New Systems and Technologies

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1. Situation

Technology options for integrated building systems

There are a number of advanced building technologies that are commercially available today, yet are not widely deployed. These include: building materials and components (e.g. phase change materials, advanced glazing, solid state lighting); building subsystems (e.g. displacement ventilation, dynamic facades); integrated controls, performance monitoring and automated diagnostics. There are many reasons for the slow uptake of advanced technologies in the building industry, including economics, codes and standards, limitations of delivery and operations processes, liability, risk aversion, etc. Another factor of direct relevance to this project is that a number of these technologies have not been developed to the point where their actual performance approaches their theoretical potential. A major underlying reason that the advanced, innovative subsystem performance is not realized is the lack of integration into the whole building design and, therefore, the lack of optimized dynamic coupling between the high performance subsystem and the other building subsystems.

Buildings that have advanced subsystems and components invariably require high levels of technical skill and other resources for design, performance predictions, construction and operation. In practice, some buildings with advanced subsystems use substantially more energy than expected because the subsystem performance characteristics are not optimized within the context of the building system energy utilization dynamics and operators do not have the skills and resources to operate and maintain these systems as intended, ref. [19].

While many advanced components and sub-systems are currently available, there are no integrated design methodologies and tool sets that explicitly take into account the underlying dynamic coupling among the main building subsystems, e.g. façade curtain wall heat gain, fenestration solar heat dynamics, HVAC functionality (ventilation, sensible cooling, latent cooling) and response dynamics. Consequently integrated system products that could reduce the burden for design, construction, and operation for minimizing energy utilization are not normally identified during building development. These integrated system products are identified in so-called custom design, point solution designs and take on an anecdotal status in the high performance building design literature. For example, consider an integrated system for mixed mode ventilation that combines an active façade with an HVAC system that treats ventilation and thermal loads separately. Today, such a system can be assembled with advanced off-the-shelf products – and will work successfully if there are adequate technical and economic resources to design, construct and operate it as intended. However, there is no off-the-shelf ‘integrated system product’ that packages all the components and sub-systems for mixed mode ventilation, such that it allows for standardized, modularized, “low-touch” design, construction, and operation. A fundamental reason is that the design tools facilitating the design, specification, construction, and operation of such subsystems by considering the underlying dynamic coupling among subsystems do not exist. In short, integrated design methodologies and toolsets that consider subsystem coupling and interdependencies in determining overall building performance do not exist. Design tradeoffs and optimization of advanced subsystem design in terms of overall building performance can not be achieved.

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Technology maturation process

The current situation is also characterized by limitations in each of four major phases of the technology development and maturation process, as described below:

1. There are no systematic methods to identify the requirements for new technologies in buildings. Even the data currently available on the building stock is barely adequate for a rigorous analysis of technology requirements. CBECS [1], while designed to be representative of the US commercial building stock, does not have enough breadth or depth for such analysis. The CEUS database [**Error! Reference source not found.**] developed for California has significantly more depth than CBECS but still does not capture adequate data on operational characteristics. The data reflects average energy utilization characterization and can not be related to the subsystems dynamic interdependencies, e.g. façade energy storage and transmittance, solar gain in fenestration, and HVAC system sizing and performance.

   A robust database for stock analysis should include building characteristics, operational performance, costs, occupancy and usage characteristics, sub-metering, the dynamic measurements of building energy use by various subsystems, measurements of building indoor environment, (e.g. humidity ratios) as a function of external and internal transient load profiles, total enthalpy load on a building system. etc.

   There is a lack of tools to analyze the building stock and to understand the limitations and opportunities of existing technologies (e.g. tools for the visualization of exergy flows).

   Finally, there is a lack of a consistent, well-established system of metrics to evaluate new technology options within an integrated design analysis. While many different metrics are used to evaluate new technology options at the component level (e.g. lm/W in lighting sources, kW/ton for electric cooling), there has not been a concomitant development in metrics to evaluate integrated systems.

2. Once the requirements for new technologies have been identified, there is no systematic way to generate, evaluate and select new concepts, particularly if one is seeking to exploit energy savings by taking into account the dynamics of building energy flows and indoor environmental states. While such approaches, including structured brainstorming techniques, have been developed an applied in other industries (e.g. the automobile industry), these techniques have not been developed for the building industry. The lack of comprehensive data sets and design toolsets inhibits the formalization of high performance design processes. The data sets and design tools that exist are generally formulated in terms of steady-state, design day conditions and subsystem performance modeling based on so-called full load operation. In reality, the building subsystems are operating dynamically at part load conditions for the vast majority of its operating lifecycle. There is a lack of fundamental understanding, basic physics models, data and measurements that manifest the underlying dynamics of the building stimulus-response behaviors.

3. The process of testing, demonstration, and risk reduction is limited and fragmented. Here again, techniques that have been used in other fields (e.g. aerospace, ship-

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building, etc.) have not been taken advantage of in the building industry. Indeed, the building industry does not even have the appropriate testing and validation facilities for such approaches.

4. There are no effective ways to deploy new technologies at scale into the market place. This would include the development of appropriate business models, for example. While this may not be within the core scope of HiPerBRIC, it is important that the technology development process have an appropriate hand-off to market transformation activities. A related issue is that when new technologies are developed, the models and tools to deliver and operate these technologies need to be incorporated into the broader delivery and operations platforms and tools.

2. Research Needs and Payoffs

The research needs associated with new building technologies relate to:

- Technology options for integrated building systems, to mature and demonstrate new technology concepts. HiPerBRIC will address the research needs related to technology options that require integration, development, and demonstration of existing technologies.

- Technology Maturation Process; to develop the processes required for the identification of opportunities, needs and requirements for subsystems, components and materials; concept generation, evaluation and selection; risk reduction and technology demonstration; technology transfer.

