for active load components
- Use of process control to force common active load component faults to stress-test features claimed by emerging system/building-level technologies (e.g., FDD, retro/continuous commissioning, model-based controls)
- High-capacity data link for process control, data acquisition, and secure web-accessible data analytics and visualization for remote users

For further information on this workshop, see http://events.energetics.com/BTRIC2010/

1.3 LIGHT COMMERCIAL BUILDING TECHNOLOGY WORKSHOP FOR INPUT ON PROBLEMS AND SOLUTIONS NEEDED

On August 4, 2011, ORNL and the University of California–Davis co-hosted the "Light Commercial Building Technology Roadmap Workshop" at University of California–Davis. The purpose of the workshop was to identify challenges or problems facing building energy efficiency (BEE) product suppliers, or owners and operators of light commercial buildings, which could potentially be addressed by applied R&D and deployment actions that overcome the challenges (problems). More than 90 people

from all over the country participated (see Appendix B for participant list). The event was facilitated by Energetics.

The focus was on new solution options whereby deployment could begin within the next 5 years and energy savings would be deep and long-lasting. Participants were asked to help identify problems and matching actions. A preliminary draft of the "Light Commercial Building Technology Roadmap" was developed by the ORNL team in advance of the workshop, and the raw notes from the meeting were used to update the roadmap (see Appendix C for roadmap). In addition to providing structured input at the workshop, participants also had the opportunity to comment on the pre-workshop and post-workshop versions of the roadmap.

1.4 RELATIONSHIP OF FRPS TO ORNL'S CENTERS OF EXCELLENCE FOR BTP

The ORNL BTRIC's mission is to serve as a solution center to accelerate industry initiatives to maximize the cost-effective energy efficiency of residential and light commercial buildings. ORNL's vision is to provide science-to-solution industry collaboration to accelerate new envelope and equipment technology development and integration into system and whole-building energy efficiency solutions for new and existing buildings. ORNL's goals are to see our (1) envelope, (2) equipment, and (3) system/building integration industry partners successfully launch new energy efficiency products and scale them in the market, thereby strengthening US energy security, environmental quality, and economic vitality. The interrelationship of ORNL's three centers of excellence is depicted in Fig. 1.

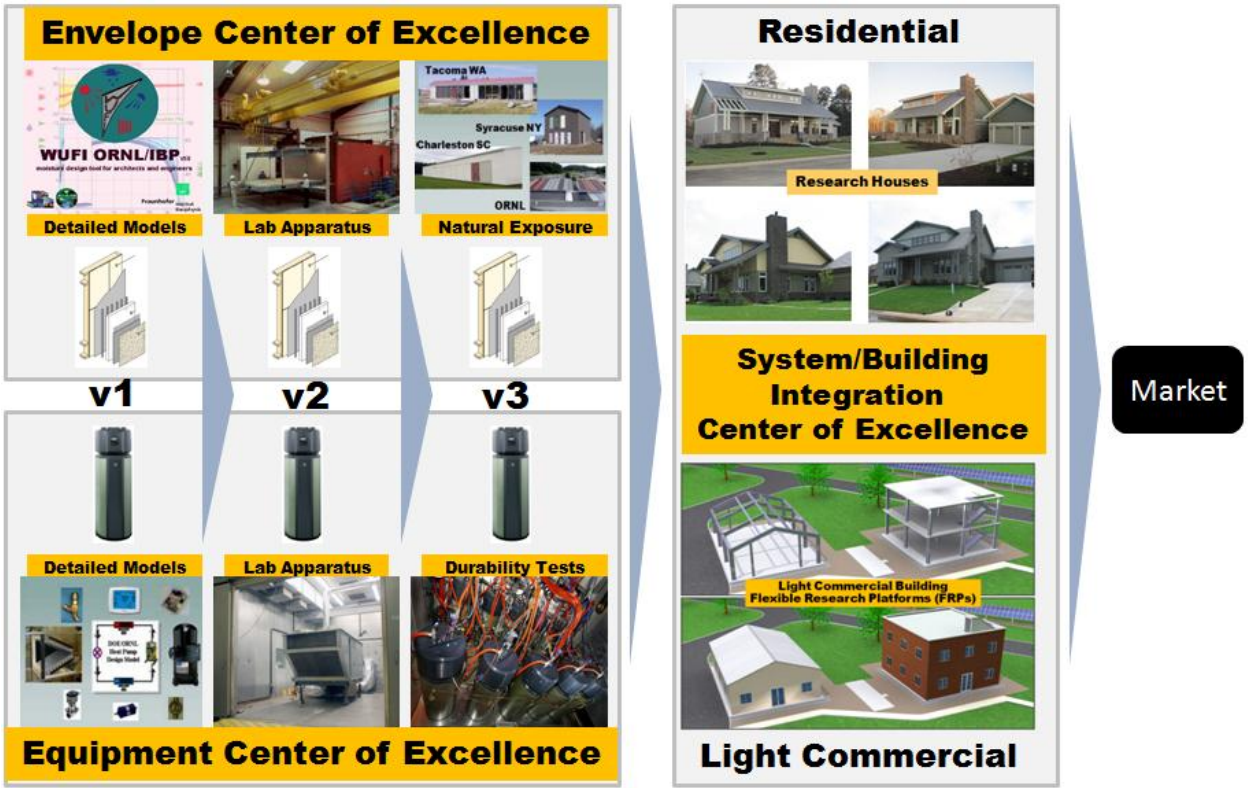

Fig. 1. ORNL's centers of excellence for BTP.

Over the years ORNL has learned that evaluating emerging pre-production prototypes of new energy efficiency products in realistic test beds is an essential step prior to market introduction. This risk-reducing step is highly valued by our industry partners. To gain access to realistic residential test beds,

ORNL uses an innovative public/private partnership approach, in which the private partners provide the land, building materials, and labor cost-share to build research houses, which then are leased for ORNL's exclusive use for research purposes over extended periods. Each house supports R&D on one envelope strategy and provides the opportunity for R&D on several generations of equipment, appliances, and controls before the house is released for sale. However, the successful residential approach is not feasible for light commercial buildings because the land, building materials, and labor investment is too great. In addition, there is tremendous functional diversity in the space utilization in light commercial buildings, which limits the R&D value that can be gained from holding any one building off the market for an extended research period. The FRPs fill this gap by providing realistic, risk-reducing, and flexible light commercial building test beds.

ORNL has over 30 years of corporate experience in the envelope, equipment, and system/building integration core areas. We know the difference between "new" and "making the same mistakes (inventions) all over again." For example, when General Electric came to ORNL looking for water heating technology, it left partnered with a team that had participated in every major US-based heat pump water heater development cycle since the 1970s. The elapsed time between signing the Cooperative Research and Development Agreement (CRADA) and GE's launch date for the new GeoSpring™ product was only 20 months. This is a great example of ORNL's fulfilling its mission to accelerate industry initiatives. Just as research houses played an important role in this success story, the FRPs will contribute to light commercial building technology success stories of the future.

ORNL is the only science-to-solution center available to help the building industry accelerate its processes for bringing new BEE products to market in the envelope, equipment, and system/building integration core areas. Our staff have enough experience in applied research to form effective CRADA teams with industry and enough experience in basic research to effectively provide access to very specialized ORNL expertise as needed to solve the specific problems of industry partners. ORNL's work also helps industry improve its manufacturing processes to increase labor productivity and offset higher domestic labor rates and thus retain domestic manufacturing jobs in clean energy technologies—presumably a goal of DOE's Energy Efficiency and Renewable Energy (EERE) office. ORNL is currently the only national laboratory with an up-and-running Advanced Manufacturing Demonstration Facility under the EERE Advanced Manufacturing Office.

2. RESEARCH APPARATUS

2.1 GENERAL

The FRP definition was finalized based on input received from (1) industry and university users of the research apparatus at the March 2010 workshop and (2) BEE component suppliers and owners and operators of light commercial buildings at the August 2011 workshop. In a nutshell, these communities told ORNL that BEE is invisible, and there is widespread skepticism among customers and lenders that estimated BEE savings actually materialize; this skepticism hampers access to low-cost financing and market scalability. A common theme of the discussions was concern regarding the lack of validation of models against measured data. These communities told ORNL that the process of implementing test buildings on the FRPs, and subsequently retrofitting test buildings, should hew as closely as possible to actual design and construction practices. If a fundamental problem is lack of physical validation of models, the problem cannot be solved with data from research apparatus implementing overly simplified and idealized physical systems.

2.2 PERMANENT FRPS

As noted in Section 1.1, the permanent portions of the two research apparatus known as the light commercial building FRPs were implemented as part of the ARRA-funded MAXLAB project in accordance with DOE Order 413.3A. Funding for erecting test buildings on the FRPs and retrofits of such test buildings for research purposes must come from research program funding (e.g., BTP, industry, or other). This bright line separating "construction" from "research" is important because DOE Order 413.3A requires construction projects to pay Davis-Bacon wages and use ORNL's unionized crafts for the work, whereas a Davis-Bacon waiver has been granted for research activities using the FRPs. This enables, for example, industry partners to come on site and erect their systems on the FRPs at their own expense. The waiver enables FRP research to be conducted much more cost-effectively than would otherwise be the case.

A one-story FRP having a footprint of 40×60 ft (2,400 gsf) and a two-story FRP having a footprint of 40×40 ft (3,200 gsf), have been constructed. The permanent FRPs consist of building frames and their slabs and the necessary utility and IT infrastructure to support a variety of test building configurations that might be applied to each FRP superstructure in the future. The FRPs are depicted in Fig. 2.

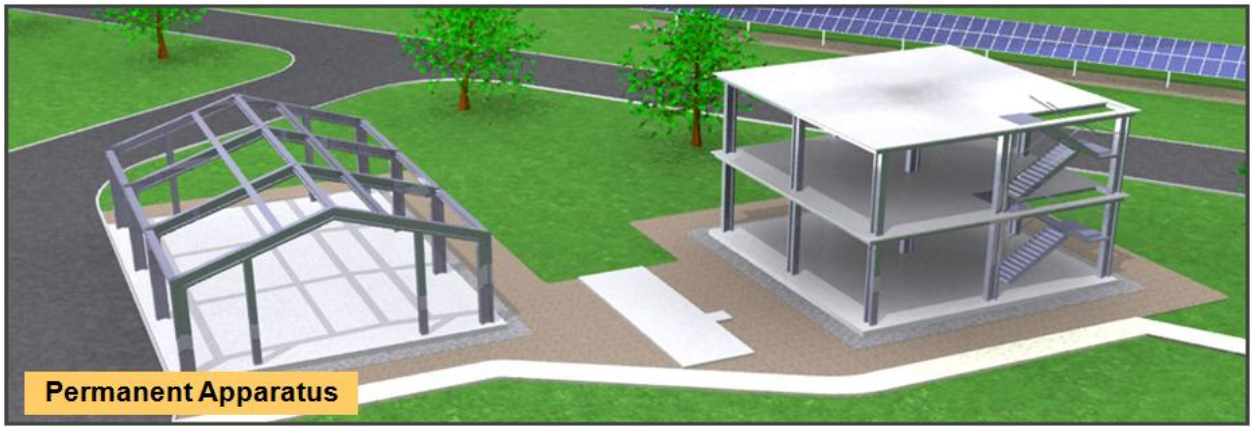

Fig. 2. Artist's conception of the permanent portions of the FRPs.

The one-story FRP is intended for research to improve the energy efficiency of metal buildings (Fig. 3). Based on floor area, metal buildings account for about 40% of the nation's light commercial building construction over a period of many decades. A conventional metal building design process was followed for the development of the frame. However, the standard performance specification for the metal building frame was modified to require that the frame be completely self-supporting without wall or roof panels installed. The floor area is clear-span with no intermediate structural members. One end wall was framed with column placements to allow the installation of a large overhead door.

Fig. 3. One-story FRP (with two-story FRP in the background).

The two-story FRP is intended for research to improve the energy efficiency of a wide variety of light commercial buildings that might have multiple stories (Fig. 4). The two-story steel superstructure was designed to accommodate many different wall systems, such as masonry, insulated precast concrete panels, or metal studs with sheathing and an exterior insulation and finish system (EIFS). The two-story platform also features access to the roof to facilitate working with various mechanical or low-slope roofing systems.

Fig. 4. Two-story FRP.

Both FRPs were designed as slab-on-grade construction. However they have "active foundations," meaning that when they are "on," the slabs are near-adiabatic to thermally isolate the test buildings on the

FRPs from the ground. To accomplish this, a deep foundation was constructed and a concrete sub-slab installed. Next, layers of expanded polystyrene (EPS) insulation were added to a thickness of 12 in. Then a second steel-reinforced top slab was installed on top of the insulation layer. The insulation layer also extends upward around the full perimeter of the top slab. The top slab design includes embedded loop piping secured to the rebar around the perimeter. When "on," a pump circulates heat transfer fluid between the piping embedded in the top slab and enclosed research equipment (a small chiller and heater) on the service pad between the two FRPs. Sensing of interior and perimeter top slab temperature is the basis for control. The pump and heat transfer equipment are operated to keep the interior and perimeter top slab temperatures the same. Under these conditions, since the interior is near-adiabatic, so is the entire slab. Key aspects of the active foundation are shown in Fig. 5.

Fig. 5. Expanded polystyrene visible below and around the perimeter before the top slab was poured (left). Top slab being poured (right).

2.3 THE FRP RESEARCH PROCESS

In general, the FRP research process follows these chronological steps:

1. A group of industry partners is found in which (1) at least one industry partner exists for each major building system (walls, roof, and HVAC at a minimum), (2) the industry partners desire to improve the energy efficiency of their offerings and are willing to invest in cost-shared collaborative research to accelerate the availability of the improved offerings, and (3) industry partner agendas are compatible enough with one another that an integrated test building adequately satisfying all partner needs can be conceptualized.

2. ORNL develops an integrated whole-building design for the test building to be erected on the FRP.

3. Each industry partner erects its building system on the FRP in accordance with the integrated design. Any test building gaps (i.e., required features having no donors) must be provided by ORNL.

4. ORNL characterizes baseline test building performance under natural weather exposure over a period of time.

5. ORNL and industry partners collaborate on development of tune-up and/or retrofit solutions (multiple alternatives may be evaluated on other research apparatus for down-selection).

6. Industry partners implement their tune-up and/or retrofit solutions onto the test building.

7. ORNL characterizes modified test building performance under natural weather exposure over a period of time.

8. Items 5 through 7 may be repeated several times during a test building research cycle.

9. ORNL removes the test building and repeats the process for the next test building research cycle.

ORNL expects that industry partners will provide (1) effort to help develop test building research plans, (2) effort to develop specifications for industry-provided building systems, (3) effort to review ORNL's integrated test building design, (4) outlays for donated materials and equipment and related shipping, (5) travel and labor outlays for industry-provided construction superintendents and crews to erect building systems on the FRPs, (6) outlays and training to local contractors in cases where "active" building systems may require after-installation service, (7) self-funded participation in collaborative research with ORNL to develop better tune-up and/or retrofit solutions, (8) effort to revisit test building research plans annually and, most important, (9) aggressive investments to commercialize energy efficiency solutions emerging from the program.

In the 9-step FRP research process described, note that ORNL has two key roles in addition to collaborating with industry partners to improve energy efficiency solutions as described in Section 2.4. These two key roles—integrated whole test-building design (step 2) and measured performance characterization (steps 4 and 7)—are described below.

The integrated whole test-building design process begins by consolidating industry partner specifications and other input into building program documents for each test building. The program documents are used to guide the team of ORNL registered architects and engineers in the development of construction documents for each test building. The test buildings are designed in three dimensions using both Autodesk's Revit program and Bentley Systems' Building Information Modeling (BIM). Students from the University of Tennessee, under the supervision of ORNL registered professionals, prepare the various BIM files. The BIM development for the test buildings proceeds in the same manner as any typical private-sector BIM project. The starting point for the baseline test building BIM design is the as-built record drawings for the permanent portions of the FRPs (the slabs and superstructures). The final BIM files include structural, architectural, electrical, and mechanical designs for the baseline test buildings. After baseline test buildings are erected on the FRPs, the as-built conditions are documented by refining the BIM files. Later, the starting point for BIM designs of retrofits is the as-built BIM files for the baseline test building being retrofitted. Figures 6 and 7 provide BIM representations for the first baseline test buildings on the FRPs.

Fig. 6. BIM representation of the first baseline test building on the one-story FRP.

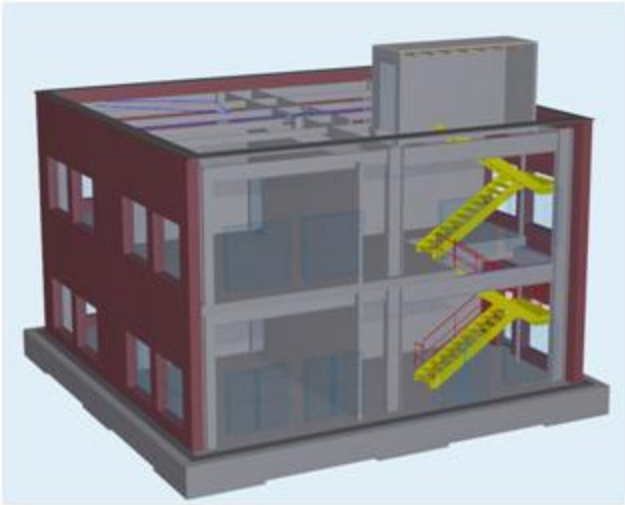

Fig. 7. BIM representation of the first baseline test building on the two-story FRP.

