

INSIGHT TECHNICAL REPORT

Green Building Information Gateway

GREEN BUILDING ENERGY TECHNOLOGY: RELATING TECHNOLOGY IMPLEMENTATION TO DESIGN GOALS AND ENERGY PERFORMANCE

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ABSTRACT

The building construction industry is in the midst of a technology revolution, but changes are slow to propagate across individuals, companies and geographies. Researchers have pointed to several market characteristics as possible causes for the adoption lag; among these are poor project liability assignment, severe demand fluctuations, and the broken agency between building owners and occupants. These factors and others limit project investment and knowledge diffusion.

Building project teams have five primary objectives when designing and constructing space for future occupants. A building must heat, cool, ventilate and light its internal space, and supply hot water. To fulfill these project goals, designers specify building systems, envelopes, and strategies that will meet the occupants' needs while adapting to the surrounding environment. However, designers do not necessarily make design choices with the most efficient finished building in mind. Even when energy efficiency is a primary objective the decision process may not be entirely unbiased.

This study identifies the need for building design decision support regarding new energy efficient technology with a concentration on building technology implementation challenges and the energy efficient and innovative technologies used by project teams to solve the challenges. LEED certified buildings were examined for the study to determine which technologies were implemented most often and their initial energy saving purpose.

Keywords: *technology, innovation, energy efficiency, decision analysis*

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I. INTRODUCTION

The building construction industry is dominated by low risk strategies and methods that encourage project completion on time and on budget. Nevertheless, a resurgence of the environmental movement in the last 10 years has pushed many architectural, engineering, and construction companies to incorporate energy efficient and renewable technologies into their final designs.

The technology revolution, however, has been slow to migrate through the building industry, which yields over \$1 trillion in annual revenue but lacks companies with a dominant market share. Thus, architectural, engineering, and construction companies lack many of the knowledge transfer pathways that exist in other industries with large integrated companies. Designers and builders need a common framework for thinking about technology choices and support in making good implementation decisions.

There are many components, processes, and ideas that must come together to create an energy efficient building. Such a goal requires the foresight of building designers, craftsmanship of construction teams, and diligence of facility managers. The designers choose solutions and technologies that greatly affect the operation and effectiveness of the end building. Through this selection process, a market for more advanced building technologies continues to be developed. Unfortunately, the most advanced technologies with high energy-saving potential are not routinely installed on commercial and residential building projects. These innovations in products and methods can drive energy efficiency forward, but not without project stakeholders advocating for the technologies on a more regular basis.

The industry is still refining green building decision support tools and working to get those tools accepted by the market. The LEED rating system, developed by the U.S. Green Building Council, has raised awareness of energy savings through proper building construction and new types of technology. LEED seeks to attain the same goals of traditional building design, but through a new sustainability design decision framework. The goals are simple—ensure occupied space is within the limits of human thermal comfort, humidity, and light levels, while maintaining indoor air quality and water purity for occupants.

Conventional technologies are capable of solving these problems, but new and innovative technologies help deliver a higher quality of space condition and lower energy use. Governments and universities are also working on decision tools and critical path analysis to increase technology implementation and help projects make better design decisions.

Three main groups of decision makers have been identified by the U.S. Department of Energy: the building owner/operator, the architect/design engineer, and the contractor/subcontractor. All three groups stand to gain a great deal from making good technology decisions that will lower integration risk and lifetime project costs while delivering the efficient buildings that many clients seek.

A. Research Aims

This paper has two primary aims. The first is to identify how frequently energy efficiency technologies are implemented in certain types of LEED certified buildings. The second is to analyze the decision process and decisions made by the project teams. There are three critical elements of any decision making process, the alternatives presented, the information the decision maker has, and the preferences of the decision maker (Howard, 2000). If any piece of this three-legged framework is missing, then there is no decision to be made. Typically, there is no shortage of design options or client preference in building construction, but there is often a knowledge gap regarding building technology and energy usage.

This decision analysis can also connect the technology selections back to their intended purpose, and then determine if selections are capable of having the most impact on actual energy consumption of the buildings studied. In order to make that connection, typical technology uses and average building energy consumption is taken as a benchmark. Some LEED projects fall into a specialized category called Existing Buildings: Operations and Maintenance or EBOM. LEED EBOM projects offer information on how designers project their building's energy use in the future based on their decisions.

II. METHODOLOGY

To understand the market, organizational or other factors that influence technology innovation and implementation, it is essential to understand why buildings need technology in their designed spaces. To this end, Figure 2.1 displays the distribution of primary energy end uses and operational expenditures as identified by the Energy Information Agency for U.S. commercial buildings. The end uses selected for study are space heating, lighting, water heating, space cooling, and ventilation.

