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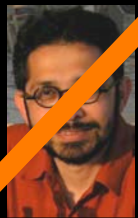
Integrated Cost Estimation Methodology to Support High-Performance Building Design



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Integrated Cost Estimation Methodology to Support High-Performance Building Design

What we are after:

Policy measures to encourage the integrated approach and reduce the barriers towards improved energy performance.

- Design teams evaluating the performance of Energy Conservation Measures (ECMs) calculate energy savings rigorously with *established modelling protocols*, accounting for the interaction between various measures
- However, incremental *cost calculations do not have a similar rigor*
  - Often there is no recognition of cost reductions with integrated design, nor is there assessment of cost interactions amongst measures
- This lack of rigor feeds the *perception* that high-performance buildings cost more, creating a barrier for design teams pursuing aggressive high-performance outcomes

Integrated Cost Estimation Methodology to Support High-Performance Building Design

- This study proposes an alternative integrated methodology to arrive at a lower *perceived* incremental cost for improved energy performance
- The methodology is based on the use of energy simulations as means towards integrated design and cost estimation

A case study showing the differences between perceived costs for energy measures along various points on an integration spectrum.

The intent is to show design tradeoffs and identify how decisions would have been different with a standard costing approach.

- The *spectrum* of integration is identified and characterized by
  - Amount of design effort invested
  - Scheduling of effort
  - Relative energy performance of the resultant design

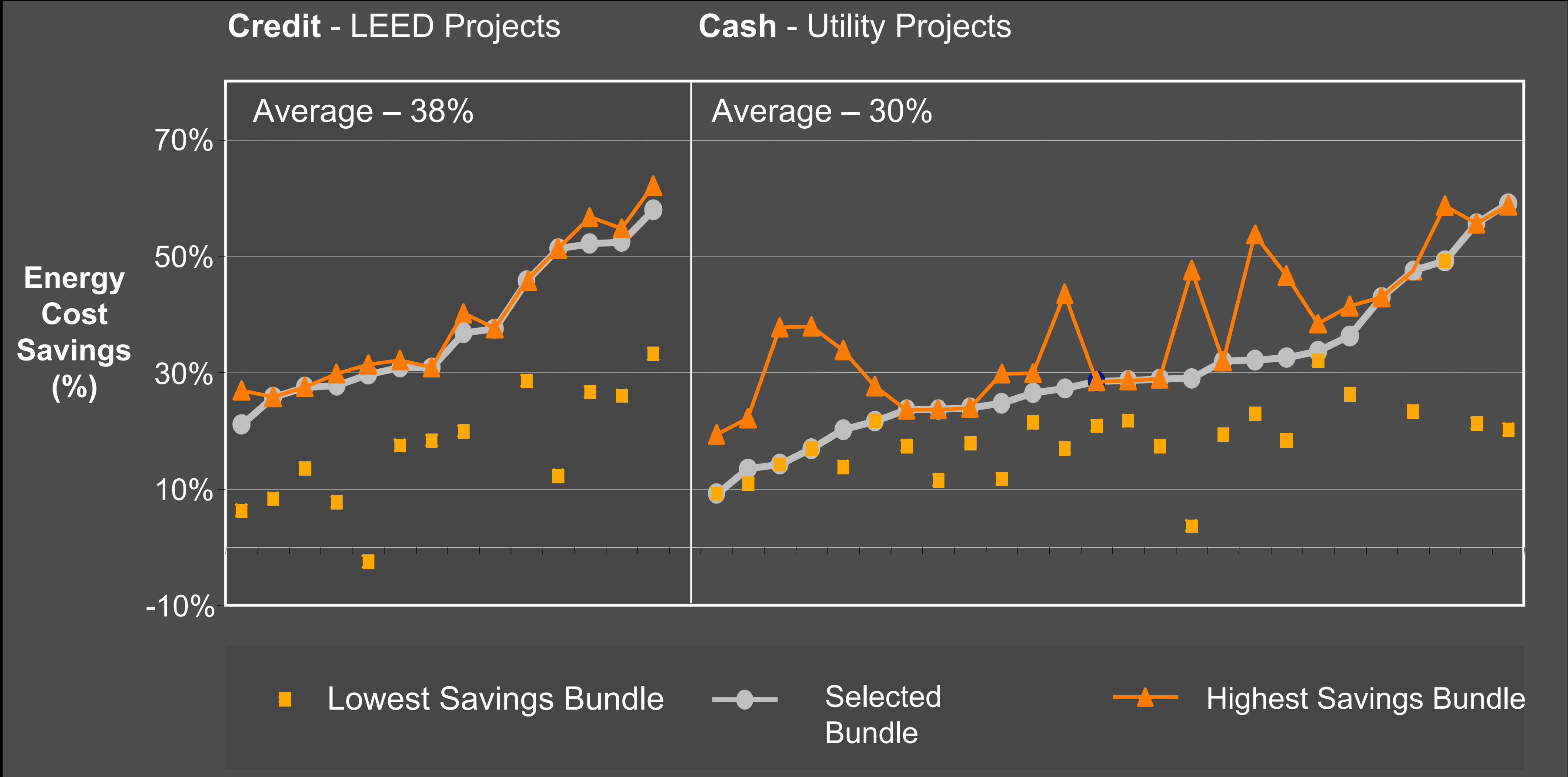
Background
Market Barriers

- Predefined construction budgets in a market place of unpredictably rising construction costs
- Even a small increase in the first cost makes energy-efficient technologies *appear* out of reach
  - With a fixed construction budget, the *perceived* ability of a design and construction team to invest in these technologies continues to be severely limited
- Integrated, design is regarded as a way of achieving high performance without significantly raising the first cost of the building
- However, this process is also seen as the most difficult aspect of green building design

Background

Energy Cost Savings Left on the Table

DSM programs, federal and local legislation, accept the "first cost barrier" and address it by seeking to reducing first costs through rebates, tax incentives and other forms of financial assistance. Perhaps it is time to change the underlying methodology such that the perception of high incremental costs is reduced.



Vaidya et. al. ACEEE Summer Study 2006

Background
Energy Cost Savings Left on the Table

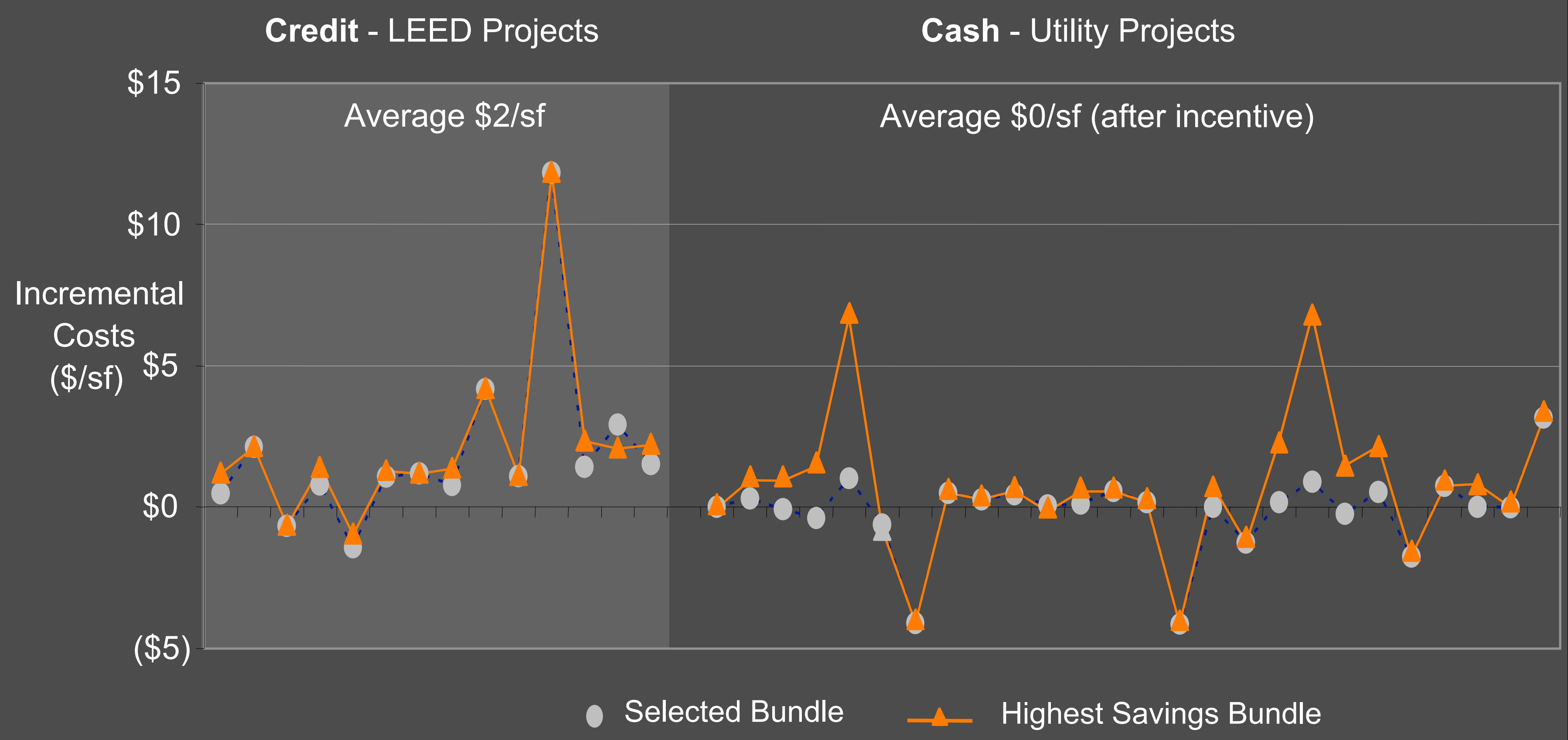
The term bundle refers to the entire set of energy conservation strategies considered as a candidate design for the building.