The approach to measured performance characterization had to be very flexible because nearly any feature of a temporary baseline test building can be changed for research purposes, and retrofit and tune-up possibilities are nearly infinite. Further, the desired measurements depend upon the specific baseline test building and retrofit and/or tune-up technologies. In addition, there are cost savings associated with having the same system acquire data and execute process control over the research apparatus. Finally, for true collaboration to occur, the industry partners need secure, web-accessible remote data analytics and visualization. For these reasons, a central data acquisition system (DAS) was selected that has all of the required data acquisition flexibility and process control capabilities and is compatible with the best available wrappers for providing data analytics and visualization to remote industry partners.

During experiments, the test buildings on the FRPs function as unoccupied research apparatus, but process control is used to simulate typical (e.g., national average) occupant effects on energy use for the type of building being simulated (e.g., office). The practical approach to occupancy simulation that ORNL has perfected over the past 4 years in its fleet of research houses will be employed in the FRPs. For example, the HVAC system may be allowed to operate based on its native controls, but lighting, sensible internal heat loads, and latent internal heat loads will be scheduled via process control so total HVAC loads are realistic combinations derived from natural weather and the simulated/controlled loads. The DAS also provides the process control for (1) the active foundations (see Section 2.2), (2) fault-forcing to test FDD or continuous commissioning schemes, and (3) rotation among the multiple HVAC systems (as explained in Section 2.4, each test building has multiple HVAC systems).

As noted in step 3 of the FRP research process, any test building gaps (i.e., required features having no donors) must be provided by ORNL. Examples include fire safety features required at ORNL, utility distribution systems (electrical power, natural gas, supply water) within test buildings, HVAC thermal distribution systems, and lighting systems. Although the costs to close these gaps are relatively modest, they cannot be forgotten.

2.4 AN EXAMPLE OF THE TECHNICAL SCOPES ADDRESSABLE WITH THE APPARATUS

As the name “flexible research platforms” implies, just about any feature of a temporary “test building” can be changed for research purposes. Input received during the 2010 and 2011 workshops has been used

to select, from among the infinite possibilities, a few specific research directions for the first test building cycles on the two FRPs.

As the two workshops unfolded, a group of industry leaders stepped forward and began to suggest energy efficiency solutions they were interested in accelerating to market through collaborative research with ORNL using the FRPs. ORNL organized these industry leaders into one-story FRP and two-story FRP groups and began working with them to establish the first baseline test buildings on the FRPs, which are depicted in Fig. 8.

Fig. 8. Artist's conception of the first baseline test buildings on the FRPs.

The industry partnering for the first test building cycles on the FRPs divides into four areas, and the status in each area is summarized below. These descriptions provide a tangible example of the technical scopes addressable with the apparatus. In general, industry interest in collaborative research using the FRPs has been very strong (see the industry support letters provided in Appendix D).

2.4.1 Envelope research

One-Story FRP: The Metal Building Manufacturers Association (MBMA) has agreed to be the primary industry partner for the first cycle of research on the one-story FRP. The Energy Committee of MBMA has determined the characteristics of a typical 20-year-old metal building based on input from their members, which comprise essentially the entire domestic metal buildings industry. MBMA has provided specifications and modified the one-story frame design to be freestanding. One MBMA member has agreed to donate the materials for the baseline vintage 20-year-old metal building skin. The other members will share the cost of having the skin erected on the FRP (planned for May 2012). MBMA has agreed to collaborate with ORNL to develop deep-savings envelope retrofit solutions for metal buildings and test plans for those retrofit solutions. (see Appendix C, roadmap Action 1.P.1-A.1: Develop wall and roof retrofit packages for metal buildings).

Two-Story FRP: The Greater Philadelphia Innovation Cluster for Energy Efficient Buildings (GPIC/HUB) is one of the primary industry partners for the first cycle of research on the two-story FRP walls. It has completed a study based on Commercial Buildings Energy Consumption Survey and CoStar data that defines the characteristics of typical walls on existing light commercial buildings in the 10-county GPIC/HUB region (e.g., brick/block masonry, uninsulated, 40 years old, window-to-wall ratio). Further, 1 of the 22 members of GPIC/HUB, Bayer Material Science (BMS), successfully competed for funds from GPIC/HUB's internal Opportunity Research Fund to cover costs for installing baseline brick/block walls on the two-story FRP that are typical of existing light commercial buildings in the same 10-county region. Separately, TRACO Windows (A Division of Kawneer) has agreed to be the primary

industry partner for the first cycle of research on the two-story FRP windows. TRACO has agreed to a 50–50 cost share on vintage (40 year old) single-pane windows installed on the two-story FRP. In addition, the Single Ply Roofing Industry (SPRI) has agreed to be the primary industry partner for the first cycle of research on the two-story FRP low-slope roof. SPRI has agreed to install, at its expense, a low-slope roof typical of an installation 20 years ago (20 years instead of 40 to account for the typical reroofing interval). BMS, TRACO, SPRI, the EIFS Industry Members Association, the Foam Sheathing Coalition, and the Asphalt Roofing Manufacturers Association have all agreed to collaborate with ORNL on developing deep-savings envelope retrofit solutions for the masonry walls, windows, and low-slope roof and to test plans for those retrofit solutions (see Appendix C, roadmap Action 1.P.1-A.2: Develop connection systems for wall cladding and thick, continuous exterior insulation; Action 1.P.1-A.3: Develop wall cavity or interior wall surface retrofit packages; Action 1.P.1-A.4: Develop retrofit packages for low-slope roofs).

2.4.2 Equipment research

For the first cycle of research on the FRPs, two HVAC systems will be installed simultaneously in the one-story FRP and three in the two-story FRP. Only one HVAC system will be active at any given time. The performance of the multiple systems will be experimentally characterized by rotating operation from one system to the next and exposing each system to a range of operating conditions. By including five different HVAC systems in the first cycle of research, ORNL and its industry partners will be able to address a large share of the light commercial building HVAC market without the expense of major renovations to the test buildings. The multiple HVAC cases provide five test beds for advanced prototype HVAC equipment, FDD systems, wireless sensor–based tune-up opportunity finder systems, and other uses.

One-Story FRP: The baseline metal test building is one big open space (one HVAC zone). The two HVAC systems deployed in parallel include a conventional NORDYNE gas-pack (air-conditioner with natural gas heat) and a Southwest Gas/NextAire gas-engine-driven heat pump. The two independent HVAC systems were designed to share a common forced-air distribution system. The HVAC units are ground-mounted outdoors. An in-line exhaust fan is used to simulate the function of a general exhaust fan that would typically serve a core restroom group. Outside air is ducted from wall-mounted intake louvers into the test building and directly connected to the central return air ductwork. Both HVAC systems are controlled from local thermostats; however, provisions have been made for a future central energy management and control system (EMCS). NORDYNE and Southwest Gas have agreed to provide specifications, review the HVAC system design, donate their equipment, select (and if necessary train) a qualified local contractor, and pay the contractor to install their units. HVAC equipment changes in out-years will be driven by advanced prototype units emerging from CRADA collaborations, the need to conduct “challenge specification” verification testing, or other BTP program priorities.

Two-Story FRP: The baseline brick/block-walled building with low-slope roof has eight space-conditioning zones (e.g., the first and second floor for three perimeter orientations [the stairwell makes up most of the fourth perimeter orientation], and the first and second floor core). The three HVAC systems deployed in parallel include a Trane rooftop unit (RTU) that is variable air volume (VAV) with electric reheat shutoff terminal boxes, a Trane water-loop heat pump (WLHP) system with fluid cooler and natural gas boiler to condition the common loop, and a Samsung variable refrigerant flow (VRF) system. The RTU is mounted on the roof with VAV boxes in each zone, the WLHP system has water-source heat pumps in each zone and a ground-mounted cooler and boiler, and the VRF has terminals in each zone and a ground-mounted compressor-bearing unit. The RTU system takes in fresh ventilation makeup air directly. The WLHP and VRF systems share a separate roof-mounted dedicated outdoor air system to provide tempered fresh air to each zone, since neither system conditions fresh air directly. An in-line exhaust fan is used to simulate the function of a general exhaust fan that would typically serve a core

restroom group. All HVAC systems are controlled with zone thermostats; however, provision has been made for a future central EMCS. Trane and Samsung have agreed to provide specifications, review the HVAC system design, donate their equipment, select (and if necessary train) a qualified local contractor, and pay the contractor to install their units. HVAC equipment changes in out-years will be driven by advanced prototype units emerging from CRADA collaborations, the need to conduct "challenge specification" verification testing, or other BTP program priorities. Trane, Samsung, and other HVAC manufacturers have agreed to collaborate with ORNL on an evaluation of HVAC approaches to multi-zone light commercial buildings (see Appendix C, roadmap Action 2.P.3-A.1: Independently evaluate common HVAC approaches to multi-zone light commercial buildings).

2.4.3 Retro/continuous-commissioning, fault detection and diagnostics, and controls research

For the first cycle of research on the FRPs, five different HVAC systems and other active loads such as lighting are installed in the two test buildings and are available for collaborative R&D with industry on improved commissioning, FDD, and controls solutions. Test buildings on the FRPs are ideally suited to this type of research, providing a low-risk, unoccupied, yet realistic (occupancy-simulated) whole-building environment, where faults can be forced and responses observed. The active energy loads have decentralized control as is typical in light commercial buildings today. However, the test buildings include backbone BACnet network wiring and other provisions for future central EMCSs, providing a platform for future research collaborations with industry partners. Both Johnson Controls, Inc. (JCI) and Schneider Electric have agreed to donate their most appropriate existing EMCSs, and several industry partners have expressed interest in collaborating with ORNL on the development of "EMCS-lite" products specifically for the light commercial market. JCI, SynapSense, Spinwave, Schneider Electric, United Technologies Research Corporation (UTRC)/Carrier, Emerson, and General Electric Global Research have all expressed interest in collaborating with ORNL on the development of a "tune-up opportunity finder" for light commercial buildings and in providing sensors and wireless hardware as contributions. Pacific Northwest National Laboratory has also expressed interest in collaborating with ORNL for the verification testing of several of their emerging technologies, including a smart monitoring diagnostic system and self-correcting controls

One-Story and Two-Story FRPs: NORDYNE, Southwest Gas, Trane, Samsung, JCI, SynapSense, Spinwave, Schneider Electric, United Technologies Research Corporation (UTRC)/Carrier, Emerson, General Electric Global Research, and Pacific Northwest National Laboratory have all expressed interest in collaborating with ORNL (see Appendix C, roadmap Action 4.P.1-A.1: Develop low-cost wireless sensors; Action 4.P.1-A.2: Develop a system to find tune-up opportunities based on temporarily installed wireless sensors; Action 4.P.1-A.3: Develop a smart monitoring diagnostic system [SMDS] for packaged unitary HVAC systems; Action 4.P.1-A.4: Develop verification protocols and independently verify the system for finding tune-up opportunities and SMDS).

2.4.4 Building information modeling, building energy modeling, and visual analytics

Autodesk, Inc., has provided ORNL with a free ADN (Autodesk Developer Network) subscription, which includes access (10 software "seats") to all Autodesk products and development support materials. Autodesk has also agreed to provide its prototype building monitoring software (known internally as "Project Dasher") and engineering staff time to customize the software so ORNL can use it as part of the data analytics and visualization system for ORNL researchers and remote industry partners.

ORNL has an Enterprise site license for the Bentley Systems BIM software (paid for by others at ORNL). The Enterprise license comes with a Bentley LEARN subscription. This subscription provides free access to Bentley subject matter experts for consulting services, commercial training, and commercial software

solutions to enable BIM data models and best practices for energy performance modeling simulation and reporting.

DesignBuilder Software, Ltd., has provided ORNL with ten free software licenses and access to training and consultation. The company has also stated it intends to incorporate project findings (e.g., interoperability enhancements) into future versions of DesignBuilder as appropriate.

Autodesk, Bentley, and DesignBuilder are all keenly interested in unbiased, authoritative, and documented case study evaluations of their software products from the point of view of users seeking to maximize energy efficiency in buildings. Key issues are interoperability between BIM and traditional software used for building energy modeling (BEM) (i.e., energy consumption and peak period demand estimation), HVAC load calculation, HVAC distribution system design, HVAC equipment selection, and HVAC system cost estimation.

ORNL has received modest funds to address a subset of these issues as part of BTP's multi-lab BIM-to-BEM activity. Working with the design team for the first one-story and two-story test buildings, the research team will evaluate and document the design workflows and inter-operability (i.e., ability to import, export, and translate data) between software tools for generating BIM files, BEM, HVAC load calculation, HVAC distribution system design, and HVAC equipment selection. The first test buildings provide a set of test cases that will inform DOE's interoperability efforts going forward. The industry partners intend to use the findings to improve the functionality, robustness and fidelity of data exchange between existing software products.

ORNL's BEM auto-tuning project will rely on data and models from ORNL's fleet of research houses until the baseline light commercial test buildings are up and running on the FRPs.

Autodesk, Bentley, DesignBuilder, Campbell Scientific, National Instruments, Onset Hobo, BizEE Energy Lens, Global View, Pulse Energy, Agentis Energy, PowerhouseDynamics, Powernab, Zerofootprint, Energy Inc. (TED), Brultech, Plotwatt, Space Time Insight, Tableau, GreenPlum, and IBM (ManyEyes) have all expressed interest in collaborating with ORNL in the areas of BIM, BEM, data acquisition, data analytics, and visual analytics (see Appendix C, roadmap Action 5.P.1-A.1: Develop the capability for autonomous data correction; Action 5.P.1-A.2: Develop the capability to auto-tune building energy models using measured data; Action 5.P.1-A.3: Develop the capability to estimate normalized building energy savings from limited sensor data in an automated fashion; Action 5.P.1-A.4: Develop a Web-based visualization and analytics portal to support virtual technology development organizations; Action 5.P.1-A.5: Demonstrate cost reduction in the process of improving the energy efficiency of existing light commercial buildings through interoperability of BIM and traditional software).

3. BUSINESS MODEL FOR USING APPARATUS

Over the last 5 years, ORNL's BTRIC has attracted about $8.4 million annually ($42 million over 5 years) in industry cost sharing for buildings-related R&D. About 70% of the industry cost share has been through CRADAs in which DOE BTP sponsors ORNL's effort within the CRADA and the industry partner is self-funded. The other avenues of industry cost sharing have included Work-for-Others (WFO, industry partner sends ORNL funding) at 13.3%, other (industry partner provides research houses; pays for leases; or provides materials, equipment or contractor services) at 7.6%, memoranda of agreement (MOAs, industry association provides natural exposure test facilities, materials, in-kind effort, and so on) at 5.7%, and user agreements (industry partner sends ORNL funding for testing services) at 3.4%.

The BTRIC laboratories are designated as a DOE national user facility, but user agreements account for only 3.4% of ORNL's buildings R&D industry cost sharing. ORNL is not in the business of providing testing services; ORNL is in the business of engaging in cost-shared collaborative research with industry to accelerate better BEE solutions into the market at affordable prices. This is an important distinction to understand. ORNL does, however, on occasion conduct testing for industry through user agreements in cases in which the work does not negatively impact its core research for BTP (e.g., cause delays) and the testing cannot be procured from private-sector laboratories (DOE national user facilities cannot compete with the private sector). This 3.4% is a very small part of what ORNL does with industry.

The business model for using the FRPs is the same as the business model for using any other research apparatus within the BTRIC national user facility. ORNL engages in cost-shared collaborative research with industry. From the point of view of ORNL, the FRPs are simply another apparatus with which to conduct cost-shared collaborative research with industry.

ORNL understands that year-to-year operating funds from BTP for the BTRIC national user facilities will be similar to historical levels. Historically, these operating funds have been very modest (~$50K annually) and insufficient to calibrate, maintain, and renew research equipment. ORNL has had to cover shortfalls (e.g., a hot box refrigeration system fails and must be repaired) by including such costs in individual project budgets. Before the $20.2 million in MAXLAB funding, the most recent DOE capital investment in BTRIC laboratories was over 20 years ago. Although apparatus have been rigorously kept in calibration, it is not surprising that over the 20+ years, any updating or maintenance of research apparatus tended to be deferred until absolutely necessary. About $4.2 million from the MAXLAB budget went toward research apparatus (as opposed to construction), and a significant portion of the $4.2 million was used to resolve the major deferred updating and maintenance issues with the existing (pre-MAXLAB) research apparatus.

ORNL has decades of experience in operating its buildings-related laboratories with negligible separately defined "operating funds" and is prepared to continue to do so by appropriately including fixed operational costs in its project portfolio. Obviously, when the project portfolio is declining, it becomes difficult for ORNL to manage uncovered costs. There have been instances over the decades, as BTP leadership teams have changed, when BTP has failed to appreciate the difference between ORNL and other performers who support BTP with smart people, PCs, desks and chairs, but minimal (or no) laboratory resources. ORNL brings all of these resources, plus more extensive buildings-related laboratory facilities than any other national laboratory by far, and about $8.4 million annually in industry cost sharing. A stable project portfolio helps make it more manageable for ORNL to cover costs such as apparatus calibration, maintenance, and renewal.

3.1 HOW BTP PARTICIPATES IN RESEARCH USING THE FRPS

ORNL understands that BTP retains complete control over the processes and decision making used to select individual projects for funding on an annual basis (e.g., statement of needs [SONs], statements of work, review, selection) There is no expectation that BTP will be funding research on the FRPs that does not align with BTP priorities and plans.