Figure 1 shows the proposed process and associated research needs for the identification and development of new technologies applied to high performance buildings. The first step in Figure 1 corresponds to *opportunity identification and analysis, needs and requirements;* this sub-process involves obtaining adequate information and data on a) building stock characteristics, which will include detailed information regarding physical characteristics, materials, insulation, geometry and dynamic energy storage and sensible and latent energy transfer properties; b) building operational characteristics, such as schedules, energy end uses and detailed occupancy characteristics, representative external and internal imposed load profiles, sub-metering; c) equipment and system characteristics, particularly part-load performance characteristics and response time characteristics; and d) building management, including the presence or absence of building operators, facility engineers, building management systems, continuous commissioning or maintenance schedules. The data obtained needs to contain not only depth of information with detailed information about particular buildings, but also breath. For this breadth, a rich set of representative buildings types, sizes in different climatic zones need to be fully instrumented and sub-metered in order to gather the performance data and other information required for new technology requirements identification.

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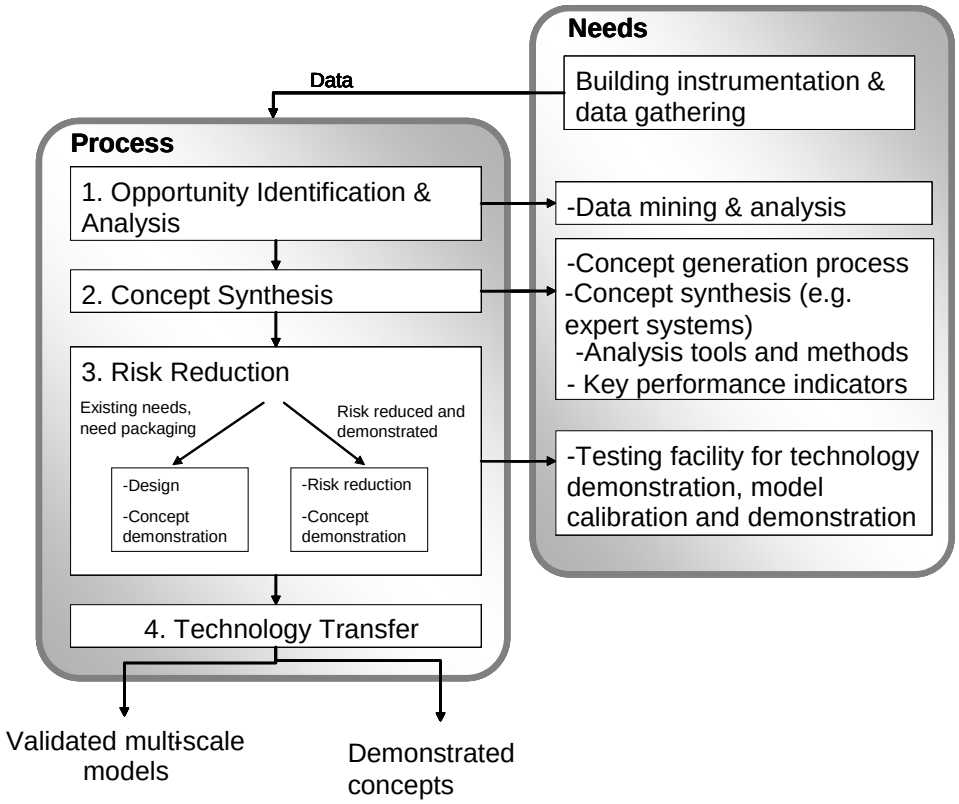

Figure 1: New Technology Identification and Development Process and Needs.

Once building data is gathered, it must be processed and analyzed. In order to achieve this analysis, a consistent set of tools, process, and metrics need to be in place. Data-mining, visualization, analysis, and estimation techniques will support the identification and prioritization of new technologies. The identification of performance limitations and opportunities in buildings, particularly those related to the dynamics of energy storage and flows of building subsystems, will lead to the generation of alternative new technologies. This identification requires new methods and tools, including estimation and visualization of building dynamics (Andrzej uncertainty analysis), and energy and exergy flows (Appendix Stella mini-paper on energy-exergy, ref [1], [5], [6], [7], [8], [9], [10], [11]). In addition, a wide set of performance metrics is needed to support the comparison, evaluation and selection of alternative technology options (Stella mini-paper on performace metrics).

These design tool capabilities must be developed from the data sets and subsystem performance analyses of the current building stock. The tools should enable dynamic modeling, abstract and detailed building analysis, and performance predictions of the building system, and must include sufficient building response prediction to allow optimized part load operation for a variety of dynamic external and internal part load scenarios. (Appendix X Stella mini-paper). This approach is in stark contrast to the conventional design day, steady state building design currently done in a silo'd, discipline, serial approach which optimizes stand-alone subsystem performance and results in underperformance of innovative building subsystems when applied in actual buildings where there performance is co-dependent with other subsystems.

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As an example of the outputs of the *'Opportunity identification and analysis'* step in Figure 1, a detailed analysis of existing buildings energy flows and climate season behavior in different zones of the country, will correlate building loads, geometries, insulation, efficiencies, external and internal humidity, temperature and pollution levels. This analysis may support the identification of energy, comfort, and environmental benefits of using natural ventilation in identified climatic zones, times of the day and seasons; and forced ventilation required in complementary times and seasons.

The second step in Figure 1 is '*system synthesis'* and involves concept generation, evaluation and selection for the opportunities identified during *'Opportunity identification and analysis'*. Research is required on systematic ways to perform this system synthesis for new technologies in buildings.

There exist a large number of new novel technologies applicable to buildings that are in different stages of research and development. These technologies include new building materials (advanced glazing and phase change materials, ref. [12], pg 43), new space conditioning and ventilation systems (e.g. radiant ceilings, dedicated outside air systems) and new power systems for buildings, ranging from photovoltaic to cogeneration. Although the development of these technologies is outside the scope of the proposed HiPerBRIC program, capturing the dynamic interactions between these technologies and the building structure and creating packaged, flexible, system-level solutions is critical to the success of the HiPerBric program.

Structured techniques to do creative concept generation are widely applied in many industries, TRIZ for example, is one of the best known technique for concept generation (ref. [17]). These techniques are generally not applied in the building industry except for design charettes, but could usefully be applied by the industry to identify new concepts.