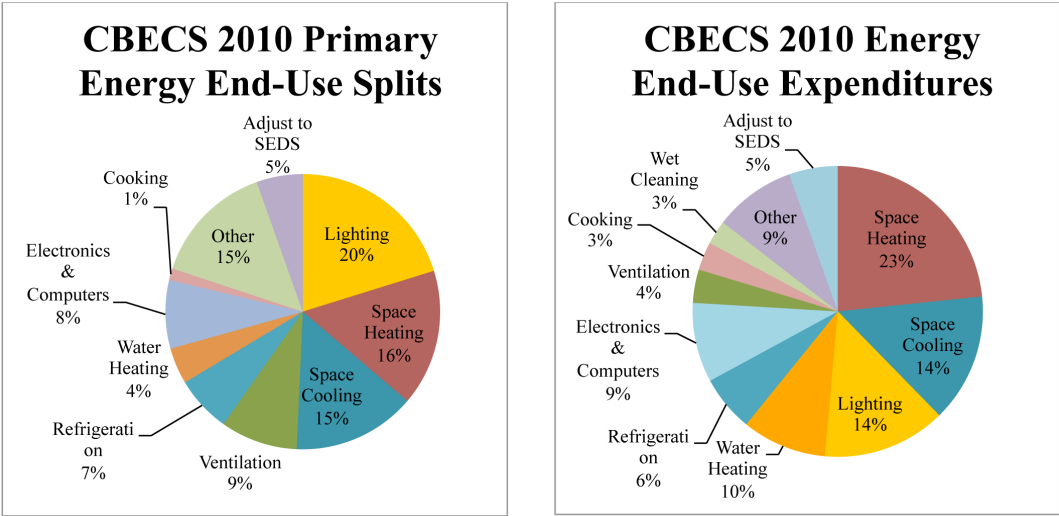


Figure 2.1 Commercial Building Energy Consumption Survey 2010 by Primary Energy End Use and Expenditure

With the five end uses as a starting point, Figure 2.2 displays general approaches to lowering the energy usage of each category. The approaches do not identify specific technologies, but simply list tactics that may be used in a final design to fulfill one of the five original goals. The approaches represent the most basic level of alternatives available to decision makers, without the added complication of technology. Based on these approaches 37 unique energy-efficient technologies that were present in LEED certified project case studies and that could achieve the identified tactics were uncovered.

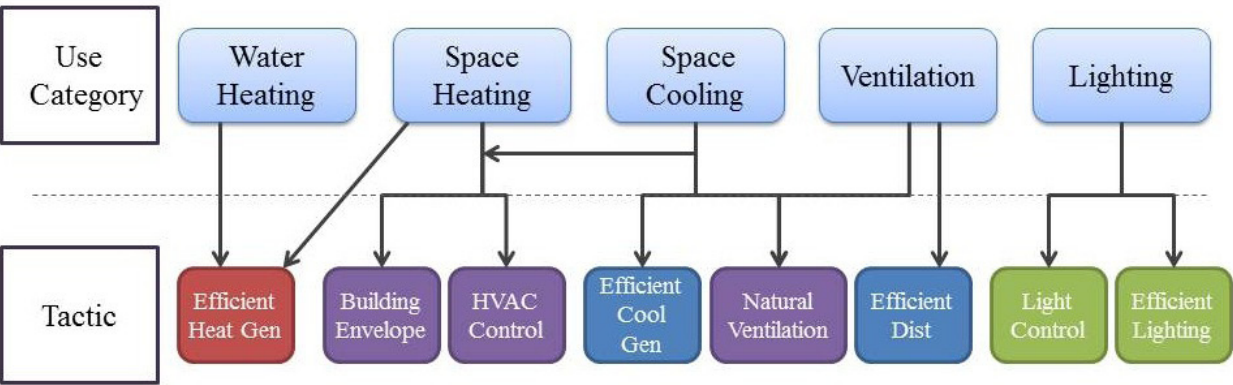


Figure 2.2 Use Category and Tactic Hierarchy

The category to tactic relation, as displayed above, represents a decision tree. Project teams must decide the amount of total resources to devote to each of the use categories and then which path within the tactic level to pursue. Many tactics influence one another; for example the amount of natural day lighting that is used has a direct impact on the heating and cooling loads. Each climate zone and building configuration will have a different ratio that makes the best design. The key to these decisions is balancing the pressures from the site environment and stakeholders along the critical path in order to develop the best-case scenario for all parties.

A. Assumptions and Study Conditions

- 1) Only technologies uniquely identified in a project case study or LEED Online submittal have been documented. On-site construction procedures and building operation procedures (e.g. lowered lighting power densities) were not included in the study.
 - a. Examples of excluded technologies (technology list can be found in Appendix A)
 - i. Construction waste recycling
 - ii. Heating and cooling set point temperatures outside normal ranges
 - iii. Reducing the lumens/area for lighting systems
- 2) Building energy usage and technology that directly relate to building operations (heating, cooling, lighting, and ventilation) were included; appliances and plug loads were excluded.
 - a. Examples of excluded technologies
 - i. Energy star appliances and computers
 - ii. Electrical outlet control of inactive plug-loads
- 3) If chiller or boiler technology became highly specific, the technology was grouped under ‘high efficiency water chillers’ or ‘high efficiency water heaters’
 - a. Examples of grouped technologies
 - i. Isolation valves to shut down certain cooling towers, pumps, equipment, etc.
 - ii. Water-cooled centrifugal chillers
- 4) Renewable energy technology used to produce heating or cooling was included in the study. Renewable energy technology used to produce electricity was not included; electricity may be sold to the grid or meet plug loads rather than meet a building goal.
 - a. Examples of excluded technologies
 - i. Building-integrated photovoltaic cells
 - ii. Small-scale wind turbines
 - iii. Solar photovoltaic panels
- 5) Cogeneration was counted as a technology in cases when electricity was generated on-site and waste heat recovered, or heat is supplied by a utility or neighboring building.