The first test building research cycle on the FRPs is a special challenge for BTP, ORNL, and ORNL's industry partners. BTP's expectation was that the ARRA-funded MAXLAB project would provide the funding for the first baseline test buildings on the FRPs. However as explained in Section 2.2, while developing the FRPs, ORNL needed to maintain a "bright line" between "construction" of the permanent portions of the FRPs, and "research" using the FRPs (e.g., implementing baseline test buildings on the FRPs in collaboration with industry partners, and taking measurements to characterize their performance). The Davis-Bacon waiver, which will enable cost-effective FRP research for decades, was contingent on maintaining this bright line.

Rather than participating in the resolution of this one-time problem, BTP directed ORNL to overcome the special challenge without BTP funding until after the first baseline test buildings were erected on the FRPs. ORNL is currently in the process of attempting to implement this directive. Resources available to apply to the task include leftover MAXLAB construction contingency (estimated at $500K) and cost sharing from industry partners. Construction contingency funds are released as construction project spending accrues, and ORNL's research team has no control over when contingency funds might be released. It is currently estimated that the first release of approximately $250K may become available in May 2012. In the meantime, ORNL's research team is attempting to provide enough pro bono project management to shepherd the industry partners into action. MBMA has signed a user's agreement, and it is estimated it will erect the envelope on the one-story FRP in May 2012. ORNL's goal is to complete both baseline test buildings by the end of calendar year 2012. It is estimated that achieving this goal will require $1.4 million in industry partner investment plus the $500K in leftover construction contingency, for a total of $1.9 million.

BTP retains complete control over FY 2013 project funding decision making. However, we note that it would be extremely embarrassing if after ORNL's industry partners invested $1.4 million in baseline test buildings, BTP should decide not to fund ORNL to (1) instrument the test buildings, (2) operate the FRP apparatus to conduct experiments and generate and analyze data, (3) provide the remote industry partners with web-accessible data analytics and visualization, and (4) collaborate with selected industry partners (via CRADAs) to develop better energy efficiency retrofit and/or tune-up solutions so that prototypes of these solutions would be available to implement onto the test buildings at the conclusion of the baseline data collection period.

It is helpful to review the nine-step FRP research process described in Section 2.3 to clarify what is and is not currently funded. At step 2, ORNL is to develop integrated whole-building designs for the two baseline test buildings. ORNL was able to complete this step using BTP funds before BTP revisited its FY 2012 Commercial Building Integration annual operating plan (AOP) and stopped work on all FRP-related projects. At step 3, ORNL must cover any gaps (i.e., features having no industry partner donors) so fully functional test buildings result. In the case of the first baseline test buildings the gaps include fire safety features required at ORNL, utility distribution systems (electrical power, natural gas, supply water) within the test buildings, HVAC thermal distribution systems, and lighting systems. ORNL estimates that the leftover construction contingency will be sufficient to cover these costs. ORNL's role to characterize baseline test building performance (step 4, i.e., instrument the test buildings, operate the FRP apparatus to conduct experiments and generate and analyze data, and provide remote industry partners with web-

accessible data) is currently unfunded. ORNL's role to collaborate with selected industry partners to develop better retrofit and/or tune-up solutions (step 5) is also currently unfunded.

In summary, ORNL is in the business of engaging in cost-shared collaborative research with industry partners. Historically, 70% of ORNL's industry cost share has been through CRADAs through which BTP sponsors ORNL's effort within the CRADA and the industry partner is self-funded. Test buildings on the FRPs involve multiple industry partners. Although we are open to better ideas from BTP, our current thinking is that ORNL should propose multiple FRP-related projects in BTP's FY 2013 AOP process. One project would cover core ORNL activities to instrument the test buildings, operate the FRP apparatus to conduct experiments and generate and analyze data, and provide remote industry partners with web-accessible data. This project supports the collaborations with all industry partners. The prospective remaining projects are generally described in Section 2.4, Appendix C, and the FY 2012 AOP statements of work that went unfunded. ORNL suggests that the ones in greatest alignment with current BTP program directions should be called out in BTP's FY 2013 SONs. Since these later projects are the ones that would support ORNL's collaborations with industry, ORNL asks that BTP give preference in the SONs to projects that would enable ORNL to collaborate with the industry partners who provided cost sharing for the test buildings.

ORNL considers BTP to be its core sponsor for R&D using the FRPs or any other research apparatus within the BTRIC national user facility. However, ORNL also plans to seek funding from other sponsors for research using the FRPs in cases where the work would not negatively impact our core research for BTP (e.g., does not interfere with ongoing test building research cycles). In our experience, WFO helps to diversify our project portfolio and tide us over during periods when the BTP core-funded project portfolio is reduced.

Although we are focused on BTP as the core sponsor for the first test building research cycles on the FRPs, current WFO opportunities serve as examples of the kinds of projects other sponsors might pursue using the FRPs. The US Army Engineer Research and Development Center Broad Agency Announcement W912HZ-12-BAA-01 seeks solutions that deliver energy services more efficiently; reduce the risk of loss of energy services; integrate into buildings CBRN (chemical, biological, radiological, or nuclear) protection systems; or improve the indoor air quality of buildings. The National Institute of Standards and Technology Federal Funding Opportunity 2012-NIST-MSE-01 seeks solutions that enable building energy-use reduction through in situ performance measurements and embedded intelligence in building controls. The Department of Homeland Security Science and Technology Long-Range Broad Agency Announcement 12-07 seeks integration of sensors into building systems and development of associated Concepts of Operations to enable rapid and adaptive responses to chemical and biological releases to protect occupants and mitigate the impact of the release. Realistic, risk-reducing, and flexible test beds like the test buildings on the FRPs are ideally suited for WFO opportunities such as these.

3.2 HOW INDUSTRY, ACADEMIA, AND OTHER COLLABORATORS PARTICIPATE

3.2.1 User agreements

ORNL has devised a user's agreement process whereby the industry partner is allowed to come on site at ORNL and erect its building system on an FRP in accordance with the integrated whole-building design. With this user agreement, no funds are exchanged between the industry partner and ORNL. The primary use of this style of agreement will be to bring a group of industry partners to ORNL, in appropriate sequence per plan, to install the several building systems that comprise the test building. Later in the research cycle, many of the same industry partners will return to ORNL under a separate user's agreement

to retrofit their building systems with prototype energy efficiency solutions emerging from collaborative R&D.

3.2.2 CRADAs and other forms of cost-shared collaboration

Where true collaboration is to occur between ORNL and an individual industry partner, the agreement form is most likely to be a CRADA. With CRADAs, BTP covers ORNL's effort within the collaboration and the industry partner is self-funded. ORNL currently participates in the pilot program for DOE's new Agreement for Commercializing Technology agreement, and will also consider this approach if it is advantageous given the circumstances. In cases in which the partner is an industry association, ORNL uses either CRADAs or MOAs and will choose the approach most advantageous given the circumstances. In cases in which there is no collaboration, but instead the partner wants to pay ORNL to implement a scope, WFO will be used.

APPENDIX A. PARTICIPANT LIST FOR "SHAPING THE FUTURE OF BTRIC USER FACILITIES WORKSHOP"

Session #1: Building Envelope – Andre Desjarlais

Glenn Cottrell	IBACOS, Inc.
Laverne Dalgleish	Building Professionals
Andre Desjarlais	Oak Ridge National Laboratory
Fred Hansen	Energetics, Incorporated
Reed Hitchcock	ARMA/RCMA
Jim Hoff	TEGNOS Research, Inc.
Jonathan Humble	American Iron & Steel Institute
Diana Hun	Oak Ridge National Laboratory
Kanti Jain	University of Illinois
Dave Johnston	EIFS Industry Members Association
Jim Katsaros	DuPont Spruance Plant
Jim Kirby	National Roofing Contractors Association
Roger Kisner	Oak Ridge National Laboratory
Frank Klink	3M Industrial Minerals Products Division
Scott Kriner	Metal Construction Association
Bob LeClare	WP Hickman
Paul Nahass	Aspen Aerogels, Inc.
Paul Shipp	USG Corporation
Leigh Streit	Flad Architects
Dan Walker	Metal Building Manufacturers Association
Dave Yarbrough	R&D Services, Inc.

Session #2: Active Building Loads – Justin Baba

Justin Baba	Oak Ridge National Laboratory
Steve Bushby	National Institute of Standards and Technology
Geir Dullerud	University of Illinois
Melissa Eichner	Energetics Incorporated
Jim Freihaut	Penn State University
Peter Fuhr	Wi-Fi Sensors
Shaun Gleason	Oak Ridge National Laboratory
Chris Gray	Southern Company
Srinivas Katipamula	Pacific Northwest National Laboratory
Jungho Kim	University of Maryland
Nicholas Kottenstette	ISIS Vanderbilt University
Sean Meyn	University of Illinois
Hung Pham	Emerson Climate Technologies
Sunil Samtani	Telcordia Technologies (Applied Research Labs)
John Seem	Johnson Controls, Inc
Steve Selkowitz	Lawrence Berkeley National Laboratory

Session #3: Building Construction – Francois Pin

Ioannis Brilakis	Georgia Institute of Technology
Kelly Headden	Barber McMurray Architects
Charles Leahy	Eco-Panels
Randy Lind	Oak Ridge National Laboratory
Alan Lytle	National Institute of Standards and Technology
Catherine Mattus	Oak Ridge National Laboratory
Mike Mazor	Dow Building Solutions
Merle McBride	Owens Corning
Gary Parsons	The Dow Chemical Company
Francois Pin	Oak Ridge National Laboratory
Jochen Teizer	Georgia Institute of Technology
Paul Torcellini	National Renewable Energy Laboratory
Gareth Williams	Energetics Incorporated

Session #4: Residential Whole-Building – Roderick Jackson

Omar Abdelaziz	Oak Ridge National Laboratory
Moonis Ally	Oak Ridge National Laboratory
Shane Angle	Emerson Climate Technologies
Van Baxter	Oak Ridge National Laboratory
Charlene Bayer	Georgia Institute of Technology
Bob Brown	Water Furnace Intl.
Subrato Chandra	Florida Solar Energy Center/UCF
Jeff Christian	Oak Ridge National Laboratory
David Dinse	Tennessee Valley Authority
Hunter Fanney	National Institute of Standards and Technology
Jason Hubbard	Simple Controls
Roderick Jackson	Oak Ridge National Laboratory
Chuck Ketterer	Emerson
Tom Leck	DuPont Fluorochemicals
Shawna McQueen	Energetics Incorporated
Scott Mitchell	Southern California Edison
David Najewicz	General Electric Appliances
Chris Ooten	Schaad Companies
Bill Rittlemann	IBACOS, Inc.
James Rudd	Southface Energy Institute
Pradeep Sood	Emerson Motor Company
Ken Walma	Cooper Industries
Vic Zaderej	Molex/Solar Homes LLC

Session #5: Commercial Whole-Building – Therese Stovall

Chris Clark	Energetics Incorporated
Paul Coleman	Huntsman
Tim Dunaway	Schaad Companies
Doug Fast	Johns Manville
Johney Green	Oak Ridge National Laboratory
Lisa Hopkins	IBM
Brian Marstellar	Oak Ridge National Laboratory
Bill Miller	Oak Ridge National Laboratory
Brian Nicholson	Barber McMurray Architects
Marylynn Placet	Pacific Northwest National Laboratory
Shanti Pless	National Renewable Energy Laboratory
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Session #7: Adv Bldg Computing – David Hetrick/Sreekanth Pannala

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APPENDIX C. LIGHT COMMERCIAL BUILDING TECHNOLOGY ROADMAP

LIGHT COMMERCIAL BUILDING TECHNOLOGY ROADMAP

Goal

The Department of Energy's (DOE's) goal for energy efficiency in existing light commercial buildings is to maximize cost-effective energy efficiency. The goal will be achieved by creating new or improved technology options that can significantly reduce energy use in existing buildings and are **affordable, reliable, and deployable with speed and on a large scale**. New or improved options may (1) optimize the performance of the existing physical building systems (e.g., tune-ups to existing systems), or (2) retrofit physical systems (e.g., add insulation or replace old and inefficient equipment). Solutions are sought that could be deployed beginning in the next 5 years and would provide substantial and long-lasting energy savings. Although the focus is on creating new and improved options for reducing energy use in existing buildings, many of the deep-savings solutions generated will also be deployable in new construction.

Potential

For the purposes of this roadmap, light commercial buildings are defined as those that are 50,000 ft^2 or smaller in size, which represent 95% of the nation's commercial buildings and 50% of the nation's commercial building floor space (Commercial Building Energy Consumption Survey [CBECS] 2003, Table A1). Light commercial buildings account for 47% of commercial building energy bills (CBECS 2003, Table C2A), or about $90 billion annually at today's energy rates (based on 2008 data, the latest in the DOE *Buildings Energy Data Book* 2010, Table 3.3.3). According to a recent study, a reasonable range of economical energy savings potential in existing commercial buildings is between 10 and 20% of current energy consumption using today's technology (David Belzer, *Energy Efficiency Potential in Existing Commercial Buildings: Review of Selected Recent Studies*, PNNL-18337, Pacific Northwest National Laboratory). The study implies that, assuming a 5-year simple payback on average and 10% of the existing building stock addressed annually, today's technology could support a $5 to $9 billion per year industry focused on energy use reductions in light commercial buildings. Implementing this roadmap expands the market potential of this industry through new or improved technology options and deployment strategies.

Background

Light and large commercial buildings have fundamental differences that greatly affect their energy performance. Architectural and engineering firms typically have limited participation in the light commercial marketplace. There is usually an architect or engineer of record, but the level of their services is often minimized by applying standard details and specifications with little use of integrated design techniques. To reduce costs, project delivery methods such as design–build contracts are common, and many light commercial buildings are fabricated by construction subcontractors who are also active in residential markets.

Prescriptive paths to energy code compliance are used almost exclusively, rather than modeling, which is required for performance path compliance. Most of these buildings have only one or a few stories, and zone control for space conditioning is accomplished with unitary heating, ventilating, and air conditioning (HVAC) equipment rather than built-up applied systems. In light commercial buildings, whether existing or new, any kind of whole-building automation or energy management and control system is an exception rather than the rule. Skilled building operators are rarely employed, and any kind of maintenance or repair beyond what can be done by a janitor or handyman is typically outsourced to a service provider. Building

owners and tenants, rationalizing their behavior on the basis of cost containment, will often defer maintenance and repair actions without necessarily realizing that these practices may actually increase their total costs if wasted energy and higher utility bills are considered.

Applied R&D to Significantly Improve Light Commercial Building Technology Options in the Next 5 Years

This section is organized around problems facing building energy efficiency product suppliers or owners and operators of light commercial buildings that could potentially be solved by actions resulting from applied research and development (R&D). The problems and matching actions are organized under headings, each representing a major component of light commercial building energy use. For each area, aggressive performance and economic targets are established. The problem and action descriptions are concise but also attempt to retain sufficient detail to convey an understanding of their essential intent. Individual actions do not necessarily have the potential to achieve the targets by themselves. In some cases they may build upon each other to achieve the target.

1. Envelope

Target: ***Through development of new envelope retrofit options for light commercial buildings, enable heating and cooling bills to be reduced by 50% compared with pre-retrofit baselines while retrofits pay for themselves in 5 years or less.***

Problem 1.P.1: Most existing buildings are un-/under-insulated and have high rates of air leakage. Most existing light commercial buildings are structurally sound and have decades of remaining service life, but the envelope components (walls, roofs) are un-/under-insulated and have high rates of air leakage. The actions listed below would address this problem through cost reduction or development of new retrofit solutions. Although not repeated in each action description, the actions include demonstrating that the solutions save the expected amount of energy annually and during peak load periods, are potentially low enough in cost to achieve market uptake, are easy (foolproof) to install with proper tools, are reliable and moisture-durable, and satisfy all code requirements.

Action 1.P.1-A.1: Develop wall and roof retrofit packages for metal buildings. Metal buildings are used for virtually all types of light commercial enterprises, including sports facilities, food preparation, warehouse/hanger/manufacturing/distribution, health care, religious organizations, offices, education, and mercantile/malls/retail. Based on floor area, metal buildings have accounted for about 40% of the nation's light commercial building construction over a period of many decades. A project focused on adding insulation and reducing thermal bridging and air leakage in existing metal buildings is needed because the construction details of such buildings are unique and challenging and the energy savings potential is large. The project should investigate both exterior and interior wall and roof retrofit solutions, including retrofit construction details for both 2-dimensional (roof panel to purlin, wall panel to sidewall girt) and 3-dimensional (corners, around doors and windows, roof to sidewall and endwall) features.

Action 1.P.1-A.2: Develop connection systems for wall cladding and thick, continuous exterior insulation. A project is needed to develop connection systems for wrapping a wide variety of existing building facades with new wall cladding and various types of thick, continuous insulation. These connection systems must accommodate the uncertain condition of existing facades, such as crumbling brick or rotted wood, while minimizing thermal bridging. Affordable and reliable connection systems are not widely available for all application conditions. Most of these older buildings do not have an air barrier in place, so the retrofit would need to add an air barrier that was not compromised by the connection system.

Action 1.P.1-A.3: Develop wall cavity or interior wall surface retrofit packages. Because of aesthetic and historical preservation issues, many existing light commercial buildings are not candidates for exterior wall retrofits. A project is needed to develop insulation and air barrier retrofit solutions that could be applied in wall cavities or on the interior of a wide variety of existing building wall assemblies without compromising the moisture-durability of the existing structure.