Beyond structured brainstorming sessions that rely exclusively on human intervention, research is needed to develop expert systems that will support the identification of opportunities for improvement and propose new technology solutions based on existing solutions that have been applied somewhere else. This expert system will include the following features; a database with a rich set of technology solutions, an inference engine that automatically identifies problems and opportunities in the building design or operation based on scientific first principles, and an intelligent design space exploration engine that would explore new technology options to eliminate or minimize the identified problems or to better take advantage of the building dynamics.

After a rich set of new potential concepts have been generated, with or without the support of expert systems, analysis tools are required to support the comparison of solutions, integration with the rest of the system and detailed design. The explicit exposure and analysis of system interfaces is required for optimization of integrated design. This is an area of research that has not been sufficiently explored.

As an example of the outputs of the *System synthesis* for the opportunity to combine forced and natural ventilation, several concepts may be generated to combine the HVAC system and the building façade, which may range from fixing the ratios between window and fan coil unit valve openings for pre-determined times of days and season, to a more sophisticated system which would include active façade and HVAC actuation to provide active humidity, temperature, and energy efficiency control.

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Once concepts have been selected, they will be further developed and demonstrated. This is the '*risk reduction* phase' in Figure 1. New experimental facilities, methods, processes, and protocols will need to be developed in order to test, verify, and demonstrate the performance of the new building system configurations and to validate the corresponding multi-scale models. This test facility will also enable the development and demonstration of technology solutions packages based on the combinations of existing components and materials. One R&D need, particularly applicable to existing buildings, is to develop standardized interfaces and protocols for integrating components and subsystems into systems with minor or no modifications to existing infrastructure. It must be emphasized that the experimental facilities developed, measurement systems, and data acquired in existing buildings and facilities having innovative subsystem will ellicit dynamics of energy flows within the building and the coupling in performance states of building subsystems. The measurement systems must facilitate the development of fundamental, dynamic response models of a building and its subsystems taken as an integrated system. The data-based approach will enable the development of appropriate design models and toolsets for integrated, team based, parallel subsystem design that is required for High Performance Buildings.

Once the systems have been demonstrated successfully, the final technology maturation process step is to transfer the technology to companies that will mature it into commercial products. As part of this step the validated multi-scale models will be integrated into the methods and tools developed under the HiPerBRIC Program.

3. Technical Barriers, Enablers and Risks

To effectively develop and deliver advanced technology options for high performance buildings the research needs described above must be addressed systematically. The following paragraphs discuss the technical barriers, enablers, and risks for each of the identified research needs.

Technology Options

Within the context of an integrated building design, it is important to identify clearly the opportunities to improve whole building performance by means of enhanced or new subsystems, components or materials. The analytical tools and methods to be developed in HiPerBRIC will be key enablers. The ability to efficiently and readily explore and visualize building design, external and internal imposed load operating scenarios, subsystem dynamic responses and the resulting dynamic building thermal and indoor environment states will enable advanced technology opportunities to be identified, specified, and prescribed in the design process in a formalized methodology environment, as contrasted with the current anecdotal, point solution design process for High Performance Buildings.

An important objective of the HiPerBRIC initiative is the effective deployment of advanced technologies in 'low touch' solution packages for high performance buildings. The lack of standardized interfaces and protocols for integrating advanced components and sub-systems is a barrier. This barrier is further compounded by the fact that current building product development is fragmented, inhibiting true system level integration of advanced technologies. As an example, there is no single supplier or supplier alliance that is capable of delivering a packaged integrated solution for HVAC, façade, and lighting.

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Technology Maturation Process

The process for successfully maturing advanced technology options for high performance integrated buildings faces barriers related to 1) the current culture within the building industry and 2) lack of a formalized technology development process.

The current culture within the building industry is more sensitive to first cost and more averse to risk than many other industries. This impacts both the receptivity to advanced technology and its actual rate of adoption. In addition, the general skill level within industry is not adequate to design, deliver, and operate advanced building technologies effectively.

There is currently no widely accepted, formalized process for maturing advanced technology options for high performance integrated buildings. Transferring best practices for technology development from the aerospace and automotive industries is a potential enabler for the buildings industry. A phased process for technology development is used. The phases include; 1) opportunity identification & analysis, 2) concept synthesis, 3) concept risk reduction & feasibility demonstration, and 4) technology transfer. In the context of advanced technology development for high performance integrated buildings, there are the several barriers and enablers.

Phase 1: Opportunity identification & analysis

There is a lack of documentation and information systems to collect and analyze building stock characteristics (design, operation). Collecting this information requires on-site skilled expertise (e.g. personnel trained in the CEUS data collection protocol) that is time consuming. The available information today is often fragmented, obtained from multiple, uncoordinated sources. In addition, many building owners are not willing to share data. Enablers include tools to collect geometry information to develop building CAD models, sensor networks that can be deployed quickly to collect limited building information, standard protocols for building information systems (e. g. DASH protocol, energy metrics, ASHRAE 105, etc.). The building system includes complex dynamic, coupled interactions between building subsystem designs (HVAC, lighting, power generation & distribution, etc). Formal decomposition or system partition methods (Ref Science tool section) will enable a clearer understanding of where technology advancement opportunities exist.

Phase 2: Concept synthesis

Structured concept synthesis methods to generate, evaluate, and down-select advance technology options for high performance integrated buildings are not widely adopted. Structured concept generation methods, such as TRIZ (ref. [17]), can be used to systematically identify and resolve component or sub-system contradictions that lead to novel technology options for integrated building systems. Tools and methods for efficient trade-space (energy, exergy, IAQ, cost, etc) visualization and exploration will enable the evaluation and down-selection of technology options.

In the longer term, it is envisioned that expert systems will support the identification and exploration of new technology options.

Phase 3: Concept risk reduction & feasibility demonstration

Technology option risk reduction and feasibility demonstration for the wide range of building context (types, climates, sizes, operations, usage, etc) poses a significant challenge for

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HiPerBRIC test facilities and also for the modeling and simulation tools that could support the analysis of options. HiPerBric test facilities must be flexible and scalable. There are specific measurement limitations for validating building airflow distribution and indoor air quality.