B. Sample

I analyzed the characteristics of 114 LEED for New Construction and Major Renovations (LEED NC 2.0 through 2009) and 35 LEED for Existing Building: Operations and Maintenance (LEED EBOM 2009) projects. The rating systems were chosen because they had the most certified projects and data available, and the energy efficiency section of the rating systems gives large incentives to implement the technologies being researched. The USGBC website yielded exhaustive technology data on 112 LEED NC case studies, and the remaining projects' information was extracted from LEED submittal data (HVAC system summaries, low-cost energy efficiency measures, etc.).

The building sample contains many different building types, sizes, and locations across the U.S. The LEED NC buildings are skewed toward the most populated states and those trending towards green building, while the LEED EBOM buildings trend toward more recent projects in urban areas in mild to colder climates. A summary of the data is provided in Figure 2.3 below:

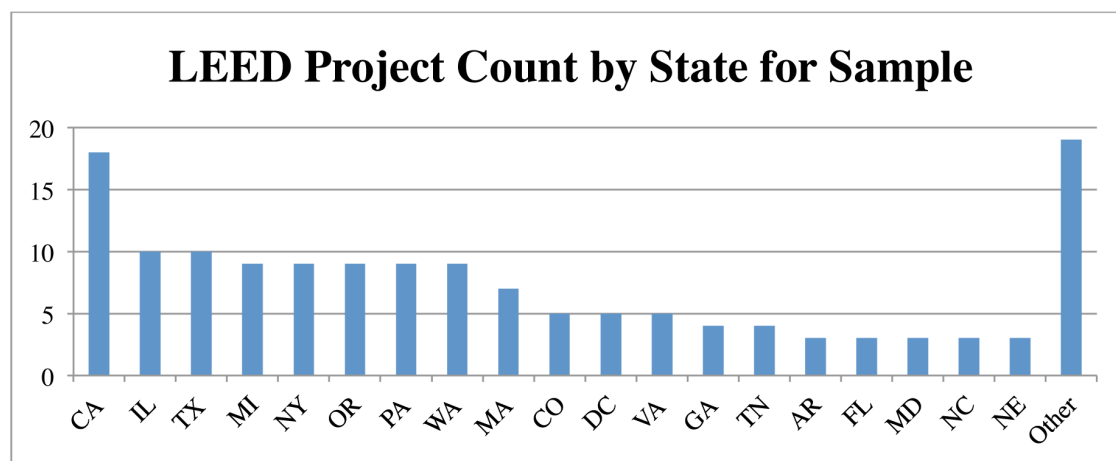


Figure 2.3 Geographic distribution in sample

The LEED NC buildings were fairly well varied in their usage types, while the LEED EBOM buildings are predominantly commercial offices. The mixed-use category often indicates a mixture of offices and retail or retail and residential. A summary of data is provided in Figure 2.4.