- During the Energy Design Assistance for each project, energy savings for bundles of strategies were calculated compared to an applicable energy code baseline.
- Multiple bundles represented the range of possible energy efficiency solutions for each building as created by each design team.
  - The *Lowest Savings Bundle* includes measures that the design team *would have done as part of their standard practice*. This bundle is thus *defined as* the *zero incremental cost* solution as *perceived* by the design team.
  - The *Lowest Savings Bundle* may be considered as closest to what the design team might have implemented in the absence of any incentive – be it Utility or LEED .
  - Incremental costs for other bundles were usually above, but in some cases below, this Lowest Savings Bundle.

Background

Perceived Incremental Costs Normalized to Building Area ($/sf)

New construction projects choose energy savings packages that are low cost additions to the budget but market leaders choose slightly higher incremental costs, the more conservative market chooses packages with almost no added cost



Vaidya et. al. ACEEE Summer Study 2006

Background

Perceived Incremental Costs Normalized to Building Area ($/sf)

- Negative incremental costs for several LEED projects arise from the inclusion of strategies in the *Selected Bundle* that are more cost effective than those that the design teams would have included without the benefit of the analysis
- For Utility projects, 3 of the 9 instances of negative incremental costs are similarly explained, and the other 6 are explained by the reduction in incremental cost due to the incentive.
- The negative costs for higher savings show the value of the optimization exercise in allowing the design team to create alternative solutions or bundles after they have seen the energy performance results of the individual strategies.

Background
Barriers

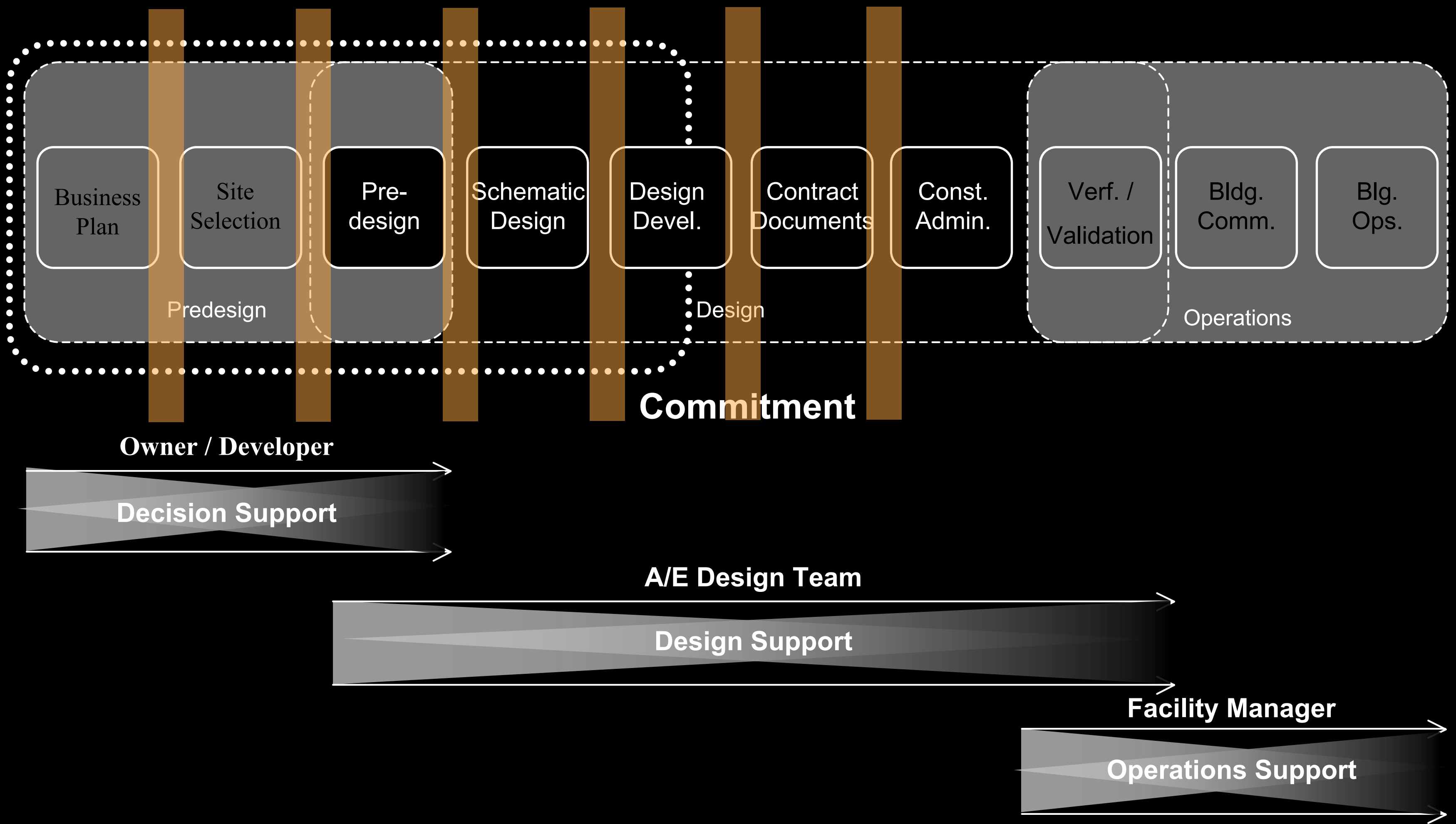
Isolated examples of integrated design in the sustainable design community have demonstrated high performance without significantly increasing the cost beyond a standard performance design.

However, without a clearly defined alternative methodology, such experiences remain few in number and inaccessible to the larger market.