Phase 4: Technology transfer

The barriers and enablers for technology transfer relate to market deployment (outside the scope of HiPerBRIC) and deployment of the specific advanced technology option analytical tools within the BDCOP (Ref Design Methods)

4. Technical Approach

The focus of this track of HiPerBRIC is the development of very high performance integrated whole building solutions (IWBS) for a wide array of building contexts (in terms of building type, climate, size, usage, etc.).

Each HiPerBRIC IWBS will be characterized by (Table 1):

- Very high performance: Up to 80% more energy efficient than current practice, with high indoor environmental quality. In addition to using high performance components and materials, this will be accomplished through exploiting efficiency opportunities inherent in subsystem dynamics and interactions.
- High degree of "packaging" for risk reduction, incorporating: Standardized "low-touch" process, models and tools for design, construction, and operation; Modularized combination of sub-systems, components and materials, with standardized "plug-and-play" interfaces between them; Integrated controls hardware and software for optimized control across subsystems, with standardized interfaces to supervisory control systems.
- Context-sensitivity: It refers to the capability of the building design, systems, and platforms and the operating strategies to be adapted or customized for different climates, building types and sizes. This has to be different than most current 'one-type-fits-all' solutions. HiPerBRIC solutions will be parameterized to allow appropriate variations for building type, climate, and usage.

While some of these characteristics have been accomplished to varying degrees, it is important to note how this approach builds and yet distinguishes itself from current practice:

- There are indeed a few examples of very high performance buildings today that achieve net-zero energy goals. These buildings are unique, novel examples with advanced designs and are exemplars. Their energy optimality is based on unique systems; one example is the IDeAs Z2 Building in San Jose, CA, which uses high efficient insulation and lighting, electrochromic windows, reflective paints, displacement based ventilation, building monitoring systems, recycled materials, ground-source heat pumps, and integrated designs. However, they are highly customized, require high level of design expertise, and will require high level of attention during operation to maintain performance. In essence, they are "high touch" products that are not scalable to the broader building industry, given the limitations cited in earlier sections.

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- There are indeed examples of “packaged” design, construction and operation, most notably in the big-box retail sector. National accounts, such as Walmart or Target, have some level of packaged design and pre-defined equipment suppliers, architects and constructors that allows these businesses to have a short construction period. However, these solutions are highly prescriptive, typically not even allowing for variation in climate and usage, let alone form and other architectural issues. As a result, they are not optimized to maximize performance. Also, they typically do not incorporate the most advanced components and materials.

Table 1: Building Systems Characteristics

	State of the art			HiPerBric
	Typical practice	National Chain	Current ZEB	
1. Performance (Energy, cost, IEQ, reliability)				
2. Packaging / risk-reduction ("low-touch" design, construction, operation)				
3. Context-sensitivity (Climate, site, size, usage)				

Non existant

Fully capable

A HiPerBRIC IWBS for schools in moderate climates, for example, may combine an active façade, displacement ventilation, high temperature cooling, and solid state lighting with integrated controls that dynamically optimize energy use, visual comfort, thermal comfort and indoor air quality based on occupancy and usage patterns. It is important to note that the emphasis in HiPerBRIC is on the performance at the whole building level, and not on incremental performance improvement of individual components or sub-systems. However, in the course of developing these IWBS, HiPerBRIC will help identify new R&D needs vis-à-vis individual performance of subsystems, components and materials.

As noted in earlier sections, product development in the building industry has not taken full advantage of structured and formal technology maturation processes (TMP). To address this shortcoming, HiPerBRIC will draw upon and adapt best practices in other industries, to develop and use a structured and formalized TMP for:

a) Opportunity Identification

b) Concept Synthesis

c) Risk Reduction and demonstration

d) Technology Transfer

The development of TMP and the IWBS will be sequential and iterative over at least two phases, as follows:

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Phase 1:

1. Develop a prototype TMP largely based on existing methods and tools. This TMP will be used to develop the first set of IWBS, as outlined in steps 2-5 below.
2. Identify very high performance synergistic combinations of systems for selected building type/climate combinations (e.g. small office, small retail, big-box retail, food-service). Include subsystems, components and materials that currently do not exist or have the required performance but which appear to be feasible.
3. Develop concepts and approaches for IWBS. Identify any required enhancements to subsystems, components and materials. Develop processes and tools to enable design, delivery, and operation of each IWBS with the HiperBRIC building design construction and operation platform (BDCOP).
4. Test and demonstrate innovative solutions, repeatedly selecting and refining promising solutions in order to obtain mature, robust high performance solution packages.
5. Deploy mature, robust high performance solution packages in the mass market

- For Phase 1, four projects have been selected to demonstrate the near term national energy benefits of IWBS packages and to provide context for developing the TMP. The projects will be explained in the next section.

Phase 2 will essentially follow the same approach as phase 1, however, it will include the development of an advanced and more detailed TMP that will allow for identification of more innovative solutions that could not be identified with the prototype TMP.

There are two primary deliverables from this track:

1. A set of integrated whole building solutions to cover most of the commercial building sector
2. An advanced formalized technology maturation process for the building industry.

A more detailed list and description of tasks, sub-tasks, and deliverables for each phase is provided in section 5.

5. Project and Subprojects

The program will be split into two phases. Each program phase will focus on developing the technology maturity process (TMP) and delivering integrated whole building solutions (IWBS) for the commercial building sector. Phase I will prototype the TMP using existing building analysis tools and US building stock data and will focus on simple building types (e.g. small office, small retail, big-box retail, food-service). Phase I will also develop standardized, “low touch” IWBS packages. The phase I IWBS projects will be: Mix-mode-ventilation, Energy Microgrids, Integrated BMS for diagnostics & prognostics, and Systems Interoperability. The phase I TMP will also be used to identify the phase II IWBS packages.

Phase I deliverables include:

1) A prototype TMP that prescribes process steps and tools for opportunity identification, concept synthesis, risk reduction and demonstration, and technology transfer.