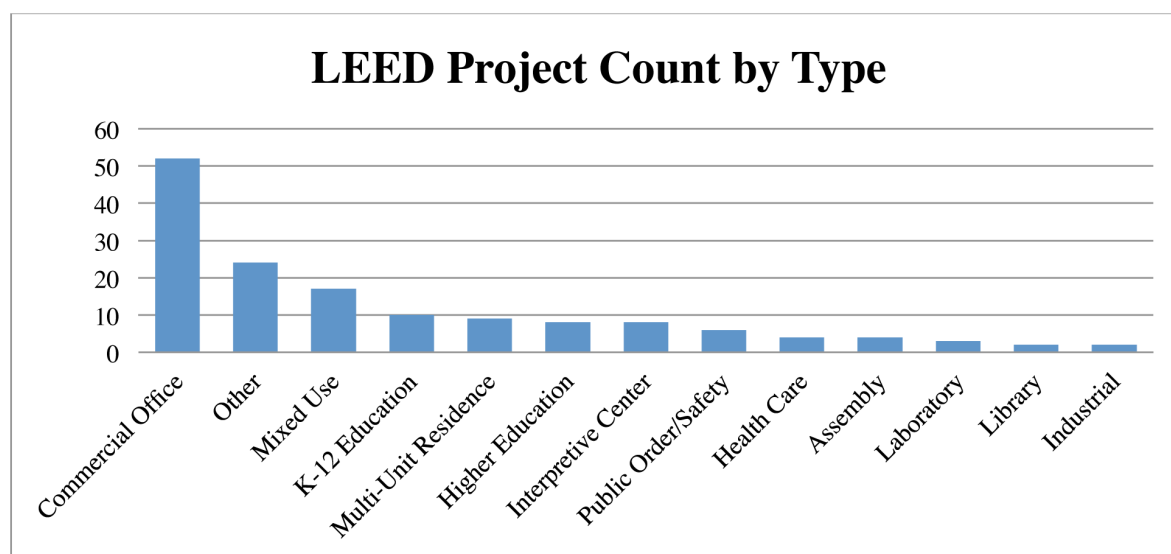


Figure 2.4 Project end-use distribution in sample

C. Measures

I then determined how often the unique technologies were implemented in each project by recording a true/false value for each technology and project combination. For the 112 LEED NC projects researched exclusively in the USGBC website case studies, the data was translated from research conducted last year at Stanford University (Sheffer, 2011). The technology implementation hits from the study required translation for a new set of technologies. This was achieved for this study with a combination of automatic processes and case study review. The other project implementation statistics were compiled using a new list of existing building projects, from which data was pulled from case study reviews and examination of LEED submittal document. In total there were 5,513 possible technology hits over the entire sample, with an effort made to ensure that no two technologies within the set of 37 are mutually exclusive within a single project. However, the technology list is not collectively exhaustive as there may be technologies that were not examined due to obscurity or not included because no project recorded its usage.

Finally, I examined which type of energy consumption each technology was attempting to reduce by labeling them according to their primary function. The five use categories come from the Energy Information Agency’s (EIA) end-use energy consumption categories, and technologies were assigned to the categories according to definitions and common usages laid out in by the American Council for an Energy-Efficient Economy (ACEEE) and the American Society of Heating and Refrigeration and Air Conditioning Engineers (ASHRAE). Some technologies fall into multiple use categories (e.g. a heat pump can be used for space heating or cooling), so a technology hit could potentially create multiple usage hits. The usage hits were totaled to determine how often end use solutions end use were attempted based on technology implementation hits.

III. RESULTS

New construction projects have a great deal more freedom compared to existing building retrofit projects in deciding on design and construction options. This is likely to be due in part to the cost involved with removing potentially valuable existing systems in existing buildings, and the difficult removal of certain building components while leaving others intact. However, the narrow technology selection within the EBOM sample may also be a result of the perception that new innovative technologies are not compatible with old buildings regardless of the opportunity.

Nonetheless, trends in some technologies appeared in both LEED NC and LEED EBOM samples. Both project types favored occupancy sensors, individual thermostat controls, high efficiency water heaters, ground source heat pumps, and demand controlled ventilation at roughly the same rates (implementation rates varied between each by 10% or less).

The differences between the rating system samples were more obvious, and may also show technology trends over time. LEED EBOM projects implemented or improved on direct digital control or energy management systems far more often than LEED NC projects. This is somewhat surprising given the difficulty of correctly implementing this kind of technology innovation. Adaptive lighting and cool roof technologies were used extensively on New Construction (more than 50% of sample LEED NC), very rarely (around 5%) on Existing Buildings. LEED EBOM technologies were also clustered around a few core technologies (only 26 of the 37 technology alternatives), leaving some technologies on the list without any hits in this side of the sample.

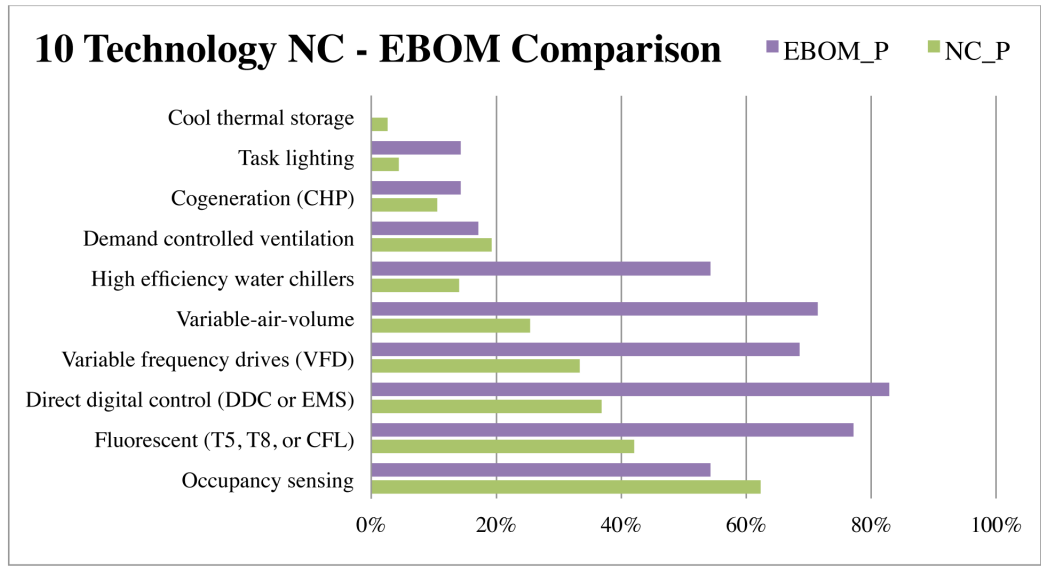


Figure 3.1 LEED NC and EBOM Technology Implementation Rates Across Sample (10 Technologies)

The technologies implemented also showed the energy end use goals of the projects. The usage of cooling technologies was much higher than the CBECS data would have predicted based on cooling energy expenses as a percentage of operating budgets spent on the five end uses (29% to 22%, respectively). Lighting technology implementation was very close to the energy usage (22% to 21%, respectively). Water heating was surprisingly small, but that may be a reflection of its shared role with space heating in many design solutions. Figure 3.2 shows the differences between the project technology selection allocations and the CBECS expenditure allocations with recalibrated proportions based on only the five end uses of interest.