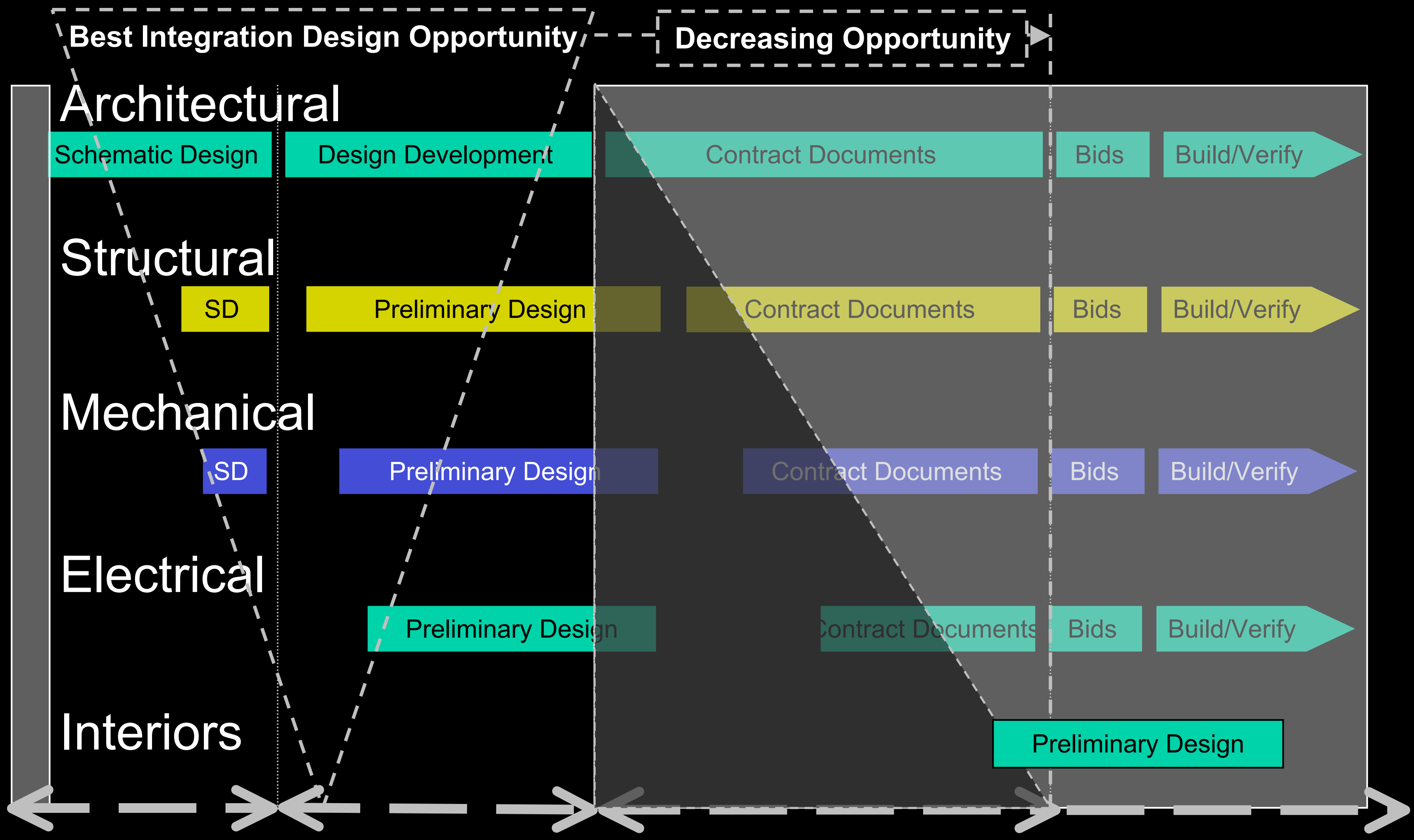
- Design teams evaluating ECMs perceive the barrier of increased capital costs
  - ECMs are widely seen as attractive long-term investments, but the lack of construction funds creates a significant barrier for implementation
- Current methods of *sequential design and cost estimation* make it hard to follow an integrated approach that would change the perception of these capital costs

Sequential Cost Estimating

Influencing the Traditional Design and Construction Process



The Design Process



Background
Market Barriers

- Market barriers frequently referred to by demand side management (DSM) representatives
  - Lack of information of energy-efficient products and practices
  - High first costs
  - Uncertainty and risk regarding the performance of the technologies
  - Lack of incentives to pursue energy efficiency in the current economic frameworks.

Background
Market Barriers

- Generally address the first cost barrier by reducing first costs through
  - Rebates
  - Tax incentives
  - Other forms of financial assistance
- First cost is never completely eliminated and that the consumer/owner is expected to bear some portion of the increased cost

Background

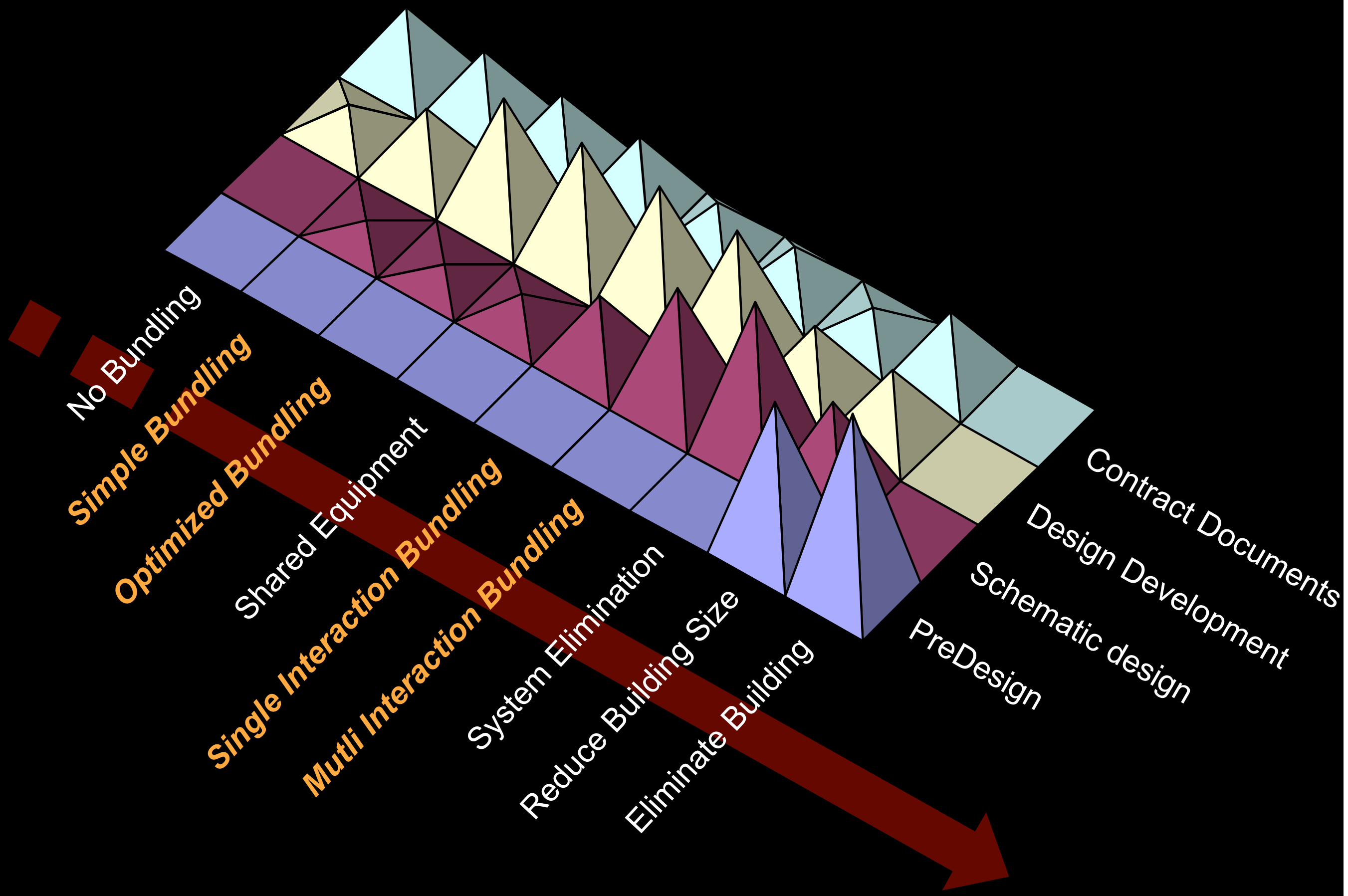
Primary Barriers to an Integrated Design Process

- Unfamiliarity with the process
  - The "business as usual" approach to design is a *sequential solving of design issues. Integrated design requires a simultaneous resolution of multiple issues by multiple experts.*
  - The lack of a clear map of an integrated design process means that design teams easily fall back to conventional linear practice.

Spectrum of Integration
Relative Design Effort

INTEGRATION SPECTRUM

- No Bundling
- Simple Bundling
- Optimized Bundling
- Shared Equipment
- Single Interact'n Bundling
- Mutli Interact'n Bundling
- System Elimination
- Reduce Building Size
- Eliminate Building



Methodology

Spectrum of Cost Integration – No Bundling

- Individual ECMs have no impact on each other in terms of design implications or first cost.
- ECMs are included based on their individual merit
  - Possibly a payback period less than a threshold value
- A design team following this process could make decisions based on analysis of individual ECMs, savings and payback reported by equipment sellers, or the availability of utility component rebates.

Methodology

Spectrum of Cost Integration – Simple Bundling

- A simple bundling process evaluates a group of ECMs as a combined solution and evaluates the entire bundle of ECMs as a single alternative.
  - A bundle could consist of ECMs that deal with building envelope, insulation, glazing, lighting, and mechanical controls, and a design team could evaluate multiple such bundles as alternative design solutions.
  - Detailed energy analysis of individual ECMs, as well as the proposed bundles, is necessary to evaluate their energy performance.
  - Bundling allows ECMs with short and long payback periods to be included in the design as long as the overall bundle payback is acceptable to the owner.
- However, evaluating the combined energy performance of a bundle does not provide sufficient information to a design team to enable accounting of the design and cost interactions of the ECMs, as they are still considered additions to a base design.

Methodology

Spectrum of Cost Integration – Optimized Bundling

An example of this is where an architect provides windows for daylight; however without analysis, the overall window area is more than the optimized value for the building. Since this is implicit in the initial design, such ECMs are considered part of the design budget and thus are assumed to have no incremental cost.