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2) IWBS packages that include:
    a. parameterized EnergyPlus model(s) that define building geometry, system types and sizing, including alternative system types where appropriate, component sizing and efficiencies
    b. standard control sequences of operation, including alternates for different system types
    c. instrumentation specifications for control and performance monitoring
    d. functional testing plan(s)
    e. automated diagnostics package, including alternates for different system types
3) Validated tools and methods for the IBWS that can be implemented into the HiPerBric framework.
4) Phase II IWBS projects identified through the TMP opportunity identification step.

Phase II will refine the TMP using the developed HiPerBric building analysis tools and detailed US building stock data and will focus on extensions to complex building types. Phase II will also develop standardized, “low touch” IWBS packages based on new technologies options delivered through the HiPerBric framework.

Phase II deliverables include:

1) A refined TMP that prescribes process steps and tools for opportunity identification, concept synthesis, risk reduction and demonstration, and technology transfer.
2) IWBS packages that include:
    a. parameterized Energy/Exergy model(s) that define building geometry, system types and sizing, including alternative system types where appropriate, component sizing and efficiencies
    b. standard local control sequences of operation, including alternates for different system types
    c. global systems control optimizer (supervisory system)
    d. instrumentation and model specifications for control and performance monitoring and estimation
    e. functional testing plan(s)
    f. automated diagnostics package, including alternates for different system types
3) Validated tools and methods for the IBWS that can be implemented into the HiPerBric framework.

The following sections detail specific project tasks and deliverables.

Phase I

Project I1: Prototype Technology Maturation Process

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This project will prototype the TMP using existing building analysis tools and US building stock data and will focus on simple building types (e.g. small office, small retail, big-box retail, food-service).

Task I1.1: Develop prototype TMP

Develop a structured process to identify, synthesize, reduce risks, demonstrate and transfer technologies for deploying IWBS packages.

Deliverable: TMP documentation - process steps and tools for opportunity identification, concept synthesis, risk reduction and demonstration, and technology transfer.

Task I1.2: Develop tool to model current building stock with existing databases

A tool to model and analyze the US commercial building stock will be developed. The tool will be based on a simple but flexible tool developed at LBNL (ref: [20]) that is based on CBECS data (ref. 1).The tool is implemented using Analytica®, which treats uncertainty and is used as the platform for DOE's new Stochastic Energy Deployment System (SEDS) energy sector model [ref. 21]. In phase I, the tool will include previously developed prototype models of different building types implemented in EnergyPlus. These models will be used as the starting points for models of designs that include system types selected for their applicability to the particular building type. The energy consumptions predicted by the models will be weighted by the frequency of occurrence of the corresponding building type/climate combination in CBECS to predict the aggregate performance of the US building stock with the levels of system performance assumed in the models.

Deliverable: Tool to model current building stock

Task I1.3: Define requirements for building stock data collection

Develop US building stock data collection requirements; target building types, data type and quality, sub-metering, measurement systems, level of data aggregation and desegregation, time sequences, etc.

Deliverable: Requirements for enhanced building stock data collection

Task I1.4: Identify phase II IWBS projects

Exercise the TMP to identify and prioritize phase II IWBS projects. Building functional decompositions will be used to map subsystem interactions (static and dynamic) to systematically identify non-obvious, high leverage opportunities for meeting net zero energy goals. Future solution sets based, in part, on subsystems, components and materials not yet available will be identified. The BDCOP will be used to model combinations of state-of-the-art lighting/façade/HVAC/on-site generation systems, including innovative systems not deemed mature or robust enough, in their current state, to be included in the IWPS packages. Visualization of energy and exergy performance will be examined to identify system enhancements and integration with substantial potential to improve overall performance. Subsystems, components and materials that currently do not exist or have the required performance, but which appear to be feasible, will be identified and performance targets specified, including cost and risk. The performance targets will be identified based on the enhanced overall performance of the building stock that would be enabled. Estimation of the benefits of achieving a given level of performance improvement, together

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will the expected cost of achieving those improvements, will be used to determine optimum allocation of R&D resources.

Deliverable: Phase II IWPS projects

Project I2: Mix-mode-ventilation IWBS package

This project will develop an IWBS package that is a hybrid approach between forced and natural ventilation and integrates the HVAC system with the building façade (windows), and with the building control system. A good mixed-ventilation system starts with the design of the building façade and HVAC system to minimize loads. The control system to coordinate and optimize the opening of the building facade and the operation of the HVAC system is the key to optimize energy consumption, while improving the IEQ.

In a first phase of development, the inputs to the controls will be based on existing methods and tools for temperature and humidity measures, HVAC and façade-related measurements; including, for instance, fan coil unit valve opening, air and water mass flows, temperatures and pressures, and the capability to have access to direct weather measurements.

- A second phase of development will include the tools that would be matured as part of HiPerBric, and these are IAQ, energy and occupancy estimation, and building loads and weather measurements and forecasting.

A study from the University of California, Berkeley shows that the potential energy savings for mix-mode ventilation HVAC systems range from 9% in Miami, to 79% in Los Angeles (ref. 13), which represents about 4 to 40% energy savings in commercial buildings.

Deliverables:

- A mix-mode-ventilation IWBS package, which will include the integration of active controls system for the building façade openings and HVAC operating set-points, i.e. water and mass flow set-points, water chiller temperature set-points, fan coil units valve opening, humidity control level, etc.
- HiPerBric tools, processes and validated multi-scale models

Project I3: Energy microgrids IWBS package

This project will develop an IWBS package that integrates existing energy sources and storage devices with the building HVAC and management system. In the context of HiPerBric, this project will exclude the development of the power electronics and controls infrastructure required to integrate the microgrid with the main grid or work in an islanding mode.

A first phase of the project will include a) the development of design tools to select microgrids components, that may range from solar PV to cogeneration systems, and specific types and capacities of electrical and thermal energy storages, and b) the development of an optimization scheme to be integrated with the building management system (BMS) to do real-time optimization and prioritization of energy flows from and to sources, storage, and loads (i.e. mainly building lighting and HVAC systems). This optimizer will be based on existing technologies for building occupancy approximation, load forecasting, communications with utilities and electric markets, remote monitoring, and equipment control.