This misallocation of technology may be an indication that building designers are not making good energy and technology investment decisions. Many factors may cause the CBECS usage allocations to be misaligned with technology implementations, to be discussed in the conclusion.

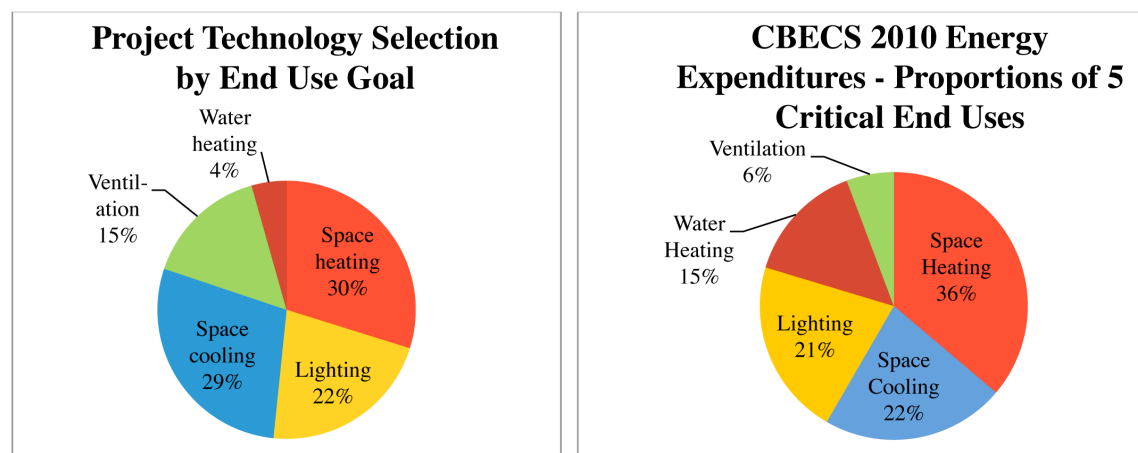


Figure 3.2 – Technology Implementation Breakdown based on Use Category

IV. CONCLUSIONS

The data indicates designers and builders are concentrating too much technology on space cooling. This result follows a trend that has developed as air conditioning equipment sales have steadily increased over the last 30 years (Hayter, 1999). Unfortunately, this study's sample of buildings varies in size, usage type, and location, but this variation is not identical to that found across all LEED projects or CBECS respondents. Therefore, the results of this study are skewed toward space cooling technology because of the prevalence of new cooling technologies and increased construction in warmer climates with fewer heating degree days. Heating requirements do not drive as much innovation because the energy conversion process is so simple, while cooling almost always requires electrical energy to be used in an array of chiller, evaporator, desiccant, and economizer technologies.

The next step of this research process will be to build a more robust regression model that takes climate, project team structure, and technology category into account to measure the decision choices more accurately. Then there may be an opportunity to draw causal inferences as to what drives increased technology implementation.

The narrow range of technologies represented in the LEED EBOM sample shows how limited designers are when making decisions for these projects. Given such low implementation rates, it is obvious that major overhauls to a building envelope or fundamental heating/cooling method are not perceived as available alternatives. This is primarily because the technology knowledge present in new construction projects changes within the context of existing buildings, and a new decision framework must be used giving rise to uncertainty. Interestingly, one type of innovative technology use did not suffer from this uncertainty—the rise of popularity in energy management systems raises questions about the degrees of this technology, and how useful it is if not all building systems are under its control.

Each building project team makes decisions based on an image the owner wants to project, economics, building function, operation and maintenance, and occupant comfort (Marshall, H & Norris, G. 1995). It is important to raise the last two factors early in the design process and present a logical decision framework for finding architectural and technology solutions to meet their demands. All of those balancing forces should be used when making technology decisions on a project. For this reason, an aggregate of technology decision rates will never perfectly match up with the corresponding use category consumption rates. However, if a project were able to roughly model energy usage by end use before designing, then a wise decision analysis approach would take a technology hierarchy into account to align technology decisions optimally with use categories.