Action 1.P.1-A.4: Develop retrofit packages for low-slope roofs. Each year, about 3 billion square feet of low-slope commercial roofs are reroofed. A project is needed to develop improved insulation and air barrier retrofit solutions for a wide variety of existing building low-slope roofs that could be integrated with reroofing.

Action 1.P.1-A.5: Develop whole-building air sealing. Many existing light commercial buildings have high rates of air leakage, but insulation levels are adequate or increasing insulation levels is cost-prohibitive. A project is needed to develop a whole-building air sealing approach akin to aerosol sealing of ducts. The approach must be no more intrusive than other activities that are common during updating, remodeling, or tenant/ownership transitions (e.g., carpet replacement, re-painting or -papering). In general, a cost-effectiveness analysis would help determine whether whole-building air sealing should be implemented by itself or in conjunction with adding insulation to the envelope system.

Problem 1.P.2: Existing buildings waste energy (especially during peak load periods) because of low thermal mass. Most existing low-rise commercial buildings are of light-frame construction and have low thermal mass. Consequently, opportunities to use building mass to reduce space-conditioning loads and move remaining loads off-peak, to periods when space-conditioning equipment operates more efficiently, are lost unless some or all of the solutions generated by actions under Problem 1.P.1 also increase envelope thermal mass. When cost savings from reducing peak load and the practical challenges of thick insulation retrofits are considered, retrofit packages that include phase-change materials (PCMs) can be more cost-effective than those based on insulation and air barriers alone. Though PCMs have emerged that are made from sustainable ingredients with stable long-term performance characteristics, their appropriate integration into envelope retrofit packages has yet to be investigated. The actions listed below address this problem. Although it is not repeated in each action description, the actions below would include demonstrating that the solutions save the expected amount of energy annually and during peak load periods, would potentially be low enough in cost to achieve market uptake, would be easy (foolproof) to install with proper tools, are reliable and moisture-durable, and would satisfy all code requirements.

Action 1.P.2-A.1: Develop validated models for optimizing envelope retrofit packages that integrate PCMs. A project is needed to develop modeling tools capable of characterizing energy, peak demand, and moisture performance as a function of PCM location in the wall or roof assembly, phase-change temperature, and percentage-by-weight loading. Since the tools would model entire wall or roof assemblies, they would also be able to characterize the benefits of assembly designs that passively or actively provide PCM cooling to prevent heat saturation. The models would be auto-tuned to component- and assembly-level data for validation.

Action 1.P.2-A.2: Develop optimal envelope retrofit packages that integrate PCMs. PCM benefit per unit cost depends on where it is located (1) in the wall or roof assembly (e.g., dispersed vs. concentrated, exterior vs. interior) and (2) on the building (e.g., only wall or roof areas with the greatest sun exposure or temperature extremes). Benefit per cost also depends on how much PCM must be used to capture the benefits. In this project, the modeling tools developed and validated under Action 1.P.2-A.1 would be integrated with whole-building simulation and auto-tuned (see Problems 5.P.1 and 5.P.2 and related actions) to assembly-level and whole-building data for

validation. Then the validated engine would be integrated into one of the existing economic optimization packages. For several climates and light commercial building types, the tool would be used to re-engineer the solutions generated under Problem 1.P.1 to optimally integrate PCMs into the retrofit assemblies, and then select either conventional or PCM-enhanced retrofit assemblies for the various building envelope surfaces based on cost-effectiveness. As an example of the latter, an optimal whole-building envelope retrofit solution might include PCM-enhanced retrofit assemblies for the roof and south and west walls but conventional retrofit assemblies for the east and north walls.

Problem 1.P.3: There is a lack of credible cost and savings data to allow contractors to promote envelope retrofit solutions effectively. The solutions emerging from actions under Problems 1.P.1 and 1.P.2 would need to be effectively promoted to be successful in the marketplace. It is anticipated that these solutions would require choices (e.g., insulation level) and/or the selection of options (e.g., "A" if re-cladding brick) that would affect installed cost and annual cost savings. In addition, local labor rates and material costs affect installed cost, and utility rate structures, climate, building type, and the existing condition of the building envelope affect annual cost savings. A tool does not currently exist that is usable by light commercial building contractors and that does a credible job of estimating envelope retrofit installed costs and annual cost savings for the solutions likely to emerge.

Action 1.P.3-A.1: Develop a free Web service for estimating envelope retrofit installed costs and annual cost savings. A project is needed to develop a free Web service for estimating installed costs and annual cost savings for envelope retrofit solutions emerging from actions under 1.P.1 and 1.P.2. The calculation engine would comprise very detailed wall and roof assembly models (e.g., WUFI, AtticSim) combined with a whole-building simulator (e.g., EnergyPlus, DOE-2). The engine would verify that the retrofit causes no moisture-related harm and then estimate annual all-fuels energy cost savings, including reduced peak electricity demand. The tool would be useful for both early and later stages of project development. To support energy auditing and provide guidance to building owners in the early stages, the tool would use generic cost-estimating sources (e.g., R.S. Means, or maybe BNi for residential-like building types). For early savings estimates, the auditor would simply select from menus the building type most similar to the target building, the wall and/or roof retrofit packages, the location, and other readily available data to define the envelope wall and roof assembly baseline conditions. Then the Web service would generate estimated annual cost savings. Where a more detailed feasibility analysis is required, the auditor could improve the savings estimation by (1) conducting a walk-through audit to verify the initial model postulated by the Web service and (2) providing modest amounts of measured data (e.g., utility billing history, interval data from smart meters) to allow the Web service to auto-tune the model. In later stages of project development, the contractors that perform the retrofits could securely store their own cost factors for material and labor in the tool and use the tool and its auto-tuned model to generate retrofit proposals that summarize price, savings, and value.

2. Equipment

***Target*: Through development of new equipment replacement or retrofit options for light commercial buildings, enable heating and cooling bills to be reduced by 50% compared with pre-retrofit baselines, while retrofits pay for themselves in 5 years or less.**

Problem 2.P.1: Cost-effective new equipment with higher energy efficiency levels is not available, but could be. A wide variety of energy-consuming equipment is used in light commercial buildings, including various sizes of commercial unitary air conditioners and heat pumps (both split and package systems), packaged terminal air conditioners, packaged terminal heat pumps, refrigerated beverage vending machines, automatic ice makers, commercial refrigeration equipment, commercial-size storage

water heaters, and walk-in coolers and freezers. The energy savings potential of replacing existing units at the end of their service life could be expanded dramatically if cost-effective equipment with higher efficiency levels were available. In every equipment category, the energy efficiency levels of commercially available equipment fall far short of the theoretical efficiency limits of the underlying thermodynamic cycles. Original equipment manufacturers (OEMs) say they would make higher-efficiency equipment if there were a market for it, large customers say they would buy higher-efficiency equipment if it were available and affordable, and higher-efficiency products must displace a significant share of today's lower-efficiency products to be affordable (i.e., shipment volume begets affordability). To break the stalemate and enable substantial energy savings, this three-sided chicken-and-egg problem (supply, demand, and affordability) must be addressed systematically in each equipment category where savings potential justifies the actions.

Action 2.P.1-A.1: Refine and articulate a generalized strategy for pushing light commercial building equipment categories to higher efficiency levels. For one equipment category — rooftop air-conditioning units (RTUs) — the DOE Building Technologies Program (BTP) has built a collaboration of potential customers with strong purchasing power through the Retailer Energy Alliance (REA). A challenge has been issued to the HVAC industry to build products that meet new specifications for high-performance RTUs by offering the potential of immediate sales through pledges by major REA members. The new specifications have been written to essentially require the use of maximum-efficiency technologies available currently that can be affordably included. After issuing the "max tech" challenge specifications, BTP initiated a second project to develop verification protocols and independently determine for customers whether those RTUs satisfied all specification requirements, and initiated a third "next gen" project to push RTU efficiencies beyond today's "max tech" and closer to the theoretical efficiency limits. The "next gen" project creates the opportunity for one or more OEMs to enter into public–private collaborations to accelerate technical progress toward very high efficiency levels, making the achievement of "max tech" simply a step along the way. These integrated activities, referred to as the RTU Challenge, are BTP's first attempt to systematically address supply, demand, and affordability using a combined market pull and technology push strategy. A project is needed to review RTU Challenge lessons learned to date, refine the strategy, and articulate it generally so the program can begin promoting the approach to OEMs and customers with strong purchasing power in other equipment categories.

Action 2.P.1-A.2: Prioritize equipment categories to be pushed to higher efficiency levels. BTP started with the RTU Challenge because packaged (unitary) equipment uses more than 50% of the space-cooling energy in commercial buildings, the RTU is the most ubiquitous configuration, and OEMs and customers expressed interest. The same approach can be applied to other equipment categories. However, having sufficient program resources to address all equipment categories simultaneously is unlikely, and therefore a project is needed to set priorities. This project would include promotion of the generalized approach developed by Action 2.P.1-A.1 to OEMs serving equipment categories other than RTUs, and to the customers with strong purchasing power in those categories. Equipment category prioritization would be based on criteria such as energy savings potential, interest and enthusiasm of OEMs and customers with strong purchasing power, and the prospective magnitude of immediate sales and energy savings through pledges. Although they are already completed or under way, action descriptions for developing the RTU "max tech" challenge specifications (Action 2.P.1-A.3), verifying that specifications have been satisfied (Action 2.P.1-A.4), and developing "next gen" RTUs (Action 2.P.1-A.5) are included below in this roadmap to serve as examples. Analogous trios of actions would be taken for other high-priority equipment categories as resources become available.

Action 2.P.1-A.3: Develop "max tech" RTU Challenge specifications. (Note: this project is completed.) A project is needed to write new RTU specifications that essentially require the use of

maximum efficiency technologies available currently that can be affordably included in the manufacture of RTUs. The RTU "max tech" challenge specifications would be written in collaboration with RTU customers having strong purchasing power and a willingness to pledge a significant portion of their future RTU purchases to the "max tech" efficiency level. It should be noted that these are performance specifications written in an inclusive manner so that all RTU OEMs will have the opportunity to voluntarily improve their products, satisfy the specifications, and compete for the business as pledges are converted to orders.

Action 2.P.1-A.4: Develop verification protocols and independently verify whether RTUs satisfy the "max tech" RTU Challenge specifications. (Note: this project is under way.) REA members pledging "max tech" RTU purchases expect verification that OEMs have met all specifications before placing orders. They also need a verified RTU component model to integrate into their whole-building energy models and thereby determine the energy, peak demand, and cost savings they can expect to achieve through a mass replacement of RTUs in their facilities. These same verified RTU models would be integrated into the Web service developed in Action 2.P.5-A.1. A project is needed to develop the verification protocols, independently verify whether RTUs emerging from the OEMs satisfy all the "max tech" challenge specifications, and provide verified RTU component models for units meeting the RTU Challenge.

Action 2.P.1-A.5: Develop next-generation RTUs with integrated energy efficiency ratios (IEERs) exceeding 20. (Note: this project is under way.) A project is needed that develops improved underlying subcomponent technologies and RTU integration approaches to achieve ultra-high energy efficiency, effectively taking RTUs a large step closer to the theoretical efficiency limits of their underlying thermodynamic cycles. The "next gen" project creates the opportunity for one or more OEMs to enter into public–private collaborations to accelerate technical progress toward very high efficiency levels, making the achievement of "max tech" simply a step along the way. Any avenue to cost-effective higher efficiency can be considered, including improvements to traditional technologies (e.g., vapor compression cycles, controls, combustion, and heat exchangers), use of alternative technologies, or hybrid combinations. In 2007 Congress directed DOE to evaluate the potential of regional minimum efficiency standards for residential-size furnaces, central air conditioners, and heat pumps (Section 306 of the Energy Independence and Security Act). Since then there has been growing awareness that climate-specific solutions may be able to reach higher efficiencies at a given level of cost for categories of equipment such as HVAC, for which performance depends on climate. Hence, some of the public-private collaborations to accelerate technical progress toward very high efficiency levels may focus on regional markets large enough to achieve significant energy savings and shipment volumes so that cost goals can be achieved.

Problem 2.P.2: Cost-effective improvements to increase the energy efficiency of existing equipment have been suggested but not proven. Many categories of energy-consuming equipment are used in light commercial buildings (see Problem 2.P.1). Depending on the category, the average service life of equipment may vary from 10 to 30 years or more. Energy efficiency improvements to existing equipment may be justified in cases where improvements pay for themselves in 3–5 years, service life thereafter is significant, and energy savings are expected to persist until time of equipment replacement. The energy savings potential of such improvements could be significant, depending on how many viable improvement opportunities meeting these criteria are found and—for the affected equipment categories—the size of existing equipment inventories, their age distributions, and their energy consumption. A few such retrofits (e.g., condenser evaporative pre-cooling, nanomaterial additives to refrigerants, adding modulating compressors to units using wasteful hot gas bypass for capacity modulation) have been suggested, but they have not been proved well enough to dissipate concerns about issues such as level of savings, persistence of savings, voided warranties, and the workforce required to reliably implement

them. Nor has there been any systematic assessment across all the categories of equipment in light commercial buildings to prioritize suggested equipment retrofit opportunities.

> **Action 2.P.2-A.1: Identify and prioritize retrofits that can push existing equipment to higher efficiency levels.** Program resources are unlikely to be sufficient to simultaneously address many different existing equipment retrofits. A project is needed to identify the retrofits that have been suggested, screen them for practicality and national impact, and set priorities among those that pass the screening test. Screening criteria include consideration of whether (1) improvements would pay for themselves in 3–5 years,(2) the improved service life of the equipment thereafter is significant, (3) there is reason to believe that energy savings would persist until the improved equipment is replaced, (4) warranty and workforce concerns are nonexistent or can be cost-effectively overcome, and (5) retrofits offer significant national energy savings. It is believed that elements of BTP's strategy for pushing new equipment to higher efficiency levels (see Action 2.P.1-A.1) could also be used to push existing equipment to higher efficiency levels through retrofits. Hence, prioritization may be based on criteria such as energy savings potential, interest and enthusiasm of customers with strong purchasing power, interest and enthusiasm of OEMs or after-market providers, and the prospective magnitude of immediate sales/implementation and energy savings through pledges. Assuming this project finds existing equipment improvement options that pass the screening tests and attract sufficient interest and enthusiasm among stakeholders to move forward, actions analogous to challenge specifications (Action 2.P.1-A.3) and verification that specifications have been satisfied (Action 2.P.1-A.4) would likely be required.

<u>Problem 2.P.3</u>: Up-to-date information necessary to select the most energy-efficient multi-zone HVAC systems for specific applications is not available. Improving the energy efficiency of new or existing packaged HVAC equipment (per actions under Problems 2.P.1 and 2.P.2) is necessary but not sufficient for maximizing the cost-effective energy efficiency of HVAC in light commercial buildings. Such buildings generally have multiple space-conditioning zones where comfort conditions are controlled independently. A variety of equipment, system, and control approaches are commercially available for multi-zone applications. There is great disparity among these systems in cost and ability to operate at lower energy use levels as areas in the building vacate or when weather is mild. In addition, multi-zone HVAC systems are constantly evolving, whole new configurations have recently emerged, and retrofitting from one system type to another is increasingly common. Unfortunately the up-to-date information necessary to ensure selection of the best multi-zone HVAC approach for specific HVAC renewal or new construction applications is not currently available from a reliable, unbiased, and independent source.

> **Action 2.P.3-A.1: Independently evaluate common HVAC approaches to multi-zone light commercial buildings**. A project is needed to experimentally characterize the performance of the most common multi-zone HVAC systems currently existing in or retrofitted into light commercial buildings. Systems could be simultaneously installed in the same light commercial building flexible research platform to allow characterization of their performance (energy, comfort in zones, fresh air allocation to zones, economizer—if any) on a common basis, by rotating operation from one system to the next and exposing each system to a range of operating conditions. Existing energy models of multi-zone HVAC systems would be examined and updated as necessary, and energy models would be developed for system types currently lacking credible representations. Measured data would be used to auto-tune the energy models, which would be integrated into the Web service developed in Action 2.P.5-A.1 and made available to generalize results to specific applications (e.g., baseline system configuration, building type, climate).

<u>Problem 2.P.4</u>: Existing supermarket refrigeration systems present many energy-saving opportunities that remain unaddressed. Supermarket refrigeration systems are built up and applied in the field using multiple components. Consequently, some advanced energy-saving features that have been

standard in packaged (unitary) equipment for years, such as demand defrost, remain rare in supermarket refrigeration systems. The situation is complicated by the fact that there are many types of systems in the field because of the long service life of major components, generational evolution of the technology, and periodic system changes associated with store expansions or renovations.

Action 2.P.4-A.1: Develop a suite of energy efficiency improvements for existing supermarket refrigeration systems that are cost-effective and easy to implement as retrofits. A variety of different refrigeration system configurations are used in existing facilities (supermarkets, convenience stores), but only a small number of configurations account for most energy use. A project is needed to experimentally characterize the performance of the most common refrigeration systems. To allow their characterization on a common basis, systems could be installed in the same "store" built on a light commercial building flexible research platform and then operated in rotation. Measurements would also be taken to characterize the performance of the "store" so that interaction of refrigeration and HVAC systems, and whole-building considerations such as loads that could be served by heat recovered from compressor racks, can be investigated. This multi-system test bed would be used for collaborative research with industry to develop and prove a suite of measures to improve energy efficiency and reduce refrigerant emission in existing refrigeration systems. Improvements would be investigated that would reduce refrigeration load (e.g., adding doors to display cases, changing display case lighting to LEDs) or cause remaining loads to be served more efficiently (e.g., compressor or controls upgrades), as well as the impact of drop-in replacement refrigerants having low global warming potential. Measurements would be used to characterize the performance of the baseline systems and improvements to those systems over a range of store ambient and weather conditions. Existing energy models for refrigeration system configurations would be examined and updated as necessary, and energy models would be developed for system configurations currently lacking credible representations. The measured data would be used to auto-tune the energy models, which then could be used to characterize the energy and peak demand savings performance of retrofit improvement options in specific applications (e.g., baseline system configuration, store type, climate). In addition, working with suppliers and their contracting networks, the installed costs of the improvements would be determined. The tuned energy models and costs would be integrated into the Web service developed in Action 2.P.5-A.1. Separately, DOE BTP would challenge its various customer alliances to retrofit these solutions into existing systems and specify their inclusion in newly purchased systems.