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A second phase of this project is foreseen after HiPerBric and energy microgrids basic elements are matured. For HiPerBric, these elements mainly include occupancy and energy/exergy flow estimation and forecasting. For microgrids, the basic elements that are not yet fully developed include power electronics, controls, and communications schemes that would allow the integration with the grid, building critical load connection and reconnection during islanding situations, and pair-to-pair equipment communications typical of current development for energy microgrids.

Depending on the selected energy sources and storage, the energy microgrid project is expected to deliver beyond 40% energy savings achievable by introducing cogeneration (CHP) equipment. However, almost 100% could be achieved when renewable sources are used to cover the rest of the loads. Beyond measured on-site energy savings, on-site generation would provide tremendous national benefits, by avoiding upgrades or construction of transmission lines, minimizing the impact of power outages, and reducing the cost that utilities have to incur for having energy and power reserves (see Appendix A)

Deliverables:

- Building management system extended to include optimized integration and operation of power generation, storage & transmission, and traditional building load, such as lighting and HVAC systems.
- HiPerBric tools, processes and validated multi-scale models to include energy microgrids components.

Project I4: Integrated Building Management System for diagnostics & prognostics IWBS package

This project will develop an IWBS package for diagnostics and prognostics integrated with the building management system. This package will include the detection and solution of the whole range of potential problems, from sub-optimal system performance, to components sub-optimal performance, fault prediction, fault detection and reconfiguration (ref. Sean/Mary Ann mini-paper).

A report on the energy impact of commercial building controls and performance diagnostics [ref. 18] identifies over one hundred types of faults in commercial building operation. Among these are mechanical or electrical problems, such as damaged VFDs, valves, dampers, or sensors; lighting systems may be left on when office space is unoccupied; or simple software programming errors may cause expensive but non- obvious faults. The same report shows as much as 20% of the energy consumed by commercial building HVAC and lighting systems could be wasted due to these faults. It is predicted that as much as 40% of the HVAC and lighting energy could be saved by combining proper monitoring and control.

Reliable information is needed to attain these savings. Estimation to extract this information is required to create effective algorithms for performance monitoring and diagnostics. Estimation is also needed to aid decision makers to create benchmarks, schedule maintenance, or repair equipment. This integrated building system relies on the following basic technology components:

- Reliable sensor and communication network architecture.

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- Data mining and machine learning that would keep historical records, gain insight from experts, analyze trends and capture capture dynamic and statistics.
- Reduced order models for building and systems that would be used for estimation purposes
- Occupancy, energy, and exergy estimation techniques to be used to create effective algorithms for performance monitoring or diagnostics, and to aid decision makers to create benchmarks, schedule maintenance, or repair equipment
- Robust decision systems to perform fault detection and diagnosis (FDD) and to provide predictive maintenance that would help detect gradual changes due to deterioration before faults occur. This requires analysis of trends and historical data, existence of reliability models, and understanding the relationships between component level behavior to system level metrics.

Deliverables:

- A BMS sub-system that performs diagnostics and prognostics. This subsystem will be based on the integration of several technologies developed in the context of HiPerBRIC, including: sensor and communication networks, reliability models, trend analysis, estimation techniques, reduced order models of buildings and systems.
- HiperBric tools, processes, and validated multi-scale models.

Project I5: Systems Interoperability IWBS package

This project will develop an IWBS package for systems interoperability between building façade, safety, security, HVAC, lighting and power systems in buildings. These systems are usually designed by different contractors and operated by different building systems without any shared information or trade-offs between system performance. Although there are examples of limited system interoperability (e.g. where the fire extinguishing system is connected to the HVAC system, closing all dampers to avoid fire propagation), most of these systems are designed and controlled separately. These systems do not leverage common sets of inputs, including occupancy, IAQ, energy information.

This project will integrate these systems during the design and operation building stages. In a first phase of development, this project will use state-of-the art methods. For example, CO2 measurements can be used for occupancy approximation and energy analysis will be based on equipment and building sensor information. Integrated building management with performance trade-offs and optimization between the different systems will be the main deliverable.

During Phase II, the information that will be used for this interoperability system will utilize HiPerBric building systems models and tools, including occupancy and energy & exergy estimation, fire/smoke propagation estimation, and optimized network & sensors design.

This project is expected to deliver at least 10% national energy savings for commercial buildings based on studies performed in buildings that have BMS (ref [15])

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Deliverables:

- Integration between building systems and platforms during the design stage to select systems and control strategies.
- BMS sub-system to enable the efficient integration (interoperability) of all building subsystems in an optimal way under normal and abnormal operation modes.
- HiPerBric tools, processes and validated multi-scale models

Phase II

Project II1: Technology Maturation Process Refinement

This project will refine the TMP using the enhanced HiPerBric building analysis tools and detailed US building stock data and will focus on extensions to complex building types.

Task II1.1: TMP refinement

Refine the structured process to identify, synthesize, reduce risks, demonstrate and transfer technologies using enhanced HiPerBric tools and detailed US building stock.

Deliverable: TMP documentation - process steps and tools for opportunity identification, concept synthesis, risk reduction and demonstration, and technology transfer.

Task II.2: Collect detailed building stock data

Deliverable: Detailed building stock databases

Task II1.3: Refine tool to model building stock with detailed databases

Deliverable: Tool to model building stock

Task II1.4: Identify future IWBS projects

Exercise the TMP to identify and prioritize future IWBS projects. Building functional decompositions will be used to map subsystem interactions (static and dynamic) to systematically identify non-obvious, high leverage opportunities for meeting net zero energy goals. Future solution sets based, in part, on subsystems, components and materials not yet available will be identified. The BDCOP will be used to model combinations of state-of-the-art lighting/façade/HVAC/on-site generation systems, including innovative systems not deemed mature or robust enough, in their current state, to be included in the IWPS packages. Visualization of energy and exergy performance will be examined to identify system enhancements and integration with substantial potential to improve overall performance. Subsystems, components and materials that currently do not exist or have the required performance, but which appear to be feasible, will be identified and performance targets specified, including cost and risk. The performance targets will be identified based on the enhanced overall performance of the building stock that would be enabled. Estimation of the benefits of achieving a given level of performance improvement, together will the expected cost of achieving those improvements, will be used to determine optimum allocation of R&D resources.