V. APPENDIX A: LIST OF TECHNOLOGIES STUDIED

1. Absorption chiller
2. Adaptive lighting
3. Biomass heating
4. Chilled beams
5. Cogeneration (CHP)
6. Condensing boilers
7. Cool roof solutions (green roof, SRI)
8. Cool thermal storage
9. Demand controlled ventilation
10. Direct digital control (BAS, DDC, EMS)
11. Displacement ventilation (UFAD)
12. Dynamic building façade
13. Electronic ballasts (light fixtures)
14. Energy recovery ventilation
15. Evaporative cooling
16. Fluorescent (T5, T8, or CFL)
17. Ground source heat pumps
18. Halogen (MR) bulbs
19. High efficiency water chillers
20. High efficiency water heaters/boilers
21. High insulation walls/roof
22. High performance windows
23. High-intensity discharge (HID) bulbs
24. Individual thermostat controls
25. Light-emitting diode (LED)
26. Nighttime cooling
27. Occupancy sensing
28. Operable windows
29. Radiant cooling/heating
30. Roof light redirection (e.g. skylight luminaire)
31. Solar hot water panels
32. Task lighting
33. Thermal mass
34. Variable-air-volume
35. Variable frequency drives (VFD)
36. Wall light redirection (light shelves)
37. Wind or buoyancy driven ventilation

VI. APPENDIX B: LIST OF LEED PROJECTS STUDIED

Project ID	Project Name	City	State	LEED System	LEED Score	Estar Score
I0000000	PNC Firstside Center	Pittsburgh	PA	NC 2.0	33	
I0000007	NRDC Southern California Office, Robert	Santa Monica	CA	NC 2.0	56	
I0000008	Renovation of the Motherhouse	Monroe	MI	NC 2.0	27	
I0000016	City of Seattle Justice Center	Seattle	WA	NC 2.0	33	
I0000017	French Wing Additon to Conservation Cent	Concord	NH	NC 2.0	44	
I0000025	Lake View Terrace Branch Library	Lake View Terrace	CA	NC 2.0	50	
I0000027	Roberts Hall	Portland	OR	NC 2.0	34	
I0000030	Third Creek Elementary School	Statesville	NC	NC 2.0	39	
I0000046	30 Hudson Street	Jersey City	NJ	NC 2.0	27	
I0000048	Clearview Elementary School	Hanover	PA	NC 2.0	42	
I0000054	Management Building, Technology Square	Atlanta	GA	NC 2.0	35	
I0000060	Colorado Court	Santa Monica	CA	NC 2.0	44	
I0000063	The Solaire/20 River Terrace	New York	NY	NC 2.0	41	
I0000069	EPA National Computer Center	Morrisville	NC	NC 2.0	35	
I0000070	IslandWood: A School in the Woods	Bainbridge Is.	WA	NC 2.0	40	
I0000074	The Patrick H. Dollard Discovery Health	Harris	NY	NC 2.0	27	
I0000081	Caribou Weather Forecast Office (WFO) (N	Caribou	ME	NC 2.0	34	
I0000085	The Herman Miller MarketPlace - an intel	Zeeland Township	MI	NC 2.0	39	
I0000089	Cambria Office Building	Ebensburg	PA	NC 2.0	45	
I0000090	Nathaniel R. Jones Federal Building and	Youngstown	OH	NC 2.0	27	
I0000100	Wayne Lyman Morse US Federal Court House	Eugene	OR	NC 2.1	39	
I0000110	Navy's Energy & Sustainable Demonstration	Port Hueneme	CA	NC 2.0	40	
I0000115	EPA Science and Technology Center	Kansas City	KS	NC 2.0	39	
I0000130	Rinker Hall	Gainesville	FL	NC 2.0	39	
I0000137	0142 CNT Renovation	Chicago	IL	NC 2.1	52	
I0000155	Fayetteville Public Library	Fayetteville	AR	NC 2.0	34	
I0000166	John M. Langston High School Continuatio	Arlington	VA	NC 2.0	35	
I0000178	Jack Evans Police Headquarters	Dallas	TX	NC 2.0	35	
I0000188	Fisher Pavilion	Seattle	WA	NC 2.0	29	
I0000189	IBM/Tivoli Systems Building I	Austin	TX	NC 2.0	26	
I0000195	Genzyme Center	Cambridge	MA	NC 2.0	52	
I0000200	Pittsburgh Glass Center	Pittsburgh	PA	NC 2.0	40	
I0000201	Seattle Terminal Radar Approach Control	Burien	WA	NC 2.0	39	
I0000202	Seminar II Building	Olympia	WA	NC 2.0	40	
I0000203	Herman Miller CI Main Site	Zeeland	MI	NC 2.0	41	
I0000208	University of Denver College of Law	Denver	CO	NC 2.0	39	
I0000214	WDNR North East Regional Headquarters	Green Bay	WI	NC 2.0	46	