<u>Problem 2.P.5</u>: There is a lack of credible cost and savings data to allow contractors to promote highly efficient equipment and systems effectively. The higher-efficiency new and existing equipment generated by actions under Problems 2.P.1 and 2.P.2, the improved characterizations of multi-zone HVAC systems (2.P.3), and the supermarket refrigeration system improvements (2.P.4), must be made easily accessible to contractors to maximize cost-effective energy efficiency in light commercial buildings. Applying these energy savings strategies effectively would require choices (e.g., multi-zone HVAC system type) and/or the selection of options (e.g., equipment efficiency level), which would affect installed cost and annual cost savings. In addition, local labor rates and material costs would affect installed costs, and utility rate structures, climate, building type, and the existing baseline systems and their operating efficiencies all influence annual cost savings. A tool usable by light commercial building contractors that does a credible job of estimating installed costs and annual cost savings—quickly—for equipment replacements and for equipment, HVAC system, and supermarket refrigeration system retrofits, does not currently exist.

Action 2.P.5-A.1: Develop a free Web service for estimating installed costs and annual cost savings of equipment and system retrofits. A project is needed to develop a free Web service for estimating installed costs and annual cost savings for efficiency-enhancing equipment replacements, equipment retrofits, multi-zone HVAC system improvements or conversions, and supermarket

refrigeration retrofit solutions emerging from actions under 2.P.1, 2.P.2, 2.P.3, and 2.P.4. The calculation engine would consist of improved detailed component and system models resulting from the previously referenced actions, combined with a whole-building simulator (e.g., EnergyPlus, DOE-2). The engine would estimate annual all-fuels energy cost savings, including cost savings from reducing peak electric demand. The tool would be useful for both early and later stages of project development. To support energy auditing and provide guidance to building owners in the early stages, the tool would use generic cost estimating sources (e.g., R.S. Means or cost data generated as part of previous actions). For early savings estimates, the auditor would simply select from menus the building or store type most similar to the target building, the improvement packages, the location, and other readily available data to define the baseline component and system conditions, and the Web service would generate estimated annual cost savings. In cases in which a more detailed feasibility analysis is required, the auditor could improve the savings estimation by (1) conducting a walk-through audit to verify the initial model postulated by the Web service, and (2) providing modest amounts of measured data (e.g., utility billing history, interval data from smart meters) to allow the Web service to auto-tune the model. In later stages of project development, contractors who implement the improvements can securely store their own cost factors for materials and labor in the tool and use the tool and its auto-tuned model to generate proposals that summarize price, savings, and value.

3. Lighting and Daylighting

Target: Through development of new lighting and daylighting retrofit options for light commercial buildings, enable electric lighting bills to be reduced by 50% compared with pre-retrofit baselines, while the retrofits pay for themselves in 5 years or less.

Problem 3.P.1: Electric lighting systems in most existing light commercial buildings are inefficient and not installed in accordance with best practices. Electric light sources and luminaires in most existing light commercial buildings are inefficient, and lighting systems are not designed and installed in accordance with best practices. Existing lighting systems are also often poorly controlled. For example, it is not uncommon to find top lighting in large open office areas grouped to one switch, with recircuiting impossible (no circuits available) or cost-prohibitive in a retrofit scenario. The lack of efficient light sources and luminaires, design and installation best practices (task lighting), and local lighting controls in individual use areas results in energy waste.

Action 3.P.1-A.1: Survey available lighting component technologies, conduct gap-filling R&D, demonstrate retrofit solutions, and develop best-practice retrofit guidelines. Electric lighting technology has improved dramatically in recent years with the emergence of more energy-efficient and long-lasting light sources, improved luminaire designs, advanced controls, and improved system design concepts. Even so, a survey may identify gaps that need to be filled to enable more cost-effective retrofits, such as development of low-cost wireless controls for retrofit to existing luminaires, or integration into replacement luminaires, to allow local lighting control via individual or a select group of luminaires. A project is needed to survey available lighting component technologies, fill gaps for retrofit applications with R&D, demonstrate retrofit solutions, and develop best-practice retrofit guidelines.

Problem 3.P.2: Daylighting remains an under-utilized resource for reducing lighting electricity consumption. Demonstrations designed and implemented by the nation's elite lighting systems experts have proved the energy saving benefits of daylighting, but mainstream designers and contractors remain overwhelmed and mass adoption remains allusive. Challenges include practical capture of the benefits of daylighting through dimming controls on electric lighting and control of dynamic fenestration (blinds) if any, while avoiding glare and increased cooling loads that offset the energy savings for lighting. An

additional challenge is overcoming the fact that generally no thought was given to daylighting when the vast majority of existing light commercial buildings were sited and oriented.

Action 3.P.2-A.1: Segment daylighting approaches into categories and evaluate available technologies. A wide variety of daylighting approaches exist, such as use of skylights, side-lighting, top-lighting, light re-direction and distribution, and clerestories with and without dynamic components such as blinds. It is not clear which of these strategies could be applied to a significant share of existing light commercial buildings without extensive modification of the envelope. A project is needed to identify all of the approaches, segment them into categories, and then evaluate the retrofit application potential of each category in light commercial buildings. Application potential is influenced by factors such as how much of the electric lighting reduction is offset by increased space conditioning, cost-effectiveness based on net benefits, risk to integrity of building envelope, orientation impact on effectiveness, impact on appearance of the building, and capability to capture and move daylight where needed.

Problem 3.P.2-A.2: Conduct gap-filling R&D, demonstrate retrofit solutions, and develop best-practice retrofit guidelines. Assuming Action 3.P.2-A.1 identifies daylighting technologies with significant retrofit application potential in light commercial buildings, a project is needed to conduct gap-filling R&D, demonstrate the solutions, and develop best-practice retrofit guides or other tools simple enough for typical designers and contractors in this market segment to use. The guides and tools would need to fully address dimming controls on electric lighting and control of dynamic fenestration (blinds), if any, and means of generating credible estimates of costs and annual energy cost savings.

4. Whole-Building Retro-Commissioning, Continuous Commissioning, and Controls

Target: Through development of new whole-building retro-commissioning, continuous commissioning, and controls (R-Cx/C-Cx/C) options for light commercial buildings, enable whole-building energy bills to be reduced by 30% compared with pre-improvement baselines while retrofits pay for themselves in 5 years or less.

Problem 4.P.1: Light commercial buildings are rife with unaddressed energy savings opportunities related to R-Cx/C-Cx/C. Those who pay the operating bills for light commercial buildings tend to get by with janitorial and handyman help and defer higher-skill services until they become mandatory (e.g., failure of heating systems or compressors). When energy-consuming components and systems go awry without causing blatant comfort or operational issues, they tend to remain unnoticed, wasting energy for long periods of time until the problem is finally detected. Similarly, most energy-consuming components and systems in buildings are constantly, if slowly, wearing out. If these components and systems received attention before failure, unnecessary outages and energy waste could be avoided. As a result of inattention and deferred maintenance, most existing light commercial buildings are rife with low-cost opportunities related to R-Cx/C-Cx/C that would save energy and pay for themselves quickly, if implemented. The primary opportunities involve HVAC, lighting controls, and plug load management. Generally, capitalizing on these energy saving opportunities involves tune-ups rather than retrofit or replacement of the physical building systems. Obviously, janitors and handymen are not very adept at finding the opportunities and performing the tune-ups independently, so the challenge is creating technologies and tools that would make a third party's business case feasible within the severe cost pressures of this market. Since the success of any given avenue is uncertain, a portfolio approach is taken to maximize the chances of success.

Action 4.P.1-A.1: Develop low-cost wireless sensors. Wireless sensors provide the benefit of nonintrusive, lower-cost retrofit installation. However, currently they are virtually price-prohibitive

in the light commercial building market, costing $300 to $500 per point. Wireless sensors are needed at prices that are approximately one order of magnitude less than current commercial offerings. The availability of lower-cost wireless sensors would enhance the chances of success of subsequent, related actions under Problem 4.P.1. To address the primary opportunities of HVAC, lighting controls, and plug load management, low-cost wireless sensors are needed for temperature, humidity, CO_2 concentration, lighting level, and power measurement.

Action 4.P.1-A.2: Develop a system to find tune-up opportunities based on temporarily installed wireless sensors. A project is needed to develop a wireless sensor system based on commercially available, off-the-shelf (COTS) technology, including companion software, that could be temporarily installed to discover tune-up opportunities. The system would verify the economic feasibility of the prospective tune-up actions and generate a tune-up proposal summarizing price, savings, and value for each action. The system would be able to measure temperature, humidity, CO_2 concentration, lighting level, and power. Since COTS wireless sensors are known to be too expensive for permanent installations in light commercial buildings, the vision is that a collection of sensors would be deployed temporarily and moved from location to location. For example, the business model could be a strategic alliance between janitorial and tune-up services. Cleaning crews visiting premises could be used to place sensor nodes at essentially no extra cost. The sensors would then communicate data to the tune-up service provider, who would identify tune-up opportunities and propose their implementation to building owners or tenants. Feasible measures with this approach include verifying proper (1) schedules (HVAC, lighting), (2) set points (HVAC), (3) occupancy controls (HVAC, lighting, plug load), (4) economizer controls (if any), (4) refrigerant charge, and (5) filter change and coil cleaning intervals.

Action 4.P.1-A.3: Develop a smart monitoring diagnostic system for packaged unitary HVAC systems. The primary tune-up opportunities in light commercial buildings are associated with HVAC, lighting, and plug loads. The HVAC system is the most likely to go unnoticed when it wears out or malfunctions. In light commercial buildings, packaged unitary HVAC equipment is the dominant type, and hence the highest priority for some sort of diagnostics. A project is needed to develop a smart monitoring diagnostic system (SMDS) for packaged unitary HVAC equipment. The SMDS should be based on wireless technology to allow diagnosis without intrusion into existing equipment and should be capable of identifying performance degradation and some fault detection based on a small number of measurements. The availability of an SMDS would augment the solution generated by Action 4.P.1-A.2 by moving the business model from a periodic retro-commissioning service closer to a continuous commissioning service that includes enhanced fault detection.

Action 4.P.1-A.4: Develop verification protocols and independently verify the system for finding tune-up opportunities and SMDS. The capabilities of the system for finding tune-up opportunities and SMDS emerging from Actions 4.P.1-A.2 and 4.P.1-A.4 will need to be verified before private-sector services firms can be expected to pursue businesses based on use of these technologies and tools. A project is needed that installs a variety of packaged unitary HVAC systems in parallel with one another in the light commercial building flexible research platform so their performance can be experimentally characterized on a common basis by rotating operation from one system to the next and exposing each system to a range of operating conditions. The research apparatus must have the capability to force tune-up opportunities (e.g., schedule gone awry) and performance degradation and faults (e.g., refrigerant charge loss, filter clogs) in order to test the robustness of the tune-up opportunity finder and SMDS. The verification tests should be conducted using the types of packaged unitary HVAC equipment most commonly found in existing light commercial buildings.

<u>Problem 4.P.2</u>: There is a lack of credible cost and savings data to allow contractors to promote tune-up and diagnostic services effectively. The tune-up opportunity finder and SMDS-based services emerging from actions under Problem 4.P.1 would need to be effectively promoted to be successful in the marketplace. Applying these energy savings strategies effectively would require choices (e.g., which tune-ups to perform) and/or the selection of options (e.g., SMDS or not), which would affect installed cost and annual cost savings. In addition, local labor rates and material costs affect installed cost, and utility rate structures, climate, building type, and the existing baseline systems and their operating efficiencies influence annual cost savings. A tool usable by contractors that does a credible job of estimating costs for tune-ups and/or SMDS installation and annual cost savings—quickly—does not currently exist.

> **Action 4.P.2-A.1: Develop a free Web service for estimating costs and annual cost savings of tune-up and diagnostic services.** Although essential for the Web services addressing Problems 1.P.3 and 2.P.5, energy models are less useful in this circumstance because they presume components and systems are operating as intended; of course, if this were the case, tune-ups and diagnostics would not be required. Therefore, the initial tune-up opportunity finder software referenced in Action 4.P.1-A.2 would be based on relatively practical and rudimentary approaches for estimating the costs and annual energy savings for each tune-up action. This poses the question of how credible these methods will be in the marketplace in the mid- and long-term without any data to substantiate the savings claims. To enhance the credibility and energy savings impact of these services, a project is needed that will establish a Web service that participating services firms can use to enhance customer satisfaction and their industry's credibility. The participating firms would feed into the Web service (1) basic building characteristics, (2) the tune-ups implemented, and (3) modest amounts of measured interval data taken on the building during periods before and after the tune-up. The Web service would apply a suite of machine learning tools to the interval data and generate before/after energy consumption and peak demand prediction algorithms to establish annual energy savings and peak load reduction. Over time, the national database would grow and provide the basis for improved estimates of annual cost savings, which could be accessed through the tune-up opportunity finder software.

5. Building Energy Modeling (BEM), Building Information Modeling (BIM), Data Visualization, and Analytics

<u>Target</u>: Through development of new tools based on BEM, BIM, data visualization, and analytics, enable (1) accelerated emergence of better energy efficiency improvement options for light commercial buildings, and (2) a 50% reduction in the transaction costs associated with developing credible energy efficiency improvement projects for light commercial buildings.

<u>Problem 5.P.1</u>: Lack of timely information delays the emergence of energy efficiency improvement options for light commercial buildings. The light commercial building energy efficiency industry is fragmented, with many different stakeholders. The greatest technical capabilities reside with the supply side of the industry—those who manufacture materials or components used to improve the energy efficiency of existing buildings. Theoretically, suppliers are capable of producing better products for integration by contractors into energy efficiency improvement projects. In reality, though, the multitude of suppliers are typically focused on gaining a maximum share in mainstream markets such as failure-driven replacements, planned renewal, or new construction, whether or not increasing energy efficiency is involved. With access to better information, suppliers who want to be leaders would invest in development of more energy-efficient products to gain a competitive edge. On the demand side, BTP has already built alliances of potential customers with strong purchasing power, but these customers need access to better information so they can justify pledging future purchases based on credible estimates of annual energy cost savings over time. Through the use of computational science, it is possible to make the

markets more efficient by providing suppliers and customers with better information to support their investment or pledge decisions, which would lead to actual orders and product shipments. There are similar information-related delays, inefficiencies, and added costs that computational science can help remove from the R&D processes leading to improved products and the processes for managing information on buildings over their life cycles. The sequence of interrelated actions described below systematically develops the capability to overcome these information failures and enable the accelerated emergence of options for improving energy efficiency in light commercial buildings.

Action 5.P.1-A.1: Develop the capability for autonomous data correction. National laboratories, universities, industry, customers, utilities, and consultants all over the country are generating sensor data streams over time from laboratory apparatus, test beds, field tests, and smart meters that would be valuable for auto-tuning building energy models. However, sensors and data acquisition systems fail periodically, and data quality control across these diverse data sources varies widely. A project is needed to develop a generalized methodology for evaluating and automatically correcting interval data in a scientifically defensible and repeatable manner. The methodology would utilize a suite of advanced signal processing, statistical, and machine learning algorithms, callable by individuals or third-party software. The evaluation of sensor data would include outlier detection and autonomous correction as a function of all other variable values from previous times. The capability would be packaged in the form of an easy-to-use tool.

Action 5.P.1-A.2: Develop the capability to auto-tune building energy models using measured data. Energy models are essential for resolving information failures. But models alone are known to be unreliable; calibrating, or tuning, them to measured data greatly enhances the credibility of their predictions. The process of tuning models has remained costly because it requires significant manual effort by skilled staff, and the results remain imperfect and nonrepeatable. A project is needed to develop a generalized building energy model auto-tuning methodology that enables models to reproduce measured data optimally, by selecting the best-match parameter inputs in an automated and repeatable fashion. The general methodology must also identify the minimum number of measurements and the quantities to be measured to achieve various confidence levels in the modeled results. The capability would be packaged in the form of an easy-to-use tool that integrates the autonomous data correction solution from Action 5.P.1-A.1. The following hypothetical case demonstrates how tuned energy models could resolve information-related market failures in a timely manner: An OEM can provide measured performance data for a few steady-state operating conditions on a new RTU design believed to satisfy the RTU Challenge, and a big box retailer has an EnergyPlus model for its standard store design and measured data on a standard store constructed two years earlier. The auto-tuner uses (1) the measured data to calibrate the EnergyPlus model of the standard store, and (2) the OEM data to tune the EnergyPlus RTU component model. Through use of the tuned models the big box retailer can determine whether swapping existing RTUs for this OEM's "max tech" RTUs is a sound investment; and the OEM gains understanding of how customers will value "max tech" RTUs and of the price points required for success in the market.