Deliverable: Phase II IWPS projects

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Project II2: Future IWBS packages

These IWBS packages will develop standardized, IWBS packages based on new technologies options delivered through the HiPerBric framework. The specific projects will be identified in Project II2, task II2.4.

It is expected that by integrating the projects in Phase I, the total HVAC energy savings that could be achieve would be from 10% to 90% (9%-79% HVAC saving reported by mix-mode ventilation, 40% HVAC energy savings by diagnostics & prognostics, 10% savings by interoperability). This represents about 5%-45% of total energy building energy savings, without even considering the introduction of energy microgrids. Additionally, integrated whole building design could enable Improvements in building envelope that could easily account for 20% load reduction, bringing energy savings to 22%-60%, depending on the climatic zone and building. Energy microgrids could easily provide additional savings to 40% to 80% only by using cogeneration equipment, or even 100% if solar PV are used.

Resources and Schedule

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	2009	2010	2011	2012	2013	People	Funding ($ M)
Phase I							
I1. Prototype Technology Maturation Process							
I1.1. Develop prototype TMP						2 FTE	$ 0.6 M
I1.1.1. Opportunity identification							
I1.1.2. Concept synthesis							
I1.1.3. Risk reduction / demonstration							
I1.1.4. Technology transfer							
I1.2. Model current building stock with existing databases						2 FTE	$ 0.6 M
I1.3.Define requirements for building stock data collection						1 FTE	$ 0.3 M
I1.4 Identify phase II IWBS projects						1 FTE	$ 0.3 M
I2. Mixed-mode-ventilation (MMV) IWBS Package							
I2.1. MMV IWBS detailed design						2 FTE	$ 0.6 M
I2.2. Develop & validate MMV IWBS tools						3 FTE	$ 0.8 M
I2.3. MMV IWBS subsystem risk reduction (analysis + testing)						2 FTE	$ 0.6 M
I2.4. MMV IWBS demonstration						2 FTE	$ 0.4 M
I2.5. Develop MMV IWBS standard work, documentation, and marketing demos						1 FTE	$ 0.3 M
I2.6. Transfer MMV IBWS to industry partners, Transfer MMV IWBS tools to HiPerBric process						1 FTE	$ 0.3 M
I3. Energy Microgrids (EM) IWBS Package							
I3.1. EM IWBS detailed design						2 FTE	$ 0.6 M
I3.2. Develop & validate EM IWBS tools						3 FTE	$ 0.8 M
I3.3. EM IWBS subsystem risk reduction (analysis + testing)						2 FTE	$ 0.6 M
I3.4. EM IWBS demonstration						2 FTE	$ 0.4 M
I3.5. Develop EM IWBS standard work, documentation, and marketing demos						1 FTE	$ 0.3 M
I3.6. Transfer EM IBWS to industry partners, Transfer EM IWBS tools to HiPerBric process						1 FTE	$ 0.3 M
I4. Integrated BMS for diagnostics & prognostics (BMS-DP) IWBS Package							
I4.1. BMS-DP IWBS detailed design						2 FTE	$ 0.6 M
I4.2. Develop & validate BMS-DP IWBS tools						3 FTE	$ 0.8 M
I4.3. BMS-DP IWBS subsystem risk reduction (analysis + testing)						2 FTE	$ 0.6 M
I4.4. BMS-DP IWBS demonstration						2 FTE	$ 0.4 M
I4.5. Develop BMS-DP IWBS standard work, documentation, and marketing demos						1 FTE	$ 0.3 M
I4.6. Transfer BMS-DP IBWS to industry partners, Transfer BMS-DP IWBS tools to HiPerBric process						1 FTE	$ 0.3 M
I5. Systems Interoperability (SysI) IWBS Package							
I4.1. SysI IWBS detailed design						2 FTE	$ 0.6 M
I4.2. Develop & validate SysI IWBS tools						3 FTE	$ 0.8 M
I4.3. SysI IWBS subsystem risk reduction (analysis + testing)						2 FTE	$ 0.6 M
I4.4. SysI IWBS demonstration						2 FTE	$ 0.4 M
I4.5. Develop SysI IWBS standard work, documentation, and marketing demos						1 FTE	$ 0.3 M
I4.6. Transfer SysI IBWS to industry partners, Transfer SysI IWBS tools to HiPerBric process						1 FTE	$ 0.3 M
Phase II							
II1. Technology maturation process							
II1.1. TMP Refinement w advanced HIPERBRIC tools						6 FTE	$ 1.7 M
Opportunity identification							
Concept synthesis							
Risk reduction / demonstration							
Technology transfer							
II1.2. Collect detailed building stock data						5 FTE	$ 1.4 M
II1.3. Refine tool to model building stock w detailed databases						5 FTE	$ 1.4 M
II1.4. Identify future IWBS projects						5 FTE	$ 1.3 M
II2. Next Generation (NG) IWBS Package Projects (assume 3 projects)							
II2.1. NG IWBS detailed design						6 FTE	$ 1.7 M
II2.2. Develop & validate NG IWBS tools						9 FTE	$ 2.5 M
II2.3. NG IWBS subsystem risk reduction (analysis + testing)						6 FTE	$ 1.7 M
II2.4. NG IWBS demonstration						5 FTE	$ 1.3 M
II2.5. Develop NG IWBS standard work, documentation, and marketing demos						3 FTE	$ 0.8 M
II2.6. Transfer NG IBWS to industry partners, Transfer NG IWBS tools to HiPerBric process						3 FTE	$ 0.8 M
People (includes 9 projects)	13 FTE	25 FTE	28 FTE	23 FTE	12 FTE	**100 FTE**	
Funding (includes only 9 projects)	$ 3.7 M	$ 7.1 M	$ 7.8 M	$ 6.5 M	$ 3.2 M		**$ 28.2 M**

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References

1. *CBECS 2003. Commercial Buildings Energy Consumption Survey commercial energy uses and costs.* Energy Information Administration. *http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html*

2. *California Commercial End-Use Survey (CEUS). http://energy.ca.gov/ceus/index.html, 2008.*

3. *About Mixed Mode*, Center for the Built Environment, University of California, Berkeley, 2005. http://www.cbe.berkeley.edu/mixedmode/aboutmm.html.

