# Executive Summary

The recent **DOE Building Technologies Program Multi-Year Program Plan**[1] (MYP) calls for research programs that use a whole buildings approach to energy efficiency that takes into account the complex and dynamic interactions between a building and its environment, among a building's energy systems, and between a building and its occupants.

The use of the whole building systems approach can achieve energy savings of 30 percent using existing proven technologies, beyond that obtainable by focusing solely on performance optimization of individual building components, such as energy-efficient windows, lighting, and water heaters[1]. Realizing net zero energy buildings NZEB[2,3] will require energy demand reduction of 4-5 times over that for current building stock (i.e. 70-80% efficiency). A vigorous R&D program aimed at maturing and implementing an integrated systems approach to the design, delivery and operation of buildings is required to close this 40-50% efficiency gap.

An integrated building system is complex because: (i) the components do not necessarily have mathematically similar structures and may involve different scales in time or space; (ii) the number of components is large; (ii) components can be connected in a variety of ways, most often nonlinearly and/or via a network. Furthermore, local and system wide phenomena may depend on each other in complicated ways; (iii) the behavior of the overall system can be difficult to predict from the behavior of individual components. Moreover, the overall system behavior may evolve along qualitatively different pathways that may display great sensitivity to small perturbations at any stage.

The delivery of NZEB at a commercially viable, economical level will require investments in new science, methods, tools, and technologies that are not available today. The investments must first focus on basic building sciences (i.e. the physics and dynamics of heat, mass and momentum transfer), develop a suite of tools, models and platforms to synthesize and optimize innovative building systems, and demonstrations of new technologies for building heating, cooling, lighting, material and power. This research effort is truly a grand challenge.

## Addressing the Challenge

The key is to achieve the very high levels of building performance that has only been reached to date by one-of-a-kind solutions, and make them routine, robust, cost effective and persistent. Furthermore, the approach must be sufficiently flexible that it can be applied to a large set of commercial building types (including new and exiting buildings), climates, and ownership models.

In response to the DOE MYP, we propose an R&D program to meet these challenges and to lead innovations in the design and operation of energy efficient commercial buildings. The proposed **H**igh **P**erformance **B**uildings **R**esearch & **I**mplementation **C**enter (**H**i**P**er**BRIC**) will be a partnership between the National Laboratories, Industry and Academia that engages relevant stakeholders to provide the broad and deep R&D base needed to enable market transformation in the commercial building sector. The focus will be on the necessary delivery methods, modeling, analysis, simulation and computational methods, and the basic science required for the economical delivery of high performance buildings and building technologies enabling broad market adoption.

> ***The goal of HiPerBRIC*** *is to enable the transformation of the U.S. commercial buildings sector in 15-20 years, starting now, by saving greater than 4 Quads of energy, and reducing by 400 million tons of CO2 annually. This will be accomplished by targeting a reduction in energy con-*

[1] "Commercial Integration Approach/Strategies for Overcoming Challenges and Barriers," DOE EERE Building Technologies Multi Year Plan – draft 04/08
[2] http://www.architecture2030.org/2030_challenge/index.html
[3] http://www.ashrae.org/doclib/20080226_ashraevision2020.pdf



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*sumption of 90% in new buildings (over current baselines) and more than 50% in retrofits, at reasonable economic costs, while simultaneously improving health, comfort, safety/security, and water usage, in buildings.*

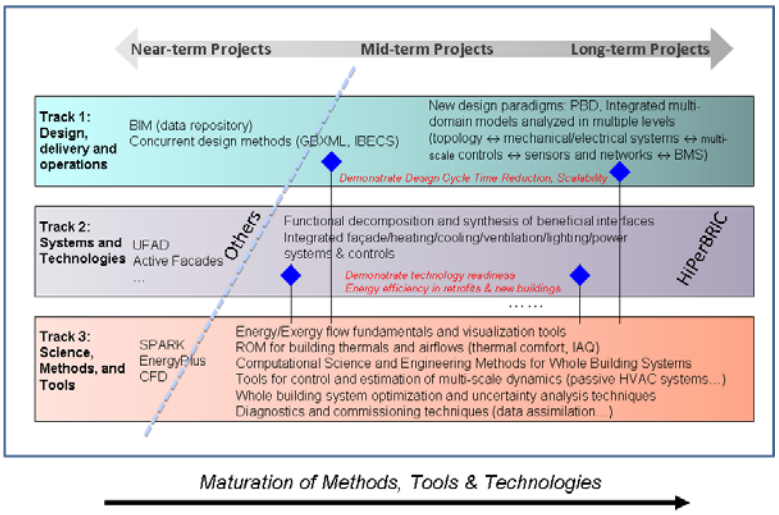
*The HiPerBRIC approach focuses on the development of comprehensive R&D and demonstration programs that are based on an integrated systems model-based approach to whole building research and development. These programs will address complex multi-scale whole building dynamics, modeling uncertainty and the interactions between a building, its component systems and disturbances.*

The proposed R&D program will develop the enabling science and engineering tools to achieve the stated goals, address equipment standards and analysis, technology validation and market introduction. Consequently, HiPerBRIC will require corresponding and coordinated efforts in technology demonstrations, education, outreach, technology commercialization and policy tools. HiPerBRIC will provide a mechanism to coordinate intra- and inter-agency collaboration and other critical drivers of innovation.