- The process of optimization evaluates implicit strategies as well as their alternatives *using a parametric analysis for energy performance* and costs.
- This method groups ECMs that are implicit in the design into a Design Base bundle
  - Implicit ECMs are assumed by the design team to have no additional first cost beyond the budget. Sometimes an ECM is included in a design based on past experience, where its energy efficiency value is either assumed or ignored

Methodology

Spectrum of Cost Integration – Optimized Bundling

However, similar to *Simple Bundling*, *Optimized Bundling* does not necessitate the accounting of cost interactions between ECMs – each parameter is still estimated individually for its incremental cost.

- Parametric modeling evaluates the performance parameters below and above those implicit in the design, thus bracketing the issue
  - A cost-benefit-analysis of performance values can remove implicit ECMs with low value and include others with higher value by trading off their costs against each other
- This process requires parametric modeling, definition of a zero cost Design Base and trade-offs between ECMs to achieve an optimized bundle of strategies.

Methodology

Spectrum of Cost Integration – Single Interaction Bundling

- At this level of integration, an ECM's impact on the design of other building systems is accounted for in the cost estimates for energy efficiency.
- Examples
  - Higher efficiency lighting that reduced cooling loads and cooling system capacity
  - Increased surface reflectances that improve the efficacy of the lighting system thereby allowing a reduction in the overall number of lighting fixtures
  - Energy recovery wheels reducing the cooling and heating system capacities.
- The extent of the cost integration is such that *one system affects only one other system*.
- Cascading, or domino effects, of costs are not considered at this level.

Methodology

Spectrum of Cost Integration – Shared Bundling

- Shared equipment is a type of interaction bundling that takes into account the *common components between different ECMs*, and this intersection of components is reflected in the cost estimation.
- Examples
  - Occupancy and daylighting controls that share low voltage wiring and relay costs
  - Occupancy sensors that are used both for lighting controls and control temperature setbacks and airflow ventilation

Methodology

Spectrum of Cost Integration – Multiple Interaction Bundling

Domino effects of systems can also require iterative assessment of system costs.

Obviously, an exhaustive accounting of multiple interactions of building systems would be a very involved process that could be achieved with very sophisticated design and estimation tools or with a very committed design team effort.

- This level of integration takes into account the domino effects of an ECM on multiple systems.
- Examples
  - Paint selection for improved interior surface reflectances can impact lighting fixture count, which affects the dimming ballast count for daylighting control and the reduced capacity of cooling equipment.
  - Improved glazing visible transmittance can reduce window areas, which can reduce the cooling system loads with smaller HVAC ducts, which allows a higher ceiling height, which then allows the windows to be raised higher, which improves the daylighting performance, which further reduces the cooling capacity and duct sizes.

Methodology

Spectrum of Cost Integration – System Elimination

- This approach explores the improvement in the efficiency of one system to the extent that it allows the complete elimination of another system.
- Examples
  - In certain climates the installation of 4-pane insulated glazing allows the elimination of the perimeter fin tube radiation.
    - This was the approach taken for the headquarters of the Rocky Mountain Institute in Colorado (U.S.A.) where a passive solar design combined with a super insulated building envelope allowed the designers to eliminate the heating system in the building

Methodology

Spectrum of Cost Integration – Reduce Building Size

- Shared spaces and assigning common physical spaces to multiple functions results in a reduced building program.
- Examples
  - Library rooms in offices can be used as conference spaces, and multipurpose rooms in schools can function as special classrooms needed for art or music education.
- This is one of the most effective ways of reducing costs and energy consumption in buildings, which can be achieved through *rigorous programming exercises in the pre-design phase*. This approach requires owner buy-in and commitment.

Methodology

Spectrum of Cost Integration – Eliminate Building

- This is perhaps the best way of reducing the environmental impacts of building and avoiding the cost of new construction.
- Examples
  - If a company expects a 10% personnel growth that would require a building addition or building a new and larger facility, an alternative approach would be to institute a telecommuting program for 10% of the employees such that the existing building area could continue to serve the increased company size.
- This avoids the cost and environmental impacts of new construction and avoids additional energy use, while also reducing the transportation energy and infrastructure related impacts of commuting.

Background

Primary Barriers to an Integrated Design Process

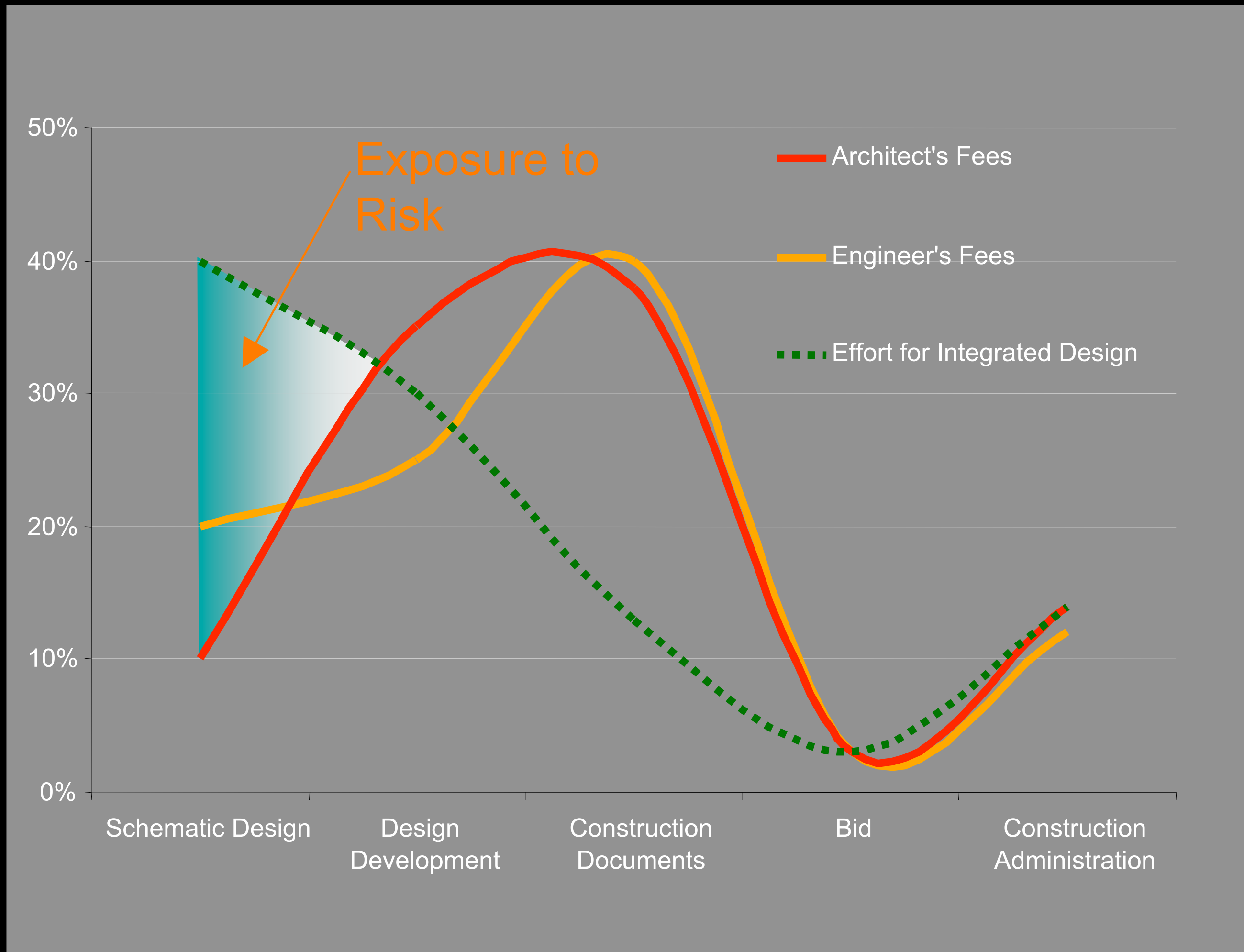
- Perception of risk by the engineers
  - The integrated process involves going *beyond rules of thumb* and abandoning traditional safety factors and margins. This requires *increased trust* between different design disciplines and a *continuous check* through the design and construction process such that fine-tuned design *parameters are not violated*.
  - Since the integrated design is interdependent on a mix of parameters, *a small change in one can have a cascading or "domino" effect on others.* Many designers do not feel a sense of comfort with these narrower margins for error.