4. Dietrich Schmidt1 and Mia Ala-Juusela, *"Low Exergy Systems for Heating and Cooling of Buildings."* VTT Building and Transport, Espoo, Finland. Plea2004 - The 21st Conference on Passive and Low Energy Architecture. Eindhoven, The Netherlands, 19 – 22, September 2004.

5. Poppong Sakulpipatsin, Elisa Boelman, Dietrich Schmidt. *"USING EXERGY ANALYSIS IN THE CONCEPTUAL BUILDING DESIGN PHASE"*, Proceedings of the 2nd International Exergy, Energy and Environment Symposium (IEEES2), Kos-Greece, 3-7 July, 2005.

6. Mehmet Kanogly, Ibrahim Dincer, Marc Rosen, *Exergetic Performance Analysis of Various Cogeneration Systems for Buildings*. 2007 ASHRAE.

7. Birol Kilkis, Siir Kilkis, *Upgrading EU Directive with Rational Exergy Model*. 2007 ASHRAE.

8. EXERGY EFFICIENT BUILDING DESIGN. http://mail.vssd.nl/hlf/f036ch01.pdf

9. The exergy approach. http://www.lowex.net/guidebook/the_exergy_%20approach/the_exergy_%20approach.htm

10. www.lowex.net

11. Radu Zmeureanu, *Sustainable Buildings: Dream or Reality?*. Journée thématique SFT-IBPSA mars 2006. http://perso.univ-lr.fr/fcherqui/IBPSAmars2006/11_RZmeureanu.pdf

12. L.D. Danny Harvey. *A handbook on low-energy buildings and district-energy systems*. Earthcan, 2006.

13. Gail Brager, Natural Ventilation & Mixed-Mode Buildings. Center for the Built Environment, Univ. of California, Berkeley, Golden Gate ASHRAE Meeting, January 10, 2008.

14. Kaarsberg, T., R.Fiskum, J.Romm, A. Rosenfeld, J Koomey and W.P.Teagan. 1998. "*Combined Heat and Power (CHP or Cogeneration) for Saving Energy and Carbon in Commercial Buildings."* In Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings, vol. 9, Washington, D.C.: American Council for an Energy-Efficient Economy.

15. *Energy Management Systems*- Platts, a unit of The McGraw-Hill Companies, Inc. All Rights Reserved. http://www.anaheim.net/utilities/ea/PA_36.html. 2002.

16. California Electric Commissioning, PIER 2003. http://buildings.lbl.gov/hpcbs/Element_5/02_E5.html

17. Altshuller, Henry, *The Art of Inventing (And Suddenly the Inventor Appeared).* Translated by Lev Shulyak. Worcester, MA: Technical Innovation Center, 1994.

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18. K.W. Roth, D. Westphalen, M.Y. Feng, P. Llana, and L. Quartararo. *Energy impact of commercial building controls and performance diagnostics: Market characterization, energy impact of building faults and energy savings potential*. Paper TIAX LLC D0180, TIAX LLC. 15 Acorn Park, Cambridge MA, August 2005.

19. Bordass, Bill. Probe *Strategic Review: Review of the Probe Process SR 1,* August. http://www.usablebuildings.co.uk/

20. Chris Marnay, Michael Stadler), Sam Borgeson, Brian Coffey, Ryoichi Komiyama, and Judy Lai*, A Buildings Module for the Stochastic Energy Deployment System*. 2008 ACEEE Summer Study on Energy Efficiency in Buildings, *Scaling Up: Building Tomorrow's Solutions*, August 17–22, 2008, Asilomar Conference Center • Pacific Grove, California.

21. Walter Short (NREL), Tom Ferguson (NREL), and Michael Leifman (DOE). *Modeling of Uncertainties in Major Drivers in U.S. Electricity Markets*. November 16th and 17th, 2006. https://www.aceee.org/conf/06modeling/doeeere.pdf

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Appendix A: Energy Microgrids Energy Savings

Energy microgrids will bring benefits for:

- Buildings owners or operators
  - Improved reliability
  - Improved power quality
  - Reduced energy costs
  - Seamless transitions
- Utilities
  - Reduced cost of ancillary services
  - Seamless transitions
  - Reduced transmission lines congestion
  - Reduced need to expand or replace existing transmission lines
- Nation / world
  - Green power
  - Energy savings
  - Security of supply

Quantifiable benefits in energy savings vary depending on the cogeneration and renewable usage. The use of cogeneration would bring savings of up to 40%, depending on the building electric, cooling and heating loads. CHP will simultaneously deliver electric and thermal energy and thus use fuel far more efficiently than separate heat and power (SHP) based on power remote plants and onsite thermal supply. In contrast to the delivered electric efficiency (after Transmission and Distribution (T&D) losses) of only 30% or at best electric efficiencies of 50-55%, CHP systems now reach 90% fuel use efficiency (ref. 14). This accounts for more than 40% savings in primary energy. If renewable are included, savings could be up to 100 %

Efficiencies of Conventional Separate Heatand Power (SHP) Technologies.

Separate Heat and Power (SHP) Technologies	**Heat**	**Electric**	**System**
New, Utility-sized Combined Cycle Gas Turbine including T&D losses	N/A	51%	51%
Current U.S. grid including T&D losses	N/A	30%	30%
Typical New Gas Furnace	80%	N/A	80%
New Gas Water Heater	65%	N/A	65%

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