VI. APPENDIX B: LIST OF LEED PROJECTS STUDIED (CONTINUED)

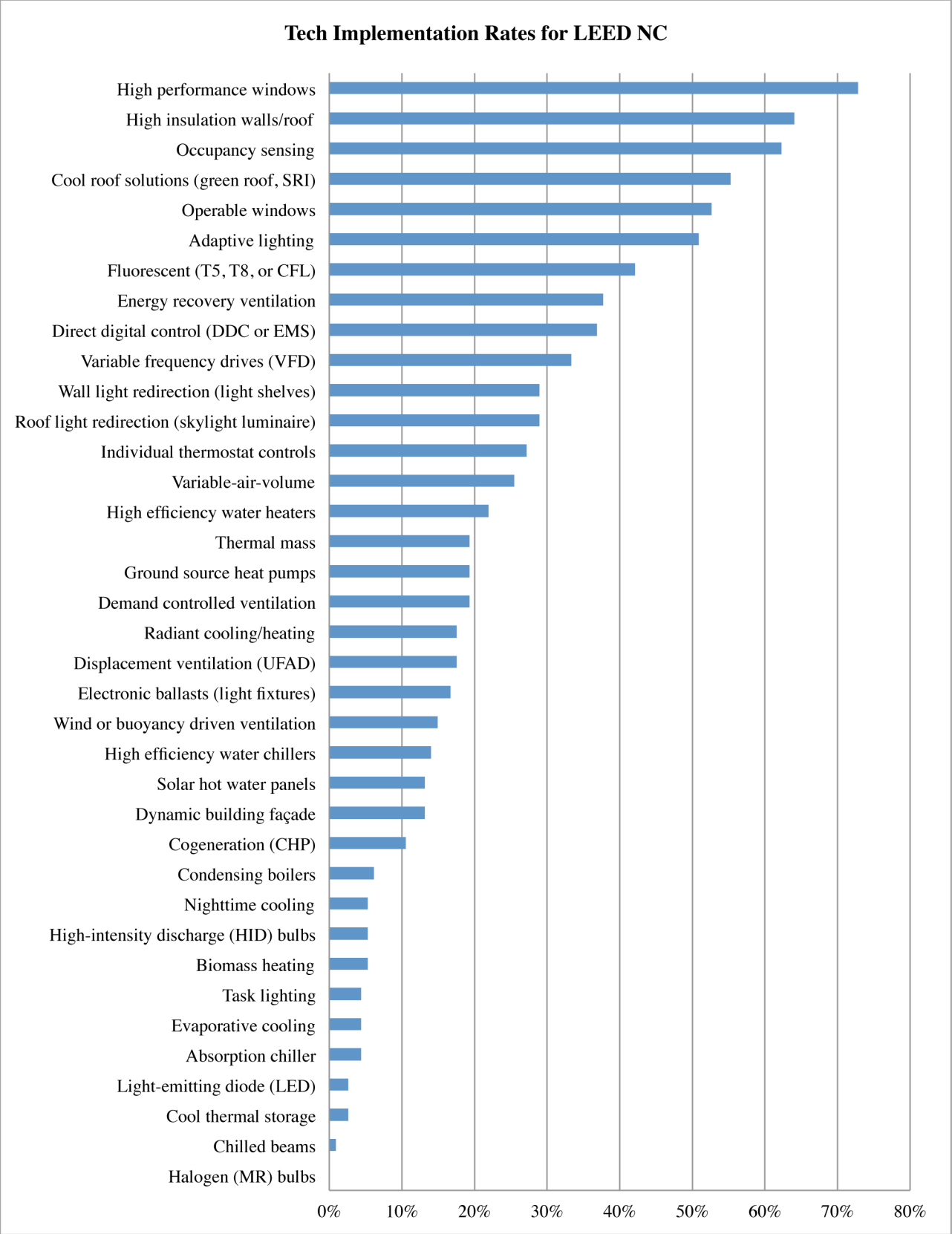
Project ID	Project Name	City	State	LEED System	LEED Score	Estar Score
I0000219	Green Operations Building	White Rock	BC	NC 2.0	44	
I0000229	Clackamas High School	Clackamas	OR	NC 2.0	33	
I0000233	The Barn at Fallingwater	Mill Run	PA	NC 2.0	33	
I0000234	US/Canada Shared Port of Entry	Sweetgrass	MT	NC 2.0	27	
I0000245	The Plaza at PPL Center	Allentown	PA	NC 2.0	40	
I0000259	Social Security Administration Child Car	Baltimore	MD	NC 2.0	28	
I0000265	Detroit School of Arts	Detroit	MI	NC 2.0	29	
I0000268	Sokol Blosser Winery: Barrel Aging Cella	Dundee	OR	NC 2.0	34	
I0000295	QBG New Admin Building & Landscapes	Flushing	NY	NC 2.0	52	
I0000303	Science and Technology Facility	Golden	CO	NC 2.0	54	83
I0000318	S.T. Dana Building Renovations	Ann Arbor	MI	NC 2.0	40	
I0000329	Austin Resource Center for the Homeless	Austin	TX	NC 2.1	34	
I0000333	Traugott Terrace	Seattle	WA	NC 2.0	28	
I0000335	Bazzani Associates Headquarters	Grand Rapids	MI	NC 2.0	34	
I0000339	Felician Sisters Convent and School Reno	Coraopolis	PA	NC 2.0	39	
I0000359	Richard J. Lacks, Sr. Cancer Center	Grand Rapids	MI	NC 2.0	29	
I0000394	Arlen Specter HQ and Emergency Op Center	Atlanta	GA	NC 2.0	33	
I0000406	Audubon Center at Debs Park	Los Angeles	CA	NC 2.0	53	
I0000415	East Campus Modernization	Oak Ridge	TN	NC 2.0	27	
I0000416	Inland Empire Utilities Agency Administr	Chino	CA	NC 2.0	52	
I0000419	William Jefferson Clinton Presidential Center	Little Rock	AR	NC 2.0	34	
I0000420	Heimbold Visual Arts Center	Bronxville	NY	NC 2.0	29	
I0000457	Lillis Business Complex	Eugene	OR	NC 2.0	33	
I0000494	Alcyone	Seattle	WA	NC 2.0	27	
I0000496	Tompkins County SPCA Dorothy	Ithaca	NY	NC 2.0	36	
I0000524	Wentworth Commons (Prev. High Prairie) A	Chicago	IL	NC 2.0	29	
I0000533	Heifer International Center	Little Rock	AR	NC 2.1	52	
I0000541	Personnel Support Facility	Virginia Beach	VA	NC 2.0	33	
I0000550	ECHO at the Leahy Center For Lake Champl	Burlington	VT	NC 2.0	29	
I0000571	Edgewood Group Home	New Wilmington	PA	NC 2.0	21	
I0000592	Joint Institute for Computational Science	Oak Ridge	TN	NC 2.1	35	
I0000595	Pavillons Lassonde	Montreal	QC	NC 2.1	46	
I0000604	Research Support Center	Oak Ridge	TN	NC 2.1	29	
I0000737	Ampere Annex	Vancouver	WA	NC 2.1	36	
I0000749	Scowcroft Building	Ogden	UT	NC 2.1	33	
I0000783	Carl T. Curtis Midwest Regional Headquar	Omaha	NE	NC 2.1	40	
I0000798	Alberici Office Headquarters	St. Louis	MO	NC 2.1	60	
I0000804	Eastern Village Cohousing Condominium	Silver Spring	MD	NC 2.1	34	