Issues with Integrated Design

Integrated Design offers a solution, but itself has barriers

- Unfamiliar process
- Owner's expectations
- Fee structure
- Perception of risk

Cost estimation is not integrated – everything is treated as an added cost, and as independent line item



Methodology
Integrated Costing

- Begin with a high-level mapping of the *spectrum* of design and cost integration
- Assess cost interactions between building parameters
- Test cost functions for important parameters
- Develop a tool to facilitate integrated costing

Spectrum of Integration
Relative Design Effort

INTEGRATION SPECTRUM

No Bundling

Simple Bundling

Optimized Bundling

Shared Equipment

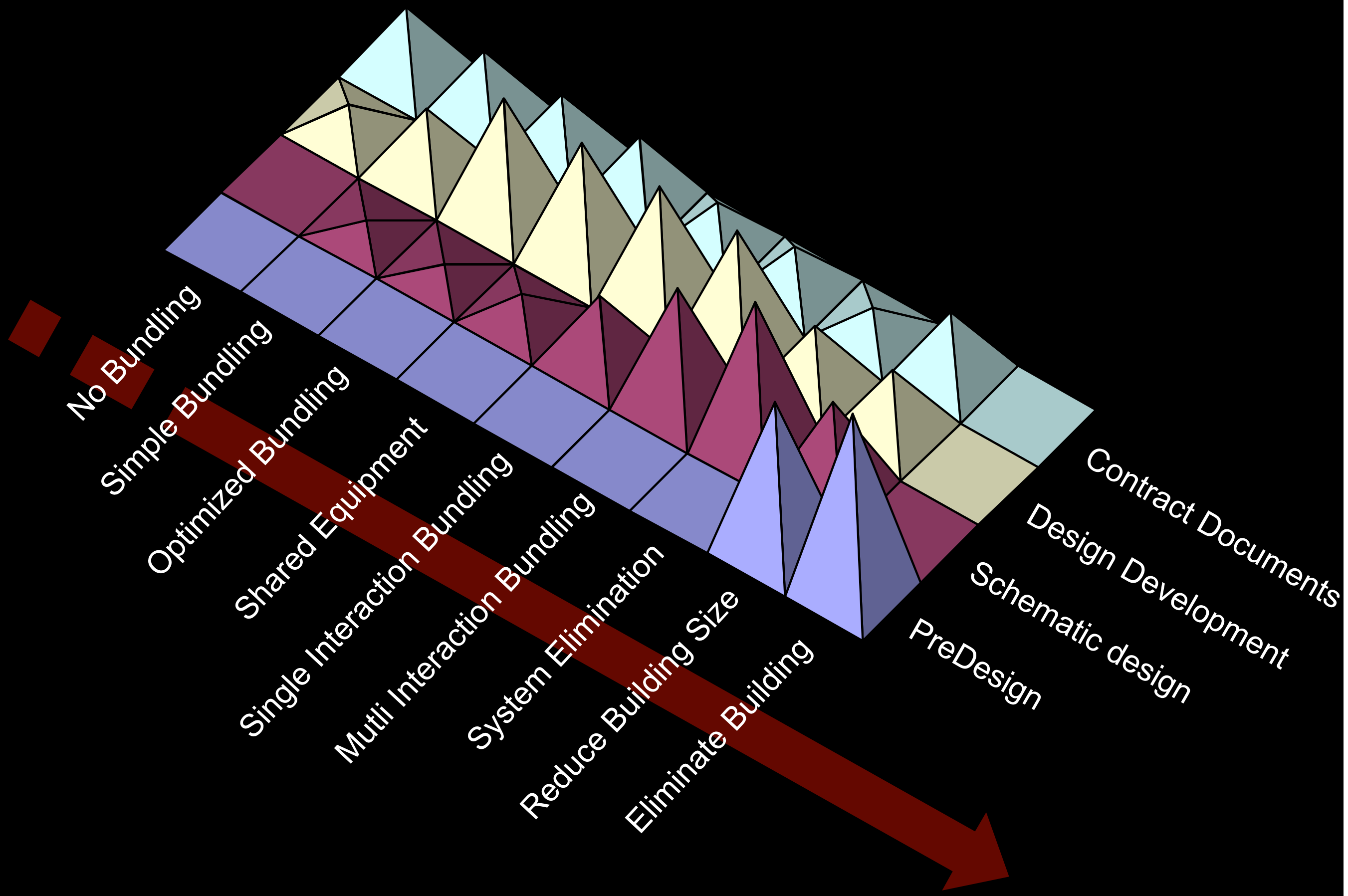
Single Interact'n Bundling

Mutli Interact'n Bundling

System Elimination

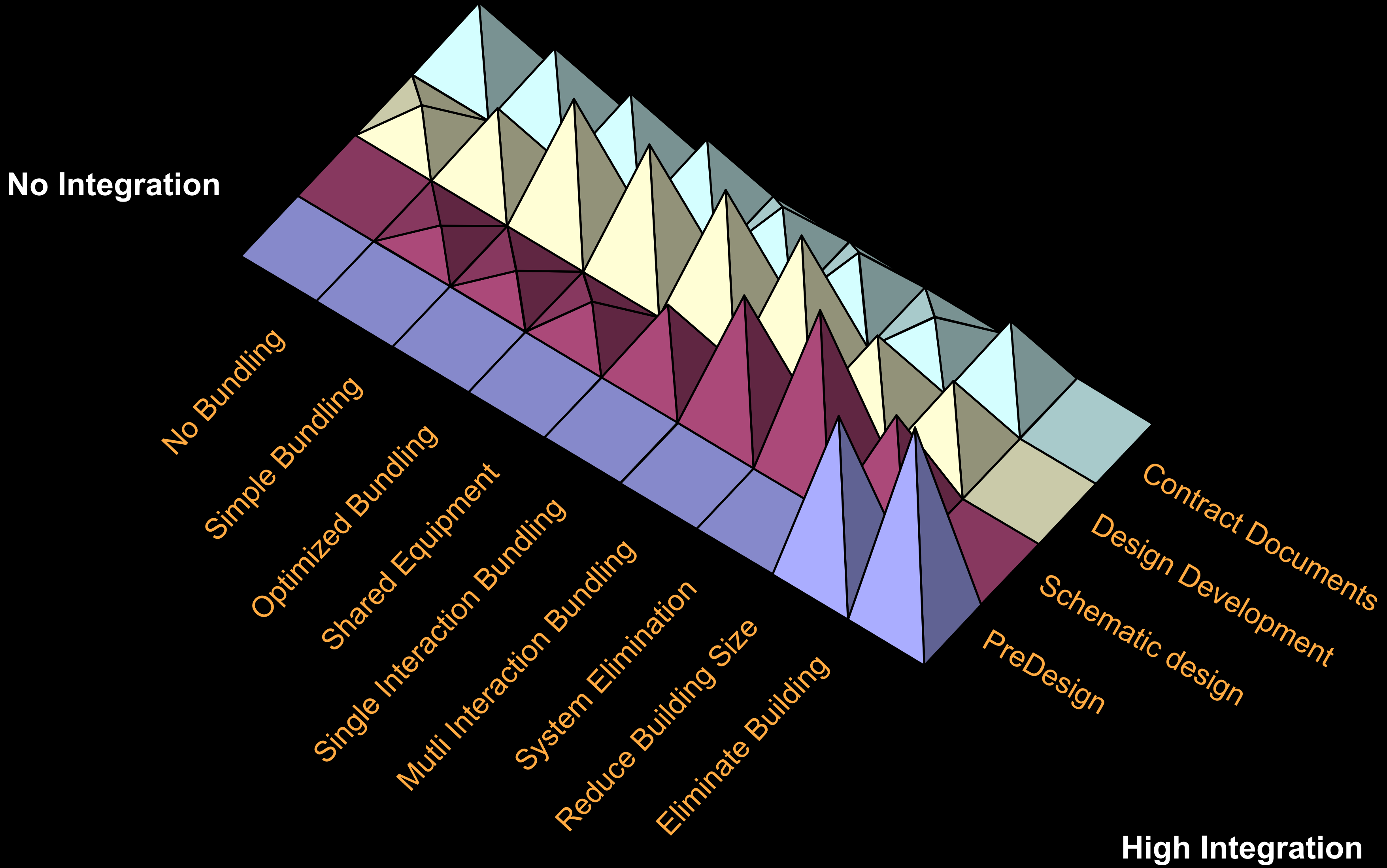
Reduce Building Size

Eliminate Building

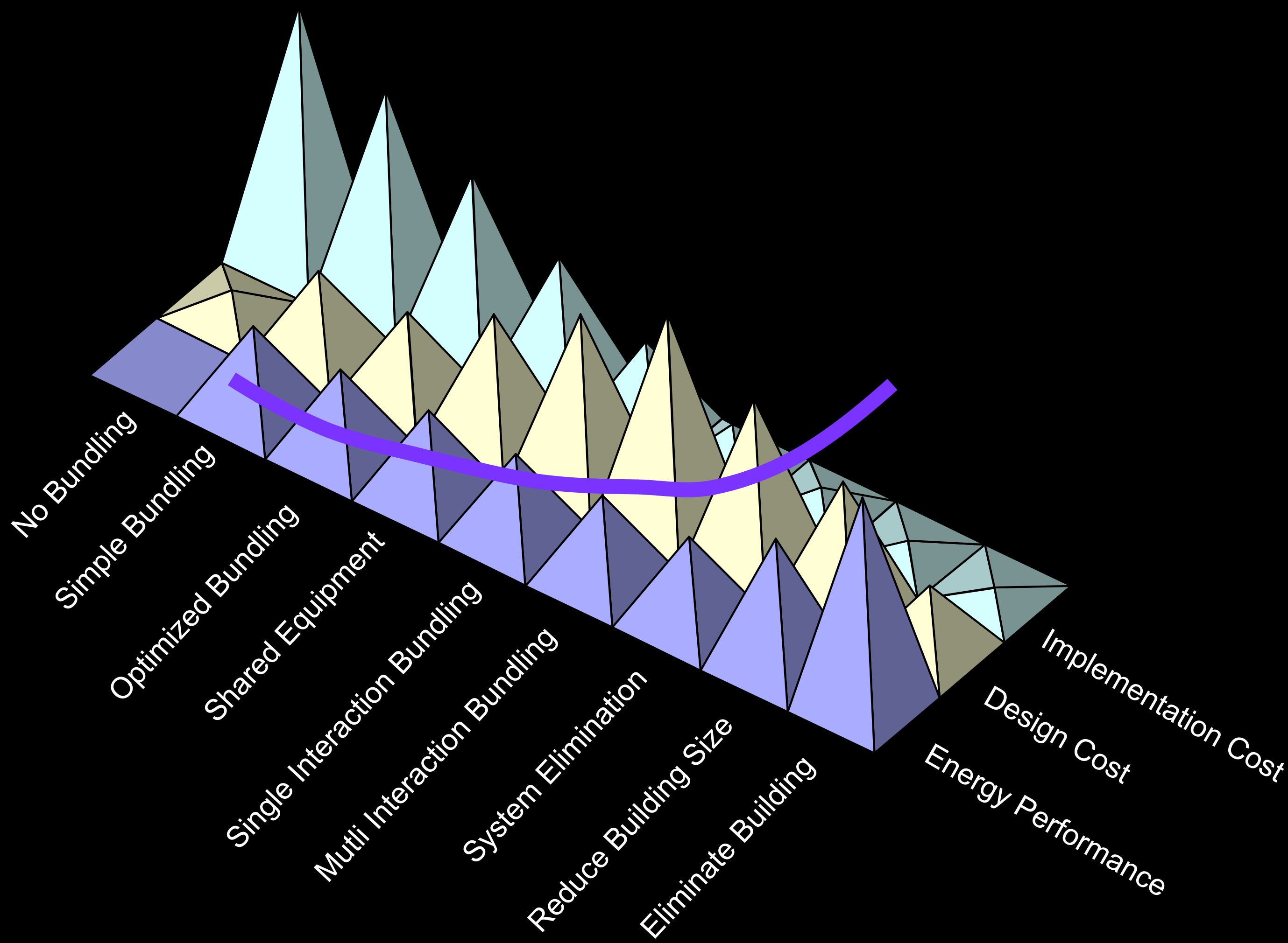


Spectrum of Integration

Relative Design Effort



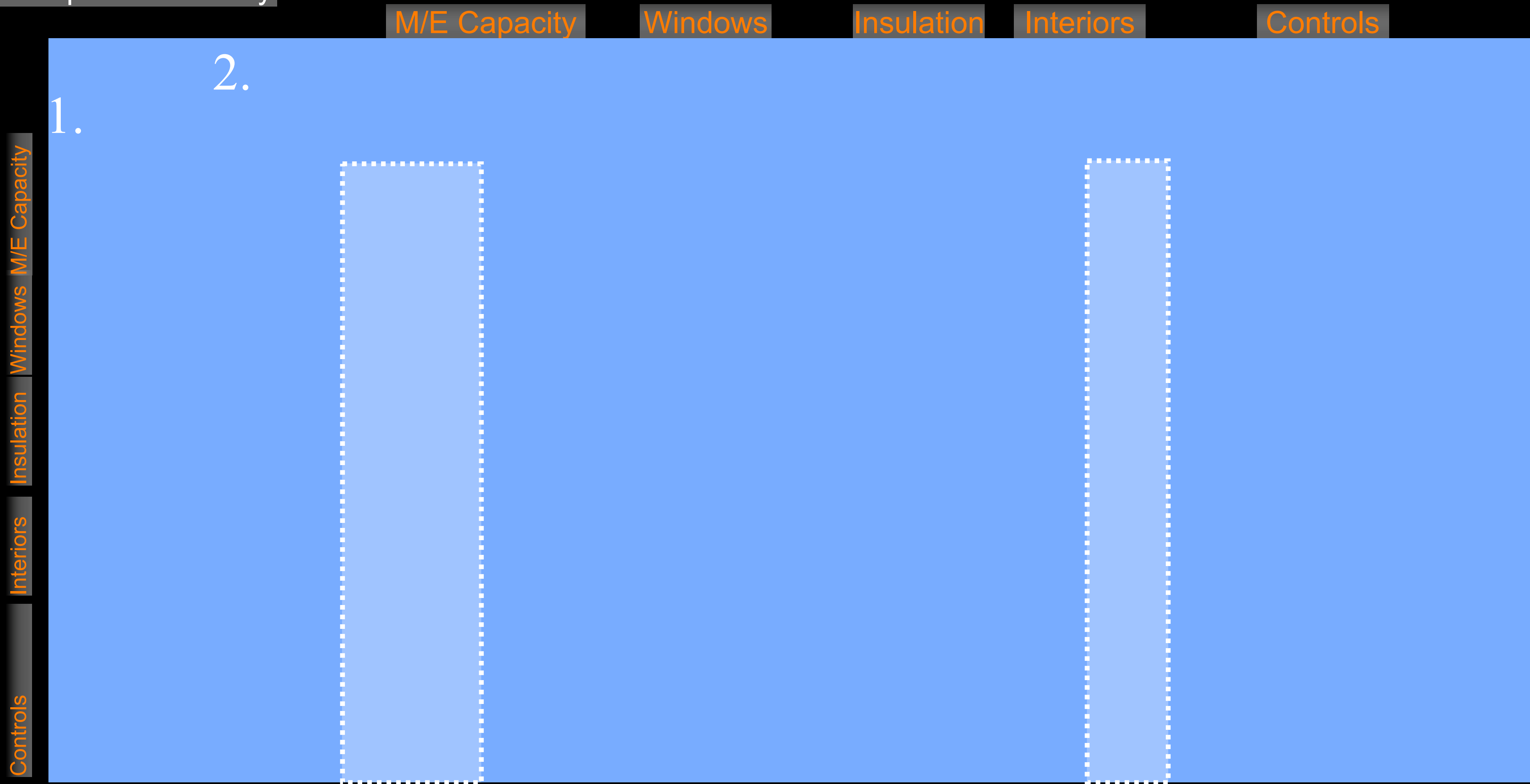
Spectrum of Integration
Relative Cost and Performance



Interaction Between Parameters

Indirect Impact (1) or Direct Impact (2)

Conceptual Draft only



Heating plant size, cooling plant size, and daylighting control are affected more often than any other parameter; the impacts on the plant size are also most often direct as opposed to indirect.

Interaction Between Parameters

Direct Impacts High (3), Medium (2), Low (1)

Conceptual Draft only

M/E Capacity | Windows | Insulation | Interiors | Controls