Action 5.P.1-A.3: Develop the capability to estimate normalized building energy savings from limited sensor data in an automated fashion. For many energy efficiency improvements, auto-tuned energy models could provide a credible means of estimating energy consumption and peak demand savings. Baseline (pre-improvement) time-interval data from the building would be used to auto-tune the baseline building energy model, implementing the improvement in the model would create the post-improvement building energy model, and the difference between energy consumption and peak demand outputted by the two models would establish the savings. However, physical building energy models assume that components and systems are operating as intended; so if the improvement action taken involves restoring components and systems to their intended operation (e.g., a tune-up), some other means to estimate savings is required. There are existing weather

normalization protocols such as ASHRAE Guideline 14. However, they require significant automation to be cost-effective in practical application, and benchmarking experience indicates that factors beyond weather need to be considered in multi-factorial normalization. A project is needed to develop a methodology for generating best-fit statistical models directly from sensor data through the application of machine learning techniques in order to develop normalized energy savings between pre- and post-tune-up scenarios. These statistical models, which would take weather data and other measurements as inputs, would then be able to predict building energy consumption and peak demand. The general methodology must identify the tradeoffs between machine learning algorithms, algorithm parameters, and instrumentation required (i.e., measurements to take in addition to outdoor temperature and energy consumption, and required measurement frequency) to achieve various confidence levels in the results estimated by the statistical models. The capability would be packaged in the form of an easy-to-use tool integrating the autonomous data correction solution from Action 5.P.1-A.1. The tool could then be used to (1) process pre-tune-up time-interval data into a statistical model for estimating the building's baseline energy consumption and peak demand, (2) process post-tune-up time-interval data into a second statistical model for estimating post-tune-up energy consumption and peak demand, and (3) estimate tune-up energy consumption and peak demand savings by taking the multi-factorial normalized difference between the results output by the two statistical models. This tool would be combined into the free Web diagnostic and savings tool described in Action 4.P.2-A.1.

Action 5.P.1-A.4: Develop a Web-based visualization and analytics portal to support virtual technology development organizations. National laboratories have many Cooperative Research and Development Agreements (CRADAs) with industry to accelerate the emergence of new building energy efficiency products, and universities have similar collaborative R&D vehicles. The collaborative process is faster and more cost-effective when industry partners have real-time visualization of ongoing experiments and the capability of viewing and analyzing historic data. A project is needed to develop a permissions-based Web portal that can effectively store instrumentation data in a public database format in real time, provide several mechanisms for visualizing and inspecting multiple sensor readings, and export historic data from customizable time ranges to user-selected software (e.g., Excel) for analysis by users. The portal incorporates autonomous data correction (Action 5.P.1-A.1), energy model auto-tuning (Action 5.P.1-A.2), and building energy use prediction from data (Action 5.P.1-A.3).

Action 5.P.1-A.5: Demonstrate cost reduction in the process of improving the energy efficiency of existing light commercial buildings through interoperability of BIM and traditional software. Software interoperability enhances labor productivity and reduces costs. Because of the severe cost pressures in the light commercial market, this segment is as likely to embrace new ways to achieve cost reduction as any. A project is needed to explore how cost reduction can be achieved through improved software interoperability between BIM and traditional software used in the design and cost estimation of retrofit projects (e.g., space conditioning load calculation, HVAC distribution system design, HVAC equipment selection, cost estimation, energy consumption estimation). For example, how can BIM functionalities such as using photographic images taken from several directions to create "as-built" drawings be leveraged to reduce the cost of conducting a walkthrough audit to verify inputs provided to an energy model? The project would generate unbiased, authoritative, and documented case studies, in the context of real building processes, explaining the best way to use available software tools in each developmental stage of an energy efficiency retrofit project.

<u>Problem 5.P.2</u>: Contractors lack the tools they need to cost-effectively develop, promote, and implement energy efficiency improvement projects. States such as California and municipalities such as New York City are beginning to pass legislation (CA AB 758 and AB 1103; NYC Local Law 85) that

may dramatically increase the need for certified auditors and implementation contractors skilled in the use of energy assessment tools that can identify cost-effective energy efficiency improvements, prioritize those improvements, and provide a credible estimate of payback period or cost-effectiveness of each one. From a technical standpoint, to fulfill these requirements, the energy assessment tool must be based on energy modeling, which is widely regarded as cost-prohibitive in the light commercial building market. This conundrum can be resolved by extending the application of computational science begun under Problem 5.P.1. The result would be a free, easy-to-use, public domain Web service that would postulate initial input files for energy models of specific existing light commercial buildings, identify the minimum number of measurements required to achieve desired confidence levels in modeled results, automatically collect supporting input files (e.g., weather data if no weather station nearby), and auto-tune the models. Auditors and contractors accessing the service could conduct a walkthrough audit to verify basic assumptions in the initial model input file and arrange capture of the time-interval data required for auto-tuning (e.g., temporarily install wireless sensors and communicate additional data through the existing smart meter, building automation system, or a temporary data logger). The user then could feed the time-interval data and updated energy model inputs to the Web service, which would auto-tune the energy model. Through the easy-to-use Web service, auditors and contractors would have free access to everything they need to cost-effectively develop, promote, and implement energy efficiency improvement projects in light commercial buildings. For ease of use, auditors and contractors specializing in different improvements (envelope retrofits, equipment retrofits, tune-ups) could use separate interfaces to the Web service customized to their needs (i.e., speaking their language). However, there would also be a whole-building interface, and all interfaces would lead to the same computational engine.

Action 5.P.2-A.1: Develop a Web service engine for estimating all-fuels hourly energy consumption and annual energy cost. A project is needed to develop a computational engine for estimating all-fuels hourly energy consumption, which would provide the necessary data for consumption and peak demand for realistic application of any utility rate structure to derive annual energy cost. The engine would be based on a whole-building simulator (e.g., EnergyPlus, DOE-2) and contain initial input files for energy models of each of the 18 building types represented in the set of DOE benchmark existing buildings, as well as full-year long-term average weather data for every location available. The engine would run all user-provided time-interval data through autonomous data correction (Action 5.P.1-A.1), and the cleaned data would be used for the energy model auto-tuning (Action 5.P.1-A.2). Then the engine would source all necessary weather data for the specific building location and user-provided data time-periods from an available weather data service. If the user-provided data included some of the weather data needed by the whole-building simulator (e.g., outdoor temperature), the auto-tuning methodology would use this additional information to improve the estimated weather file obtained from the weather data service. In cases in which the user provided all of the weather data needed by the whole-building simulator, it would be used directly. After the energy model was tuned to baseline data, the annual simulations used for evaluating energy efficiency improvements would be based on the long-term average historic weather data. The engine would include several options for applying utility rates to estimate annual energy cost from all-fuels hourly energy consumption. Average blended utility rates (consumption and demand charges combined and expressed as a cost per unit consumption) would be included in the engine at the finest regional granularity available, but users would also be able to input the building's specific utility rate structure.

Action 5.P.2-A.2: Develop the GUI and integrate the free Web service for estimating installed costs and annual cost savings for envelope retrofits. A project is needed to develop an appropriate graphical user interface (GUI) and wrap it around the auto-tuned model performance prediction engine (see Action 5.P.2-A.1) and cost engine (see Action 1.P.3-A.1) to create a Web service for estimating envelope retrofit installed costs and annual cost savings (see Action 1.P.3-A.1). For clarity, the hygrothermal model (WUFI) for verifying that a contemplated envelope retrofit would

cause no moisture-related harm is not integrated with the whole-building simulator (e.g., EnergyPlus, DOE-2). Rather, the GUI would provide the necessary inputs so that a standalone WUFI run could verify the moisture management efficacy of the contemplated envelope retrofit. If the retrofit passed the WUFI test, the whole-building simulator (e.g., EnergyPlus, DOE-2) would be used to evaluate the performance of the retrofit.

Action 5.P.2-A.3: Develop the GUI and integrate the free Web service for estimating installed costs and annual cost savings for equipment and system retrofits. A project is needed to develop an appropriate GUI and wrap it around the auto-tuned model performance prediction engine (see Action 5.P.2-A.1) and cost engine (see Action 2.P.5-A.1) to create a Web service for estimating installed costs and annual cost savings for equipment and system retrofits (see Action 2.P.5-A.1). For clarity, the improved detailed component and system models coming out of the actions under 2.P.1, 2.P.2, 2.P.3, and 2.P.4 would be integrated directly into the whole-building simulator (e.g., EnergyPlus, DOE-2).

Action 5.P.2-A.3: Develop the GUI and integrate the free Web service for estimating costs and annual cost savings for tune-up and diagnostic services. A project is needed to develop an appropriate GUI and wrap it around the engines for autonomous data correction (see Action 5.P.1-A), building energy use prediction from data (Action 5.P.1-A.3), and cost and savings (see Action 4.P.2-A.1) to create a Web service for estimating tune-up and diagnostic services costs and annual cost savings (see Action 4.P.2-A.1). For clarity, the cost and savings engine would not be useful until a database of data from past projects voluntarily contributed by tune-up and diagnostic service providers reached critical mass.

Action 5.P.2-A.4: Develop the GUI and integrate the free Web service for utilities to streamline implementation of their energy efficiency programs. A project is needed to develop an appropriate GUI and wrap it around internal utility data sources such as billing data, the engines for auto-tuned model performance prediction (see Action 5.P.2-A.1), and tune-up and diagnostic services cost and annual cost savings prediction (see Action 5.P.2-A.3). Such an application would enable utilities to visualize and understand the massive amounts of light commercial building energy consumption data they have, and to analyze this data to evaluate scenarios for satisfying their customers' future building energy services needs while minimizing utility investments to do so. The Web portal and computational framework could also include granularity to the level of individual utility revenue meters, or multi-data-channel smart meters where they exist, so that light commercial building consumers could use the portal to benchmark themselves against their peers and be motivated to reduce their building energy costs, peak demand, and consumption. The portal and computational framework could be used to implement innovative light commercial building energy efficiency programs. For example, utilities could provide free or very attractively priced tune-ups for all customers and require implementation contractors to seed actual project cost and savings data into the Web service database, so that the application for estimating tune-up and diagnostic services costs and annual cost savings (see Actions 4.P.2-A.1 and 5.P.2-A.3) would become functional. Light commercial building customers completing tune-ups could then qualify to receive free auto-tuned energy models for their buildings, along with a list of qualified energy auditors and implementation contractors who know how to use the tuned model and the rest of the Web service to identify additional cost-effective energy efficiency improvements, prioritize those improvements, provide a credible estimate of payback period or cost-effectiveness for each one, educate customers on available incentives, and implement the customer-selected measures.

Coordinated Deployment Activities for Ready-for-Market Technologies

Deployment of energy efficiency technologies into buildings is a very broad endeavor with significant related activities already under way. For example, in 2009, states and utilities spent approximately $5.3 billion on electric energy and gas efficiency programs, not including weatherization assistance programs, state/local government spending on public buildings, or any federal funds (ARRA, etc.) directed to state energy offices (M. Nevius, R. Eldridge, and J. Krouk, 2010, "The State of the Efficiency Program Industry: Budgets, Expenditures, and Impacts 2009," Consortium for Energy Efficiency). In round numbers, then, about $6 billion is being spent annually.

The DOE BTP annual budget is about $200 million in a good year, or about 3% of existing deployment spending; hence, significant BTP spending on deployment would be "in the noise" and disingenuous. However, since BTP is the only federal program sponsoring applied collaborative R&D with industry to accelerate the launch of improved building energy efficiency technology options, a BTP programmatic focus on helping emerging technologies cross the "valley of death" and achieve sufficient annual shipments to be affordable (volume begets affordability) has merit. Then through use of its regulatory authority, BTP is in a position to help the emerging technologies unseat older, less efficient technologies in mainstream markets.

Realistically, even a BTP programmatic focus on escorting emerging technologies to shipment volumes that can sustain affordability would necessarily be modestly funded and would require partnering and leverage from other programs with mutual interests. Consequently, as an initial step, this roadmap simply describes what BTP is already doing and identifies known programs with which BTP may want to establish programmatic connections in order to further its goals.

BTP has already formed several Commercial Building Energy Alliances (CBEAs) —: the REA, Hospital Energy Alliance, and Commercial Real Estate Energy Alliance. For one equipment category—RTUs—BTP has built a collaboration of potential customers with strong purchasing power through the REA. A challenge has been issued to the HVAC industry to build products that meet new specifications for high-performance RTUs by offering the potential of immediate sales through pledges by major REA members. BTP also supports verification that specifications have been satisfied and provides opportunities for industry to enter into CRADA collaborations to accelerate product improvements. BTP could repeat these actions (specification writing, CBEA pledge coordination, specification verification, CRADA collaboration) for additional equipment categories.

BTP also sponsors the competitively selected Greater Philadelphia Innovation Cluster for Energy Efficient Buildings (GPIC/HUB). This program has a strategic focus on retrofitting light commercial buildings with speed and scale in a ten-county region. The specific geographic focus and significant funding enables the program to drill down vertically and comprehensively address all barriers to deep-savings retrofits simultaneously, including research, development, demonstration, deployment, policy, business models, financing, and work force development programs. With such a focus, industry needs only to train a small portion of its distribution channel, lowering the cost to effectively put emerging technologies into the field for the first time.

The DOE Federal Energy Management Program (FEMP) has experience promoting use of newly emerging or proven but under-used energy efficiency technologies. In a nutshell, FEMP's mission is to help all US federal agencies meet their mandates to reduce nonrenewable energy use in federally owned buildings. In the late 1990s, FEMP implemented a worldwide geothermal (ground-source) heat pump Super ESPC (energy savings performance contract) procurement. This step ensured that every federal site worldwide would have access to several quality sources for development, financing, and implementation of GHP projects. Since every project implemented under these umbrella contracts was required to include

GHPs, these energy service companies (ESCOs) were highly motivated to find agency sites where pay-from-savings GHP projects were feasible. GHP shipments to the federal market increased more than ten-fold from FY 1999 to FY 2001. The indefinite-delivery, indefinite-quantity (IDIQ) contract form was used for this procurement. One could envision, for example, implementing an IDIQ procurement under which agencies could bundle into one delivery order under the umbrella IDIQ the purchase of RTUs at RTU Challenge efficiency levels for mass replacement of old RTUs at multiple sites.

The Department of Defense (DoD) Environmental Security and Technology Certification Program uses military installations as a test bed to demonstrate and create a market for emerging building energy efficiency technologies. The military has 150 years of experience as a sophisticated first user of new technology and an early, market-creating customer (jet engines, aircraft, integrated circuits, GPS, internet) and is well positioned to assist. DoD owns approximately 70% of all federally owned building floor space, and its energy bill for its facilities is about $4 billion annually. The technologies emerging from BTP's industry partners could feed into this program.

BTP could form a partnership with the nation's utility ratepayer-funded building energy efficiency deployment programs. The nationwide administrators of such programs can be reached through existing organizations such as the Consortium for Energy Efficiency. Deploying newly emerging technologies with system benefit funds can be a challenge because such technologies are generally more expensive in the early years, and energy efficiency and demand response programs are not allowed unless they satisfy specific cost-benefit tests, which may vary by regulatory jurisdiction. Nonetheless, some public utility commissions might be open to including modest programs focused on emerging technologies within the portfolio.

Another approach might be to form a partnership with the nation's ESCOs specialized in building energy efficiency deployment in non-federal markets. The nationwide ESCO industry can be reached through the National Association of Energy Service Companies, the Energy Services Coalition (ESC), and the ESC state chapters. Deploying newly emerging technologies with the ESCO pay-from-savings business model can be a challenge because such technologies are generally more expensive in the early years. FEMP was able to make it work for GHPs with very large projects. Buying down interest rates and other means could also be used to make pay-from-savings projects, which bundle in emerging technologies, feasible.

APPENDIX D. FLEXIBLE RESEARCH PLATFORM INDUSTRY SUPPORT LETTERS

List of Industry Partners for R&D Associated with the First Test Buildings on ORNL's Light Commercial Building Flexible Research Platforms

(Alphabetical Order)

1. Autodesk Inc.
2. Bentley Systems, Inc.
3. Carrier Corporation
4. DesignBuilder Software Ltd
5. EIFS Industry Members Association (EIMA)
6. Foam Sheathing Coalition (FSC)
7. General Electric Global Research
8. Greater Philadelphia Innovation Cluster for Energy Efficient Buildings (GPIC/HUB)
9. Johnson Controls, Inc.
10. Metal Building Manufacturers Association (MBMA)
11. NORDYNE Corporation
12. Samsung Electronics
13. Schneider Electric
14. Single Ply Roofing industry (SPRI)
15. Southwest Gas Corporation
16. SynapSense
17. United Technologies Research Center (UTRC)

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Canada

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www.autodesk.com

PHONE 416-362-9181
FAX 416-369-6150

27 June 2011

Mr. Patrick Hughes
Director - Building Technologies Research & Integration Center
Oak Ridge National Laboratory
P.O. Box 2008 MS6070
Oak Ridge, TN 37831-6070

SUBJECT: Collaborative Research Using ORNL's Flexible Research Platforms

Dear Patrick:

Autodesk is committed to collaborating with Oak Ridge National Laboratory (ORNL) in applied R&D work using the MAXLAB light commercial building flexible research platforms (FRPs) currently being established at ORNL.

This collaborative research project will have two primary components: simulation calibration using real-time weather data, and real-time building sensor network monitoring in the FRP building. We will contribute to the project in-kind with an ADN (Autodesk Developer Network) subscription, providing access to all Autodesk products and development support materials. We will also contribute in-kind, prototype building monitoring software and engineering staff time to customize the software and Building Information Model to the FRP site. This in-kind contribution would be valued at $100,000 and will benefit Autodesk by being an integral part of the FRP project which, we believe, is a critical part of sustainability.