## Proposed R&D Program

Central to the HiPerBRIC program is use of modeling, systems analysis, computational science and engineering to integrate building design, optimization and operation, focused on creating and exploiting new subsystem interfaces in a building. This will enable accountability for whole building performance to be enforced throughout the life-cycle, something that is not possible currently but which can drive a radical transformation of the commercial buildings sector. The design methodology, process, tools and algorithms to be developed will be used to identify and mature new solutions for very low energy buildings, including: new systems and controls, components and materials, and standard designs-based proven technologies for particular classes of commercial buildings and climate zones. To achieve this, investment in a series of research projects, test beds, pilot projects and collaborations is necessary, and methods of readily delivering these in a commercially viable manner must be developed. It is the methods and systems required to deliver these future, high performance whole building systems that is the focus of the HiPerBRIC R&D program.

HiPerBRIC will consist of a series of interrelated projects in parallel tracks to comprise a comprehensive research program. The program will have a series of intermediate industry deliverables, focused on specific advances to design systems and tools and to technologies and systems. Three program tracks (illustrated below) will enable focused execution of the research projects to meet HiPerBRIC goals via (i) design and delivery of integrated systems for high performance buildings, (ii) maturation of novel systems technologies and concepts, and (iii) foundational science, methods and tools underpinning the whole building design methods and systems.




BIM: Building Information Modeling
BMS: Building Management System
CFD: Computational Fluid Dynamics
CS&E: Computational Science and Engineering
GBXML: Green Building XML schema
HVAC: Heating Ventilation Air Conditioning
IAQ: Indoor Air Quality
IBECS: Integrated Building Environmental Communications Systems
PBD: Platform Based Design
ROM: Reduced Order Model
UFAD: Under Floor Air Distribution System

**Research and Development Tracks**

*Track 1: Design, Delivery and Operations:* This track is focused on developing and maturing methods used to design and deliver systems for both new and existing buildings. The proposed projects will focus on the required tools and methods that architects, engineers, contractors and operators will use for future NZEB projects. Projects will implement new processes and toolsets in the context of specific low energy building designs, and quantify the benefits in design cycle time reduction and improved performance verification capability. The specific advances required in understanding of the underlying building physics and dynamics, the associated models, analysis framework and tools will be the focus on the third track. Examples of methodologies, processes and tools proposed to be developed include:

- Use of digital models (such as BIM) for use in integrated design, construction, and operations
- System-level methodologies to analyze and optimize the configuration and integration of building components and subsystems and new design paradigms involving multiple analysis and synthesis layers (using principles of platform-based design) to handle complexity
- Environment for integration modeling and analysis tools to enable cost-performance trades at various scales of a building and stages of the design and delivery process

*Track 2: Systems and Technologies:* This track is focused on the integrated systems and innovative subsystems required to realize high performance buildings with significantly lower energy usage footprint. These include the building envelope, site placement, mechanical, electrical and controls systems. Each of these systems must be integrated to maximize energy efficiency, by managing the interfaces or introducing new ones between the various subsystems (such as between the building environment and envelope and between the equipment and the indoor occupants and aero-thermal environment). Just as importantly, they will need to be delivered in a form that is both economical and readily used by current and anticipated future industry players. To do this will require a focus on not just the technology used in these systems but also the proper methods of delivery, serviceability, cost, integration and operability of these systems. Projects in this track will identify, engineer, develop and mature (via demonstrations) innovative systems that result in measurable, non-incremental gains in energy demand reduction in new construction as well as retrofit commercial buildings. The engineering of these systems will employ and leverage advances in system synthesis and analysis methods (proposed in the first track) and methods and tools being proposed in the third track (to follow). The project investments needed here include identification of new technology solutions, optimization and scalable designs and prototypes of solutions for which physical implementation is already defined or those for which the implementation strategy is understood but not the implementation details. Proposed projects focus on subject matter such as:

- Strategies for separation of ventilation from heating and cooling
- Strategies for optimizing mixed mode and passive/natural ventilation systems
- Passive heating and cooling strategies and systems
- High efficiency integrated envelope and lighting systems, and controls
- Innovative thermal storage systems
- Automated diagnostics, performance monitoring and self-commissioning building systems
- Combined heat and power systems and their integration with building thermals and systems
- Optimized integration of on site renewables with building systems

*Track 3: Science, Methods and Tools:* In the buildings area there has been relatively little basic research conducted over the last 50 years in areas related to the delivery of building services including comfort, safety, and indoor environment. This track proposed investments in understanding the basic physics and dynamics of heat, mass, momentum and information transfer that underlies building performance with highly integrated systems and the essential delivery of associated building services. Research issues to be tackled include: physics of coupled building thermals and airflow transport, and models to capture relevant behavior, analytical techniques to explore multi-scale dynamics, controls and estimation required to exploit and manage integration and coupling



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of energy and information flow among building subsystems, and methods to compute multi-physics and multi-scale dynamics of coupled building phenomena and systems. The proposed investments will be instantiated via projects to impact the systems and technologies and design and delivery tracks for the delivery of new system solutions and optimized designs. Proposed projects focus on subject matter such as:

- Physics of heat transfer, thermal storage and heat rejection in integrated systems
- Exergy and energy flow analysis methods
- Performance issues related to human comfort
- Reduced-order models of above phenomena for rapid analysis/optimization of new control strategies
- Tools to analyze and optimize multi-scale control strategies, involving dynamic phenomena such as building thermals, airflow patterns and occupancy usage and patterns
- Computational science and engineering methods for multi-physics simulation-based design and whole building optimization and control
- Uncertainty propagation and sensitivity analysis techniques for the design of integrated systems
- Information theoretic methods for real-time assimilation of building operations and performance data