1. Cause / 2. Effects	Lighting Power Density	Heating plant size	Cooling plant size	Supply air/duct/fan size	Glazing U-factor	Glazing SHGC	Glazing VT	Window Size	Window overhangs	Wall Insulation/ mass	Roof Insulation	Interior refletances	Ceiling Height	Floor to floor height	Structural design	OS Control Lighting	Daylighting Control	Ventilation air quantity	CO2 control of OA	OS control of air	Heat Recovery
Lighting Power Density		2	3	2													3				
Heating plant size															I						
Cooling plant size															I						
Supply air/duct/fan size		3	3										2	2	I		2				
Glazing U-factor		3																			
Glazing SHGC		1	3	3			1														
Glazing VT						1											3				
Window Size		3	3	3	3	3											3				
Window overhangs		1	2	2				1													
Wall Insulation/mass		3	2	1																	
Roof Insulation		3	1	1																	
Interior refletances	3	I	I														3				
Ceiling Height	3	I	I	2										2	I		3				
Floor to floor height																					
Structural design																					
OS Control Lighting		1	1														2			3	
Daylighting Control		1	1													2					
Ventilation air quantity		3	3	1																	
CO2 control of OA		2	2																	3	
OS control of air		2	2													3			3		
Heat Recovery		3	3																		
Building orientation		3	3					2									3				

simple | simple

Other parameters have low impacts. Lighting controls such as occupancy sensors have low impacts because they do not reduce loads significantly at peak times means; CO2 control of outside air has low impacts on plant sizes for the same reason.