We feel the FRPs will enable us to conduct research and address issues that no other research facility in the world can address, at least that we are aware of, and we are very excited about the prospect of working with ORNL to develop a research plan to improve our products so they can be used to reduce energy use in buildings.

Sincerely,

Azam Khan
Senior Research Scientist
Head of the Environment & Ergonomics Research Group
Autodesk Research

Autodesk®

August 26, 2011

Mr. Patrick Hughes
Director, Building Technologies Research & Integration Center
Oak Ridge National Laboratory
P.O. Box 2008, MS–6070
Oak Ridge, TN 37831–6070
Sent Via Email: hughespj1@ornl.gov

SUBJECT: Collaborative Research Using ORNL's Flexible Research Platforms

Dear Patrick:

Bentley Systems, Inc. is committed to collaborating with Oak Ridge National Laboratory (ORNL) in applied R&D work using the MAXLAB light commercial building flexible research platforms (FRPs) currently being established at ORNL.

Our team will focus and support acceptance and utilization of the existing Enterprise Software and LEARN Subscription available at ORNL. Bentley will provide subject matter experts for consulting services, commercial training, and commercial software solutions to enable BIM data models and best practices for Energy Performance Modeling Simulation and Reporting.

- Bentley will provide in-kind services and travel costs to enable BIM data models and best practices for Energy Performance Modeling Simulation and Reporting with research teams through the BTRIC.
- Bentley will provide in-kind services and travel costs to assist in writing annual reports.
- Bentley will provide in-kind services and travel costs to jointly publish a building energy efficiency whitepaper with DOE.
- Bentley will provide in-kind services and travel costs to participate in joint annual meetings domestically.

The value of our cost-share is $ 100,000.00.

We feel the FRPs will enable us to conduct research and address issues that no other research facility in the world can address, at least that we are aware of, and we are very excited about the prospect of working with ORNL to develop a research plan to improve our products so they can be used to reduce energy use in buildings.

Sincerely,

Steve Sims

Steve Sims
Bentley Systems, Inc.
DOE – Federal Account Manager

Dru Crawley

Dru Crawley
Bentley Systems, Inc.
Director, Building Performance Products

Carrier Corporation
Carrier Parkway
P.O. Box 4808
Syracuse, NY 13221

Carrier
A United Technologies Company

September 30, 2011

Mr. Edward A. Vineyard
Group Leader, Building Equipment Research
Energy & Transportation Science Division
Oak Ridge National Laboratory
One Bethel Valley Road
P.O. Box 2008, MS 6070
Oak Ridge, Tennessee 37831-6070

Dear Ed,

Carrier Corporation, a subsidiary of United Technologies Corporation, is one of the industry leaders in introducing innovative, highly energy efficient space conditioning systems into the commercial mass market. We intend to maintain our leadership role in this regard, and thus are very interested in participating with Oak Ridge National Laboratory (ORNL) in efforts to reduce energy consumption and reduce the peak load of utilities through various improvements. This work is part of Carrier's and UTC's broader initiatives to demonstrate our leadership role and desire to help the nation reduce its energy and carbon footprint by commercializing market-transforming technologies at affordable prices.

Carrier's interest is saleable products for the HVAC residential and commercial market as it exists today, as well as the future. In particular, we are interested in developing and commercializing space conditioning systems that are ultra efficient and cost effective. We will be evaluating the market and refining our product strategy simultaneously within the cooperative proposed work.

Opportunities to reduce electric peak demand while increasing energy efficiency and holding the line on costs are rare, which is why we are pursuing this with vigor in the form of both resources and investment dollars. Carrier has expended considerable resources to develop advanced equipment designs and plans to continue efforts in the future.

Carrier would be pleased to partner with ORNL on the Flexible Research Platforms to develop advanced equipment designs that would reduce energy consumption by up to 50%. As part of this effort, Carrier would be willing to provide equipment for testing as well as making a contribution to install the equipment. In addition, Carrier would make in-kind contributions in the form of participation on a Steering Committee for the Flexible Research Platforms. UTC's research arm (UTRC) may also be interested in participating on the Steering Committee. The details of the participation will be refined at a future date as the platforms are constructed and as the demonstration proceeds. We look forward to a partnership that will benefit Carrier, the U.S. Department of Energy, ORNL, and the nation.

Both Carrier and UTRC will be involved from our side. Below is the contact information for Ricardo Munoz at UTRC and me.

Robert Whitwell, Mgr RCS Cml and DFS/VRF Engineering
Carrier Corporation
PO Box 4808 Syracuse, NY 13221
Phone: 315 432-6825
Email: Robert.whitwell@carrier.utc.com

J. Ricardo Muñoz, Director Carrier Programs
United Technologies Research Center
411 Silver Lane, MS 129-78
East Hartford, CT 06108
Phone: 860-610-7785
Email: MunozJR@utrc.utc.com

Regards,

Bob Whitwell

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tel: +44 1453 755500
fax: +44 1453 750507
email: sales@designbuilder.co.uk

Joshua New, Ph.D.
Energy & Transportation Science Division
Oak Ridge National Laboratory
One Bethel Valley Road
P.O. Box 2008, MS-6070
Oak Ridge, TN 37831-6070
865-241-8783 (office)
865-574-9354 (fax)

Re: Flexible Research Platforms R&D project

Dear Joshua,

DesignBuilder Software Ltd aims to bring advanced building modeling into the mainstream by providing tools that are easy to use and highly accessible both in terms of initial cost and in the time taken to learn them. We are particularly keen to encourage the uptake of environmentally responsible design techniques. Our flagship product DesignBuilder, which uses DOE's EnergyPlus simulation engine, can provide information on building energy consumption, CO2 emissions, occupant comfort and helps in designing energy efficient buildings.

Following discussiuons with Mahabir Bhandari and other ORNL staff, DesignBuilder Software Ltd would be pleased to partner with ORNL on the Flexible Research Platforms (FRP) *to* demonstrate practical means to utilize BIM and building energy modeling software to foster energy efficiency in light commercial buildings. As part of this effort, DesignBuilder Software Ltd would be willing to provide 5-10 software licenses. DesignBuilder would also provide advice on BIM/thermal modelling to our ORNL counterparts and incorporate any findings from the project into DesignBuilder as appropriate. We would also like to collaborate on the development of research papers relevant to BIM and energy modelling. We look forward to a partnership that will benefit DesignBuilder Software, Ltd, ORNL and building industry in general, including the building energy modeling community.

Your Sincerely,

A. Tindale

Dr Andy Tindale

Director
DesignBuilder Software Ltd

EIMA

EIFS INDUSTRY
MEMBERS
ASSOCIATION

May 9, 2011

Mr. Andre O. Desjarlais
Group Leader, Building Envelope
Engineering Science & Technology Division
One Bethel Valley Road
P.O. Box 2008, MS-6070
Oak Ridge, Tennessee 37831-6070

Dear Mr. Desjarlais:

On behalf of the EIFS Industry Members Association's Board of Directors, I thank you for taking the time from your schedule to attend the EIMA 2011 Annual Meeting on April 5th and 6th in Las Vegas. Your participation at both the General Session on April 5th and the Board Meeting on April 6th greatly enhanced the EIMA Annual Meeting. We sincerely hope you enjoyed attending as much as we enjoyed having you as our guest.

Your presentation on the industry collaboration opportunity was warmly received and spurred the EIMA Board to approve a motion to accept your invitation to participate in a demonstration on one of the two research platforms that are now being developed at the Oak Ridge National Laboratory (ORNL) by the Building Envelope Group. In general, such a demonstration that EIMA envisions, and as generally outlined by you, would entail the initial development of a structure based on previous building codes and earlier building technologies. Following an adequate benchmarking period in which the performance of the platform/structure was ascertained, that structure would then be retrofitted with a more energy efficient building envelope that is comprised of Exterior Insulation and Finish Systems (EIFS).

EIMA participation would include furnishing the materials to retrofit the exterior of the research platform as well as making a significant contribution to the application of those materials. Further, EIMA would make available significant in-kind contribution including the participation of EIMA's Technical and Research Committee to participate in the monitoring of the demonstration and to comment on the results of the demonstration. Of course, the details of the participation for both EIMA and ORNL could be refined at a future date and be altered as the demonstration proceeds forward.

In closing, EIMA thanks you again for attending the 2011 Annual Meeting and for extending the invitation to EIMA to work cooperatively once again with the Oak Ridge National Laboratory. EIMA looks forward to a most productive demonstration.

Sincerely,

David A. Johnston

David A. Johnston, CEP
Executive Director/CEO

www.EIMA.com
513 West Broad Street
Suite 210
Falls Church, VA 22046-3257
Tel 703-538-1616
Toll Free 800-294-3462
Fax 703-538-1736

Foam Sheathing Coalition

FSC – Sharing Leading-Edge Technology

July 11, 2011

Mr. Patrick Hughes
Director - Building Technologies Research & Integration Center
Oak Ridge National Laboratory
P.O. Box 2008 MS6070
Oak Ridge, TN 37831-6070
Sent Via Email: hughespj1@ornl.gov

SUBJECT: Collaborative Research Using ORNL's Flexible Research Platforms

Dear Patrick:

It was a pleasure meeting you January 5, 2011 at the American Chemistry Council meeting with DOE, and thank you for hosting my visit to Oak Ridge National Laboratory (ORNL) on March 7. The Foam Sheathing Coalition is committed to collaborating with ORNL in applied R&D work using the MAXLAB light commercial building flexible research platforms (FRPs) currently being established at ORNL.

As we discussed the Foam Sheathing Coalition (FSC) was created to provide a technical research and code development function for the foam sheathing industry. The main goal of FSC is to ensure appropriate (safe, cost-effective and code compliant) use of foam sheathing products in future building and energy codes. Toward that end, the FSC has conducted research and developed expertise in areas that should be helpful in our collaborations with ORNL.

Recent U.S. model building/energy code changes are driving increased use of thicker continuous insulation foam sheathing to achieve advanced energy code compliance. These changes are being driven by the national policy to improve energy efficiency of both renovated and new building construction. The application of continuous insulation over existing building facades and in design of new construction to help meet energy efficiency improvements has created debates around various connection issues when increased thicknesses of foam insulation are used as one of the more cost effective solutions. There is therefore an immediate need to examine the structural performance of the connection systems required to accommodate thicker, energy efficient wall systems attached to various structural framing elements.

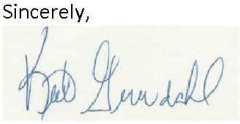
6300 Enterprise Lane, Madison WI 53719
FSC Administrative Support • 608-310-6719 or 608-310-6710
FSC Technical Support Phone Numbers • 410-867-9617 or 608-358-0766
Info@foamsheathing.org • www.foamsheathing.org

Of particular interest is research and development work with respect to the attachment of foam sheathing and cladding materials (various cladding types and installations such as use of furring strips) over various thicknesses of foam sheathing, and then effectively attaching the thicker and higher energy efficient system to a variety of structural framing members. Connectors and any related components/systems must support the weight of the cladding and secure the cladding to the wall to resist wind and seismic forces. Validity and the need for R&D with respect to a wider variety of attachment approaches has been confirmed through testing conducted for the Foam Sheathing Coalition, the Steel Framing Alliance and the New York State Energy Research and Development Authority (NYSERDA). Properly connected thick foam systems are a very effective means of meeting or exceeding green building rating requirements such as LEED, Green Globes, Energy Star, and the ICC 700 National Green Building Standard.

The ORNL/FSC collaborative research program will focus on affordable and reliable thick insulation connection systems to enable deep energy savings wall retrofits. The Foam Sheathing Coalition will provide in-kind effort to participate in development of research plans to identify and evaluate connection systems, the design of one or more thick insulation retrofits to test connection systems, and will underwrite the cost of a complete thick insulation retrofit for the two-story FRP. This in-kind and bricks and mortar contribution would be valued at $100,000. This work will benefit Coalition members and building owners by expanding the number of code complying thick foam applications and reduce "anti-foam use" points of view based on hearsay or misinformation.

We feel the FRPs could enable us to conduct research and address issues and we are very excited about the prospect of collaborating with ORNL to develop a detailed research program and demonstrate thick insulation system performance so foam insulation can be used to reduce energy use in buildings to the greatest economic extent possible.

Sincerely,



Kirk Grundahl, P.E.
FSC Management Consultant

GE
Global Research

Brent Brunell
Technology Leader
Controls, Electronics & Signal Processing

One Research Circle
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USA

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F 518 387 5164
brunellbr@ge.com

July 19, 2011

Mr. Patrick Hughes
Director, Building Technologies and Research Integration Center,
Oak Ridge National Laboratory,
1 Bethel Valley Road, MS-6070,
Oak Ridge, TN 37831.

Subject: General Electric (GE) Letter of Support for Energy Management, Sensors and Controls Research on Flexible Research Platforms

The GE Global Research is one of the world's most diversified industrial research labs, providing innovative technologies to all of GE's businesses. We are pleased to support the Energy Management, Sensors and Controls (EMCS) research on Flexible Research Platforms (FRP) at Oak Ridge National Laboratory (ORNL) in efforts to make existing and new buildings energy efficient using advanced control solutions. Intelligent building controls also provide the utilities with the ability to reduce peak electricity consumption.

GE, through its business units, owns significant amount of real estate and is constantly in search of innovative concepts that could significantly improve the state-of-the-art in energy efficient building controls. We are currently investigating intelligent control strategies that use data from the building's sensors for improving energy efficiency. GE could use the FRPs to validate the algorithms and evaluate the performance of the prototypic controllers. GE could support the program via our capabilities in and knowledge of advanced building control algorithms and building automation systems. GE would make in-kind contributions in the form of participation on a Steering Committee for the FRP, industry guidance, and review meetings. As part of this effort, GE would be willing to provide prototypic equipment for testing. The details of the participation will be refined at a future date, as the platforms are constructed and as the initial demonstration of EMCS proceeds. Once the FRPs are in place and instrumented, GE is interested in pursuing potential partnerships with ORNL. We look forward to a partnership that will benefit GE, the U.S. Department of Energy, ORNL, and the nation.

This Letter of Support is provided as evidence of our commitment to supporting this program. Thank you for your consideration, and please direct any inquiries concerning technical matters to Dhiraj Arora, arora@research.ge.com.

Sincerely,

Brent J. Brunell, Technology Leader
Controls, Electronics & Signal Processing

PENNSTATE

Phone: (814) 865-6394
Fax: (814) 863-4789

Department of Architectural Engineering

104 Engineering Unit A
The Pennsylvania State University
University Park, PA 16802-1417

July 29, 2011

Mr. Patrick Hughes
Director - Building Technologies Research & Integration Center
Oak Ridge National Laboratory
P.O. Box 2008 MS6070
Oak Ridge, TN 37831-6070
Sent Via Email: hughespj1@ornl.gov

SUBJECT: Collaborative Research Using ORNL's Flexible Research Platforms

Dear Patrick:

The Greater Philadelphia Innovation Cluster for Energy Efficient Buildings (hereafter GPIC/HUB) is committed to collaborating with Oak Ridge National Laboratory (ORNL) in applied R&D work using the MAXLAB light commercial building flexible research platforms (FRPs) currently being established at ORNL. The Two Story Flexible Research Platform project is central to our building database repository as well as the Hub predictive, design model efforts and building property - load and energy characterization relationships we are trying to establish for the design community. The data and simulations will become "references" for subsequent characterization and modeling efforts.

Either via the Opportunity Research Fund (ORF) RFP process or Collaborative Project Funding, the GPIC/HUB has selected for funding a collaboration between one of our members, Bayer Material Science LLC, and ORNL to define a wall system that is typical for existing light commercial buildings in the 10-county GPIC/HUB region in sufficient detail to support its erection, and to provide the materials and erect the wall system on ORNL's two-story light commercial flexible research platform (FRP). These "existing" walls will then serve as the baseline for R&D to develop one or more wall retrofit solutions that are cost-effective, provide deep energy savings, and will become available for wide scale deployment in the GPIC/HUB region within two to three years. The goal of this collaborative arrangement is to ensure that the first wall retrofit solutions generated by ORNL and its industry partners are suitable for deployment in the GPIC/HUB region. The funding allocated for this project is $185,501 from GPIC/HUB and $11,375 from Bayer, for a total of $196,878. On this $140,000 will be available to ORNL for brick, mortar and erection.

We feel the FRPs will enable us to participate in research and address issues that no other research facility in the world can address, at least that we are aware of, and we are very excited about the prospect of working with ORNL on this initial collaborative engagement. Furthermore, we already foresee additional collaborative opportunities to reduce energy use in light commercial buildings.

Sincerely

Jim Freihaut

Jim Freihaut, Ph.D.
Director of Technology Development, DOE Energy Efficient Buildings HUB
104 Engineering Unit A
Department of Architectural Engineering
Pennsylvania State University
Tel: 814-863-0083
jdf11@psu.edu

An Equal Opportunity University

Johnson Controls

May 17, 2011

Mr. Edward A. Vineyard
Group Leader, Building Equipment Research
Energy & Transportation Science Division
Oak Ridge National Laboratory
One Bethel Valley Road
P.O. Box 2008, MS 6070
Oak Ridge, Tennessee 37831-6070

Dear Ed,

Johnson Controls, Inc. (JCI) is one of the industry leaders in introducing innovative, highly energy efficient space conditioning systems into the commercial mass market. We intend to maintain our leadership role in this regard, and thus are very interested in participating with Oak Ridge National Laboratory (ORNL) in efforts to reduce energy consumption and reduce the peak load of utilities through various improvements. This work is part of JCI's broader initiatives to demonstrate our leadership role and desire to help the nation reduce its energy and carbon footprint by commercializing market-transforming technologies at affordable prices.