Interaction Between Parameters

Complex Interactors

Conceptual Draft only

M/E Capacity | Windows | Insulation | Interiors | Controls

1. Cause / 2. Effects

Cause	Lighting Power Density	Heating plant size	Cooling plant size	Supply air/duct/fan size	Glazing U-factor	Glazing SHGC	Glazing VT	Window Size	Window overhangs	Wall Insulation/ mass	Roof Insulation	Interior refletances	Ceiling Height	Floor to floor height	Structural design	OS Control Lighting	Daylighting Control	Ventilation air quantity	CO2 control of OA	OS control of air	Heat Recovery
Lighting Power Density		2	3	2													3				
Heating plant size															I						
Cooling plant size															I						
Supply air/duct/fan size		[illegible]	3										[illegible]	[illegible]	I		2				
Glazing U-factor		3																			
Glazing SHGC		1	3	3			1														
Glazing VT						1											3				
Window Size		3	3	3	3	3											3				
Window overhangs		1	2	2				1													
Wall Insulation/mass		3	2	1																	
Roof Insulation		3	1	1																	
Interior refletances	[illegible]	I	I														3				
Ceiling Height	3	I	I	2										2	I		3				
Floor to floor height																					
Structural design																					
OS Control Lighting		1	1														2			3	
Daylighting Control		1	1													2					
Ventilation air quantity		3	3	1																	
CO2 control of OA		2	2																	3	
OS control of air		2	2													3			3		
Heat Recovery		3	3																		
Building orientation		3	3					2									3				

simple

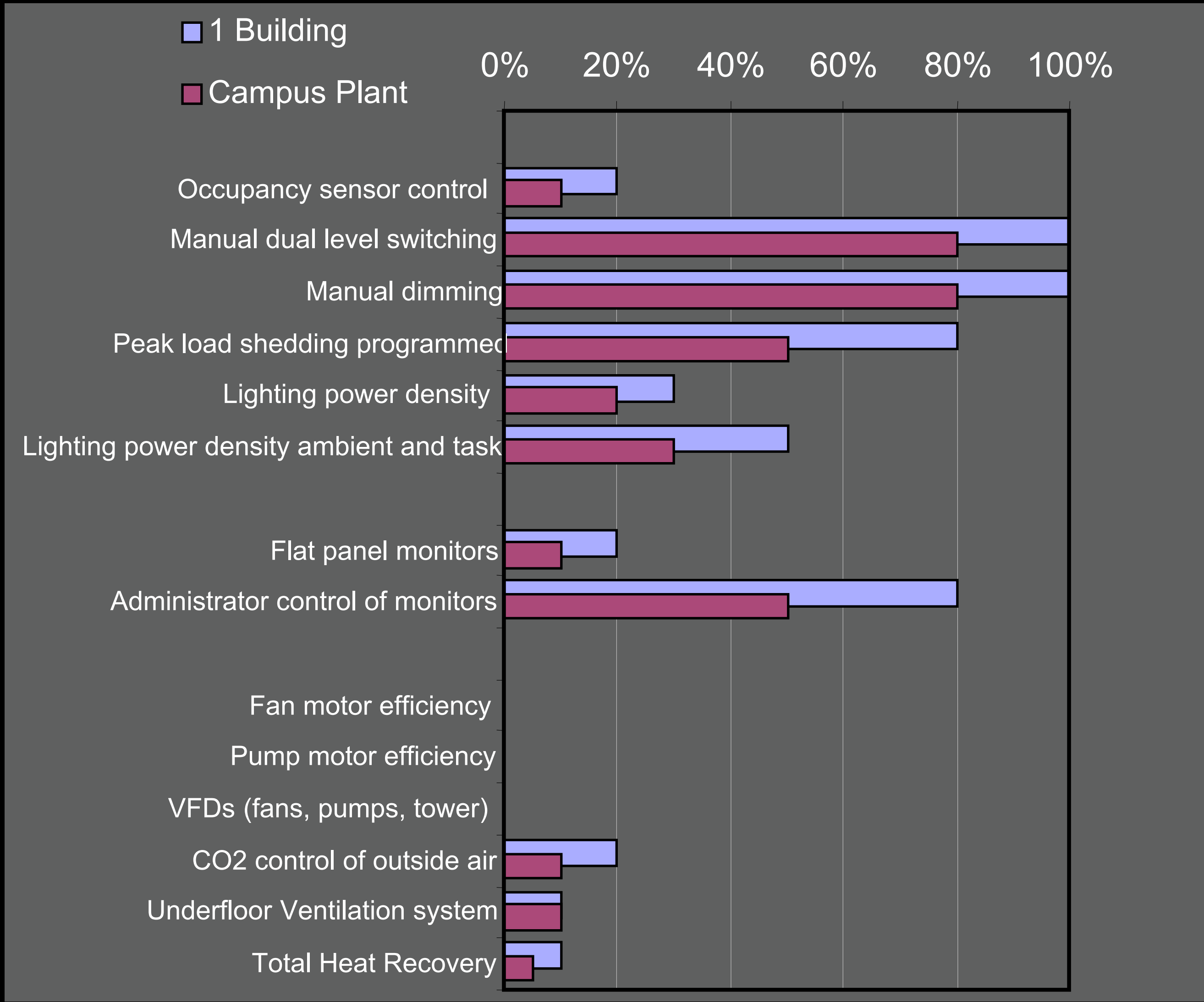
simple

The next step was to look at interactions. Items are not exclusive to only the cause or just the effect list because design is systemic. Those items with scores greater than 2 as both a cause and effect are deemed “complex interactors.”

Risk Factors for Plant Downsizing

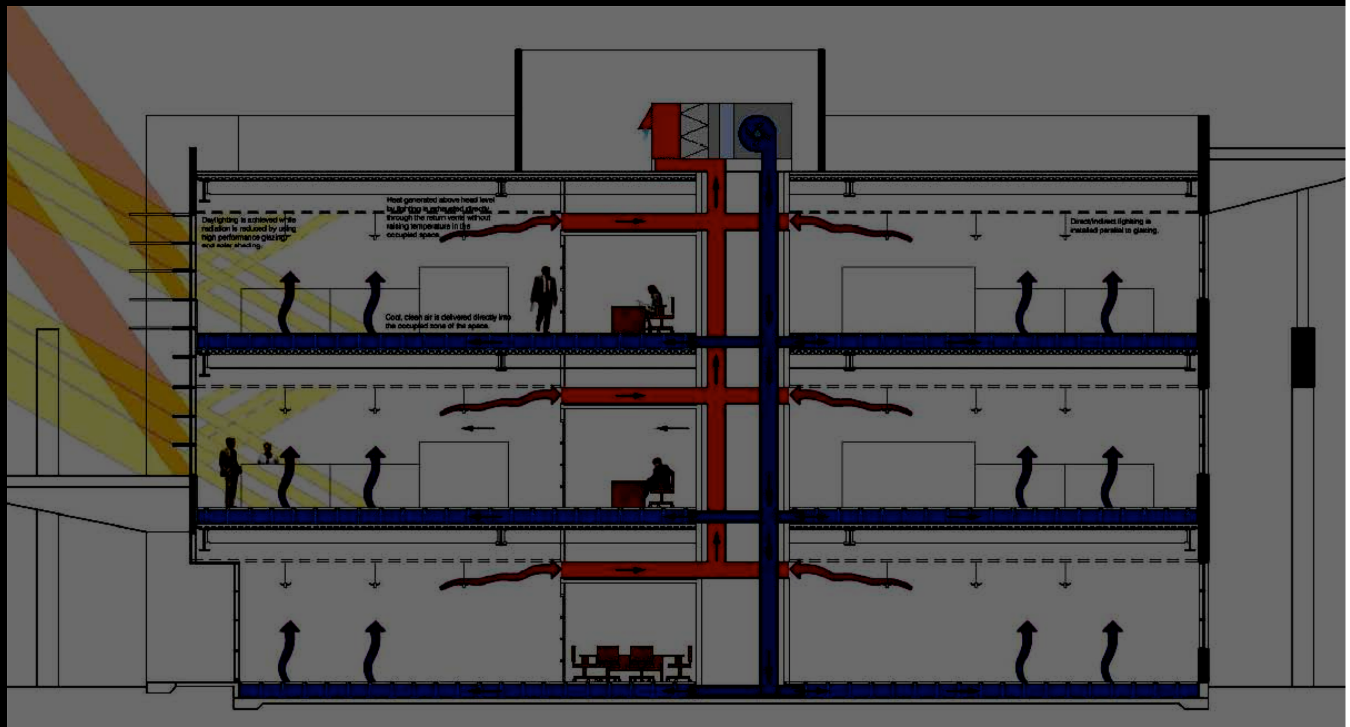
Typically engineers consider the impact of a building parameter on plant capacity as a “yes/no” decision.