JCI's interest is saleable products for the HVAC residential and commercial retail market as it exists today, as well as the future. In particular, we are interested in developing and commercializing space conditioning systems that are ultra efficient and cost effective. We will be evaluating the market and refining our product strategy simultaneously within the cooperative proposed work.

Opportunities to reduce electric peak demand while increasing energy efficiency and holding the line on costs are rare, which is why we are pursuing this with vigor in the form of both resources and investment dollars. JCI has expended considerable resources to develop advanced equipment designs and plans to continue efforts in the future.

JCI would be pleased to partner with ORNL on the Flexible Research Platforms to develop advanced equipment designs that would reduce energy consumption by up to 50%. As part of this effort, JCI would be willing to provide equipment for testing as well as making a contribution up to $5,000 to install the equipment. In addition, JCI would make in-kind contributions in the form of participation on a Steering Committee for the Flexible Research Platforms. The details of the participation will be refined at a future date as the platforms are constructed and as the demonstration proceeds. We look forward to a partnership that will benefit JCI, the U.S. Department of Energy, ORNL, and the nation.

Sincerely,

Ipseng Iu

P.O. Box 19014 • Wichita, KS • 67204-9014
3110 N. Mead • Wichita, KS • 67219
(316) 832-6400 Phone • (316) 832-6598 Fax

METAL BUILDING MANUFACTURERS ASSOCIATION
1300 SUMNER AVE., CLEVELAND, OHIO 44115-2851 • (216) 241-7333 FAX (216) 241-0105
E-Mail: mbma@mbma.com • URL: www.mbma.com

General Manager – THOMAS ASSOCIATES, INC.

February 7, 2011

Mr. Patrick Hughes
Director - Building Technologies Research & Integration Center
Oak Ridge National Laboratory
P.O. Box 2008 MS6070
Oak Ridge, TN 37831-6070
Sent Via Email: hughespj1@ornl.gov

SUBJECT: ORNL Flexible Research Platform

Dear Mr. Hughes:

Thank you again for visiting our offices in Cleveland on November 30, 2010 to speak about the opportunity for MBMA to participate in the forthcoming ORNL Flexible Research Platform projects.

MBMA is committed to collaborating with DOE/ORNL in this work as outlined in our meeting, and we look forward to further discussions as details are finalized. We understand that the first step in our collaboration will be to assist ORNL with the development of a research plan for the first experiment, including the initial design of the low-rise test building, primary structural framing, secondary steel support members and exterior roof and wall cladding and insulation materials.

As we discussed at the November 30, 2010 meeting, MBMA has a standing Energy Committee that is comprised of a diverse group of building system manufacturers and suppliers to the industry that would serve as a resource during this research. We believe our Energy Committee's Mission Statement is compatible with what we've discussed as the focus of this planned research:

> *"To promote the use of metal building systems in the non-residential construction industry, by encouraging fair and equitable treatment of metal building systems by energy codes, standard organizations, testing and rating groups, and other governmental and non-governmental groups."*

We proposed that the research plan, first experiment, and building design should be coordinated by ORNL staff with the assistance of MBMA's in-house association technical staff and member volunteers. In order to make informed decisions that are meaningful to the industry, we propose that a steering committee should be formed that would be comprised of MBMA Building Systems members who are leaders in the industry. We envision this steering group consisting of about eight individuals from different sized manufacturers to ensure the decisions made are representative of the market.

We feel the Flexible Research Platform will enable us to conduct research on metal buildings in a way that is unrivaled by any other research facility in the world, and we are very excited about the prospect of working with ORNL to develop a research plan and begin the design of the first test building experiment.

Please contact us at your earliest convenience so that we can begin discussing next steps.

Sincerely,

DANIEL J. WALKER, P.E.
Senior Staff Engineer

DJW:emb

cc: Mr. Andre Desjarlais, ORNL

NORDYNE
COMPLETE COMFORT. GENUINE VALUE.

8000 Phoenix Parkway · O'Fallon, Missouri 63368 · 1 800 422-4328 · www.nordyne.com

Mr. Edward A. Vineyard
Group Leader, Building Equipment Research
Energy & Transportation Science Division
Oak Ridge National Laboratory
One Bethel Valley Road
P.O. Box 2008, MS 6070
Oak Ridge, Tennessee 37831-6070

Dear Ed,

NORDYNE is one of the industry leaders in introducing innovative, highly energy space conditioning systems into the commercial mass market. We intend to maintain our leadership role in this regard, and thus are very interested in participating with Oak Ridge National Laboratory (ORNL) in efforts to reduce energy consumption and reduce the peak load of utilities through various improvements. This work is part of NORDYNE's broader initiatives to demonstrate our leadership role and desire to help the nation reduce its energy and carbon footprint by commercializing market-transforming technologies at affordable prices.

NORDYNE's interest is saleable products for the HVAC residential and commercial retail market as it exists today, as well as the future. In particular, we are interested in developing and commercializing space conditioning systems that are ultra-efficient and cost effective. We will be evaluating the market and refining our product strategy simultaneously within the cooperative proposed work.

Opportunities to reduce electric-peak demand while increasing energy efficiency and holding the line on costs are rare, which is why we are pursuing this with vigor in the form of both resources and investment dollars. NORDYNE has expended considerable resources to develop advanced equipment designs and plans to continue efforts in the future.

NORDYNE would be pleased to partner with ORNL on the Flexible Research Platforms to develop advanced equipment designs that would reduce energy consumption by up to 50%. As part of this effort, NORDYNE would be willing to provide equipment for testing as well as making a contribution to install the equipment. In addition, NORDYNE would make in-kind contributions in the form of participation on a Steering Committee for the Flexible Research Platforms. The details of the participation will be refined at a future date as the platforms are constructed and as the demonstration proceeds. We look forward to a partnership that will benefit NORDYNE, the U.S. Department of Energy, ORNL, and the nation.

Sincerely,

Matt Lattanzi
Director of Product Management
NORDYNE LLC

CC: Al Reifel, Carol Baker

SAMSUNG ELECTRONICS

6/20/2011

Mr. Patrick Hughes
Director - Building Technologies Research & Integration Center
Oak Ridge National Laboratory
P.O. Box 2008 MS6070
Oak Ridge, TN 37831-6070
Sent Via Email: hughespj1@ornl.gov

SUBJECT: Collaborative Research Using ORNL's Flexible Research Platforms

Dear Patrick:

Samsung Electronics is committed to collaborating with Oak Ridge National Laboratory (ORNL) in applied R&D work using the MAXLAB light commercial building flexible research platforms (FRPs) currently being established at ORNL. We wish that participate in FRP project with the R&D objective to below.

1. Project Objective
   A. Evaluation: VRF performance efficiency compare to general HVAC system.
   B. Verification : Energy savings effect by Cooperative Control Algorithm
2. Project Expectation
   A. Data Reliability: Collaborative R&D working with major player and ORNL.
   B. Strong R&D partnership : Build up to strategic relationship with ORNL
3. Investment Plan
   A. Facilities / System : VRF facilities and control system (include S/W, H/W)
   B. R&D expense : at least 1 yr

We feel the FRPs will enable us to conduct research and address issues that no other research facility in the world can address, at least that we are aware of, and we are very excited about the prospect of working with ORNL to develop a research plan to improve our products so they can be used to reduce energy use in buildings.

Sincerely,

Jae-young Choi

Vice President
Energy Solution Team
Digital Appliance Business
Samsung Electronics

July 14, 2011

Mr. Patrick Hughes
Director, Building Technologies & Research Integration Center
Oak Ridge National Laboratory
1 Bethel Valley Road, MS-6070
Oak Ridge, TN 37831

Mr. Hughes:

Subject: Schneider Electric Letter of Support for Energy Management Sensors and Controls Research on Flexible Research Platforms

Schneider Electric is a global specialist in energy management, focused on making energy safe, reliable, productive efficient and green. We are pleased to support the Energy Management, Sensors and Controls (EMCS) research on Flexible Research Platforms (FRP) at Oak Ridge National Laboratory (ORNL) in efforts to make existing and new buildings energy efficient using energy management and advanced control solutions. We are also interested in demand response technologies that will help utilities reduce peak demand.

Schneider Electric has significant presence in advanced diagnostics and controls for buildings, IT management, and process & machines management. We would like to support the FRP EMCS program via our capabilities in and knowledge of advanced building control algorithms and building automation systems. Schneider Electric would make in-kind contributions in the form of participation on a Steering Committee for the FRP, industry guidance, and review meetings. As part of this effort, Schneider Electric would be willing to provide prototypic equipment for testing. The details of the participation will be refined at a future date, as the platforms are constructed and as the initial demonstration of EMCS proceeds. Once the FRPs are in place and instrumented and a business case is established, Schneider Electric is interested in pursuing potential partnerships with ORNL. We look forward to a partnership that will benefit Schneider Electric, the U.S. Department of Energy, ORNL, and the nation.

This Letter of Support is provided as evidence of our commitment to supporting this program. Thank you for your consideration, and please direct any inquiries concerning technical matters to John Dierkes, john.dierkes@us.schneider-electric.com

Sincerely,

John R Dierkes
National Sales Manager ~ Federal Government
Square D /Schneider Electric
1010 Airpark Center Drive
Nashville TN 37217 |
Ê Fax: 859 372 1941 (Mobile: 615 504 6421)
* e-mail john.dierkes@us.schneider-electric.com

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http://www.schneider-electric.us

Received 5/16/2011

SPRI
SINGLE PLY ROOFING INDUSTRY

May 13, 2011

Mr. Andre Desjarlais
Oak Ridge National Laboratory
P.O. Box 2008 MS6070
Oak Ridge, TN 37831-6070

SUBJECT: ORNL Flexible Research Platform

Dear Mr. Desjarlais:

Thank you again for participating in our Technical and Board of Direction meetings on 26-27 April 2011 to speak about the opportunity for SPRI to participate in the forthcoming ORNL Flexible Research Platform projects.

SPRI is committed to collaborating with DOE/ORNL in this work as outlined in our meetings, and we look forward to further discussions as details are finalized. We understand that the first step in our collaboration will be to assist ORNL with the development of a research plan for the first experiment, including the initial design of the test building roofing system and insulation materials. Furthermore, we will assist in the development of a research agenda for this test roof and organize the supply of materials and labor to install these roofing systems as required.

We propose that the research plan, first experiment, and roof system design be coordinated by ORNL staff with the assistance of SPRI's technical steering committee and member volunteers. This group will meet quarterly to develop the research agenda and plan on the next quarter's tasks.

We feel the Flexible Research Platform will enable us to conduct research on roofing systems in a way that is unrivaled by any other research facility in the world, and we are very excited about the prospect of working with ORNL to develop a research plan and begin the design of the first test roof experiment.

Please contact us at your earliest convenience so that we can begin discussing next steps.

Sincerely,

David M. Bailie

David M. Bailie
SPRI President

411 Waverley Oaks Road, Suite 331B – Waltham, MA 02452
t. 781.647.7026 f. 781.647.7222 e. info@spri.org

SOUTHWEST GAS CORPORATION
Energy Efficiency Technology Department

June 2, 2011

Mr. Edward A. Vineyard
Group Leader, Building Equipment Research
Energy & Transportation Science Division
Oak Ridge National Laboratory
One Bethel Valley Road
P.O. Box 2008, MS 6070
Oak Ridge, Tennessee 37831-6070

Dear Ed,

Southwest Gas (SWG) is one of the leading utilities in introducing innovative, highly energy efficient space conditioning systems into the commercial mass market. We intend to maintain our role in this regard, and thus are very interested in participating with Oak Ridge National Laboratory (ORNL) in efforts to reduce energy consumption and peak load of utilities through various improvements. This work is part of SWG's broader initiatives to demonstrate our leadership role and desire to help the nation reduce its energy and carbon footprint by commercializing market-transforming technologies at affordable prices.

SWG's interest is increased gas sales through saleable products for the HVAC residential and commercial retail market as it exists today, as well as the future. In particular, we are interested in developing and commercializing space conditioning systems that are ultra efficient and cost effective. We will be evaluating the market and refining our product strategy simultaneously within the cooperative proposed work.

Opportunities to improve energy efficiency while reducing electric peak demand and holding the line on costs are rare, which is why we are pursuing this with vigor in the form of both resources and investment dollars. SWG has expended considerable resources to develop advanced equipment designs and plans to continue efforts in the future.

SWG would be pleased to partner with ORNL on the Flexible Research Platforms to develop advanced equipment designs that would reduce energy consumption by up to 50%. As part of this effort, SWG would be willing to provide equipment for testing as well as making a contribution to install the equipment. In addition, SWG would make in-kind contributions in the form of participation on a Steering Committee for the Flexible Research Platforms. The details of the participation will be refined at a future date as the platforms are constructed and

2953 Westwood Drive / Las Vegas, Nevada 89109
(702) 364-3933 Fax (702) 369-0542
www.swgas.com

as the demonstration proceeds. We look forward to a partnership that will benefit SWG, the U.S. Department of Energy, ORNL, and the nation.

Sincerely,

Anthony W. Hills
Director, Energy Efficiency Technology Department

SYNAPSENSE

August 21, 2011
Mr. Patrick Hughes
Director, Building Technologies and Research Integration Center,
Oak Ridge National Laboratory,
1 Bethel Valley Road, MS-6070,
Oak Ridge, TN 37831.

Subject: SynapSense Letter of Support for Energy Management, Sensors and Controls Research on Flexible Research Platforms

SynapSense Corporation provides complete wireless instrumentation solutions that offer energy efficiency and carbon footprint reduction for the world's leading data centers and enterprises. SynapSense offerings include wireless sensors, monitoring, data collection, data analysis and visibility, and control capabilities to increase energy efficiency for data centers. SynapSense would like to use it's extensive experience in data center energy efficiency to develop solutions for improving energy efficiency of light commercial buildings.

We are pleased to support the Energy Management, Sensors and Controls (EMCS) research on Flexible Research Platforms (FRP) at Oak Ridge National Laboratory (ORNL) in efforts to make existing and new buildings energy efficient. SynapSense is interested in working with the ORNL team in applying current and new products to the problem of wireless instrumentation, monitoring, and control for light commercial buildings. Collaboration opportunities could include wireless sensing, monitoring, and control of the building environment, fault-detection and diagnosis, and smart building demand response. SynapSense would like to use the FRP platforms to test and validate performance of their advanced product line when applied to light commercial buildings. SyanpSense could support the program via our capabilities in and knowledge of wireless sensing, monitoring, control, and energy efficiency. As part of this effort, SynapSense would be willing to provide prototypic equipment for testing. The details of the participation will be refined at a future date, as the platforms are constructed and as the initial demonstration of EMCS proceeds. Once the FRPs are in place and instrumented, SynapSense is interested in pursuing potential partnerships with ORNL. We look forward to a partnership that will benefit SynapSense, the U.S. Department of Energy, ORNL, and the nation.

This Letter of Support is provided as evidence of our commitment to supporting this program. Thank you for your consideration, and please direct any inquiries concerning technical matters to Patricia Nealon, pnealon@synapsense.com.

Sincerely,

Dr. Raju Pandey
CTO

2365 Iron Point Rd, Suite 100 • Folsom, CA USA 95630 • T:+1-916-294-0110 • F: +1-916-294-0270

United Technologies Research Center
411 Silver Lane
East Hartford, CT 06108
(860) 610-7000

United Technologies Research Center

June 7, 2011 1.BB0.0004-37

Oak Ridge National Laboratory
1 Bethel Valley Road, MS-6070
Oak Ridge, TN 37831

Attention: Patrick Hughes
Director, Building Technologies and Research Integration Center
Phone: 865-574-9337
Email: hughespj1@ornl.gov

Subject: UTRC Letter of Support for Energy Management, Sensors and Controls Research on Flexible Research Platforms

The United Technologies Research Center (UTRC), the central research organization of United Technologies Corporation (UTC), is pleased to support the Energy Management, Sensors and Controls (EMCS) research on Flexible Research Platforms (FRP) at Oak Ridge National Laboratory in efforts to reduce energy consumption, improve energy management, and reduce the peak load of utilities through various improvements to buildings. Integrated multi-modal sensing and adaptive building controls has the potential to improve the energy efficiency of existing, as well as, new construction buildings leveraging advanced Fault Detection and Diagnosis (FDD) capabilities.

United Technologies Corporation, through our Carrier, UTC Power, Otis and UTC Fire & Security divisions, is a leading supplier to the building sector and pursues innovative technologies to significantly improve the state-of-the-art in energy efficient building system and control technologies. UTRC's in-kind contributions may include participating on a Steering Committee for the FRP, providing industry guidance, and attending review meetings. Subject to progress on program tasks and successful proof-of-concept studies with EMCS, UTRC will explore collaborative research programs and prototype equipment testing. We look forward to a partnership that will benefit the U.S. Department of Energy, ORNL, and private sector in addressing a critical national need.

This Letter of Support is provided as evidence of our commitment to supporting this program. Thank you for your consideration, and please direct any inquiries concerning technical matters to Satish Narayanan, Project Leader, Integrated Building Systems, Energy Systems Program Office, UTRC, at 860-610-7412.

Sincerely,

Craig R. Walker

UNITED TECHNOLOGIES RESEARCH CENTER
Craig Walker
Director, Energy Systems