When multiple ECMs are considered, the uncertainty of impacts can be seen in the form of risk that can be diversified amongst the various strategies considered.



Case Study Background

- 3-story, 6,000 m2 office building in Las Vegas, Nevada (U.S.A.)
- Daylighting with window head heights and ceilings at 3.5m
- Window to floor area ratio of 16%, window to wall area ratio of 31%.
- HVAC is VAV water-cooled DX units, central gas boiler.
- The energy code baseline was ASHRAE 90.1-1999



Case Study

Energy Simulations DOE 2.1E, ASHRAE 90.1-1999 Baseline

Baseline Results

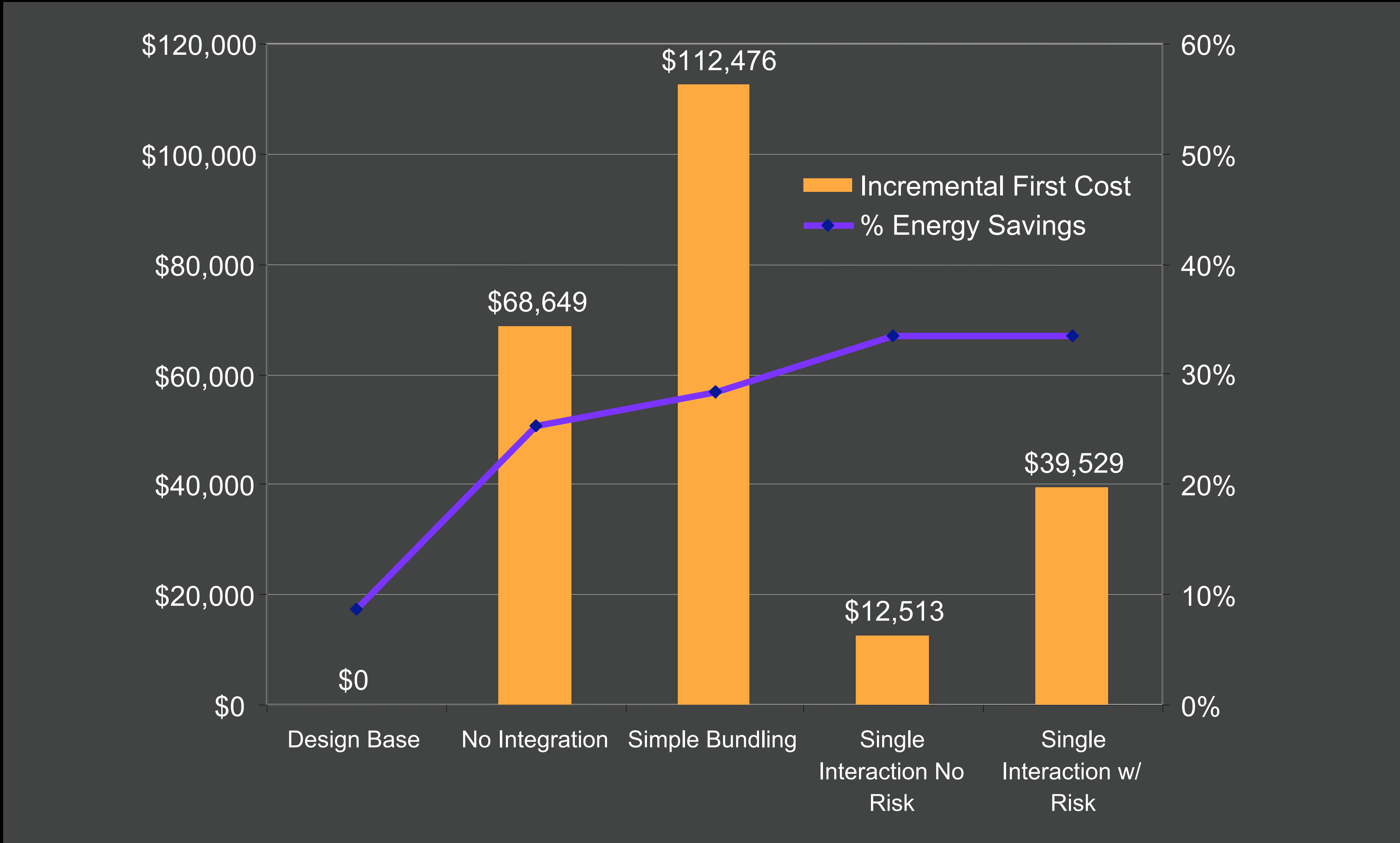
- Parametric energy modelling was done with DOE-2.1E using the local weather file, and utility rates
- Energy savings for each parametric run or strategy were calculated by comparing with the baseline.
- Incremental costs for the strategies were developed by a cost estimator on the design team.

Case Study

Alternative approaches to Efficiency and Cost Estimation

- ***Alternative 1* No integration.**
  - Includes individual ECMs with payback < 5 years
  - Improved insulation and glazing, dimming daylighting controls, occupancy sensor control and dual level switching of lighting, a direct lighting system with Super T8 lamps, efficient pump motors, variable frequency drives (VFDs), and demand control ventilation.
- ***Alternative 2* Simple Bundling**
  - Include ECMs such that the overall bundled payback < 5 years
  - Adds wall insulation, other daylighting controls, more lighting controls, efficient fan motors, more VFDs, and total heat recovery.
- ***Alternatives 3 S*ingle (cost) interaction – no risk**
  - Here the impact of all ECMs on the cooling and heating system capacity is taken into account. Alternative 3 treats all ECMs as risk-free for plant capacity downsizing and uses the entire extent of equipment downsizing as predicted by the simulation models.
- ***Alternative 4 S*ingle (cost) interaction – with risk**
  - Uses risk factors identified in this study to factor down the equipment downsizing as predicted by the simulation models. Has the same ECMs as Alternative 3

Case Study
Energy and Cost Results for Alternatives



Conclusions

The design elements that have iterative interactions with others as a systemic design is modified are identified.

Overall, these parameters can be considered as the focus of the integrated cost estimation exercise for typical medium sized commercial buildings.

- Integrated design needs an associated integrated costing methodology to overcome the perceived first-cost barriers of high-performance building design.
- Integrated design and costing shifts the levels of effort to earlier design phases and increases effort by, and cooperation amongst, design team members.
- The spectrum integration provides a roadmap to guide pursuits of integrated design and a framework for communication of the performance and cost parameters as the first step towards successful contract negotiation to reduce the owner or designer's perception of risk.
- Risk factors for sizing consideration can be analyzed such that the system sizing is based on a rational framework.
- As demonstrated in the case study, greater energy conservation can be achieved with lower first costs when reductions in HVAC system sizing are considered.

Conclusions

Policy Recommendations

- Similar to LCC requirements by public agencies, integrated costing could also be required to assure that capital cost savings are accounted for in integrated design
- Public agencies lead the market by changing fee structures to recognize greater importance of early design consideration of cost integration.
- Utility rebates and tax deduction programs can also encourage integrated design of building systems by providing high incentives to the designers for overall building energy performance. These design incentives should be decoupled from reported incremental costs
- Funding support to develop publicly available cost databases and costing functions for system or assembly cost estimation
- Develop best practice case studies that show how design teams save owners' money through integrated designs.

Policies
Encouraging the practice of integrated design

- Government organizations and public agencies could require integrated costing to assure that capital cost savings are accounted for in integrated design
- Public agencies can lead the market by changing the design fee structures to recognize greater importance of early design consideration of cost integration. Design fees should be decoupled from capital cost expenditure for equipment;
- Utility rebates and tax deduction programs can also encourage integrated design of building systems by providing high incentives to the designers for overall building energy performance. These design incentives should be decoupled from reported incremental costs
- Provide funding support to develop publicly available cost databases and costing functions for system or assembly cost estimation;
- Develop best practice case studies that show how design teams save owners' money through integrated designs.

Thank you

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