Project ID	Project Name	City	State	LEED System	LEED Score	Estar Score
I0000813	Fossil Ridge High School	Fort Collins	CO	NC 2.1	36	
I0000862	Baca/Dlo'ay azhi Community School	Prewitt	NM	NC 2.1	26	
I0000863	Chartwell School	Seaside	CA	NC 2.1	57	
I0000888	Artists for Humanity EpiCenter	Boston	MA	NC 2.1	53	
I0000906	Provincetown Art Association and Museum	Provincetown	MA	NC 2.1	36	
I0000920	The Helena	New York	NY	NC 2.1	41	
I0000976	Bachelor Enlisted Quarters Bldg 1044	Bremerton	WA	NC 2.1	29	
I0001001	Wind NRG Partners, LLC. New Facility	Hinesburg	VT	NC 2.1	44	
I0001140	Michigan Alternative and Renewable Energy	Muskegon	MI	NC 2.1	46	
I0001172	Dominican Sisters House of Formation	San Rafael	CA	NC 2.1	39	
I0001259	Xanterra's Annie Creek Rest/Gift Shop	Crater Lake	OR	NC 2.1	34	
I0001414	Portland Center Stage - Armory Renovatio	Portland	OR	NC 2.1	53	
I0001542	One Potomac Yard	Arlington	VA	NC 2.1	43	
I0001590	Sidwell Friends Middle School	Washington	DC	NC 2.1	57	
I0001713	Shangri La Botanical Gardens & Nature Ctr	Orange	TX	NC 2.1	57	
I0001752	Friends Committee on National Legislatio	Washington	DC	NC 2.1	33	
I0001857	Home On The Range	Billings	MT	NC 2.1	57	
I0001967	Air Force Weather Agency Headquarters	Offutt Air Force Base	NE	NC 2.1	41	
I0002090	EPA Region 8 Headquarters	Denver	CO	NC 2.1	40	
I0002093	Two Potomac Yard	Arlington	VA	NC 2.1	42	
I0002151	GISH APARTMENTS	SAN JOSE	CA	NC 2.1	40	
I0002180	Multiprogram Research Facility	Oak Ridge	TN	NC 2.1		
I0002254	Macallen Building	South Boston	MA	NC 2.1	41	
I0002353	THE ALDO LEOPOLD LEGACY CENTER	BARABOO	WI	NC 2.1	61	
I0002555	Balzer Theater at Herren's	ATLANTA	GA	NC 2.1	37	
I0002717	Staley High School	Kansas City	MO	NC 2.1	35	
I0002850	Boston Children's Museum	Boston	MA	NC 2.1	39	
I0002953	Yale Sculpture Building	New Haven	CT	NC 2.1	52	
I0002955	221 MOLALLA	OREGON CITY	OR	NC 2.1	40	90
I0003226	Police and Security Operations	Norfolk	VA	NC 2.1	34	
I0003289	LETTINGA HOUSING PHASE 2	GRAND RAPIDS	MI	NC 2.1	30	
I0003448	JEWISH RECONSTRUCTIONIST CONGR	EVANSTON	IL	NC 2.1	53	
I0003578	NYC OFFICE OF EMERGENCY MGMT.	BROOKLYN	NY	NC 2.1	34	
I0044481	Sigler Office and Warehouse	Albuquerque	NM	NC 2.2	33	
I0005013	Hawaii Gateway Energy Center at NELHA	Kailua-Kona	HI	NC 2.1	52	
I0005096	Atlantic Fleet Drill Hall P-667 Recruit	Great Lakes	IL	NC 2.2	41	
I0009585	Great River Energy	Maple Grove	MN	NC 2.2	56	90
I0054493	Nueva School	Hillsborough	CA	NC 2.2	45	

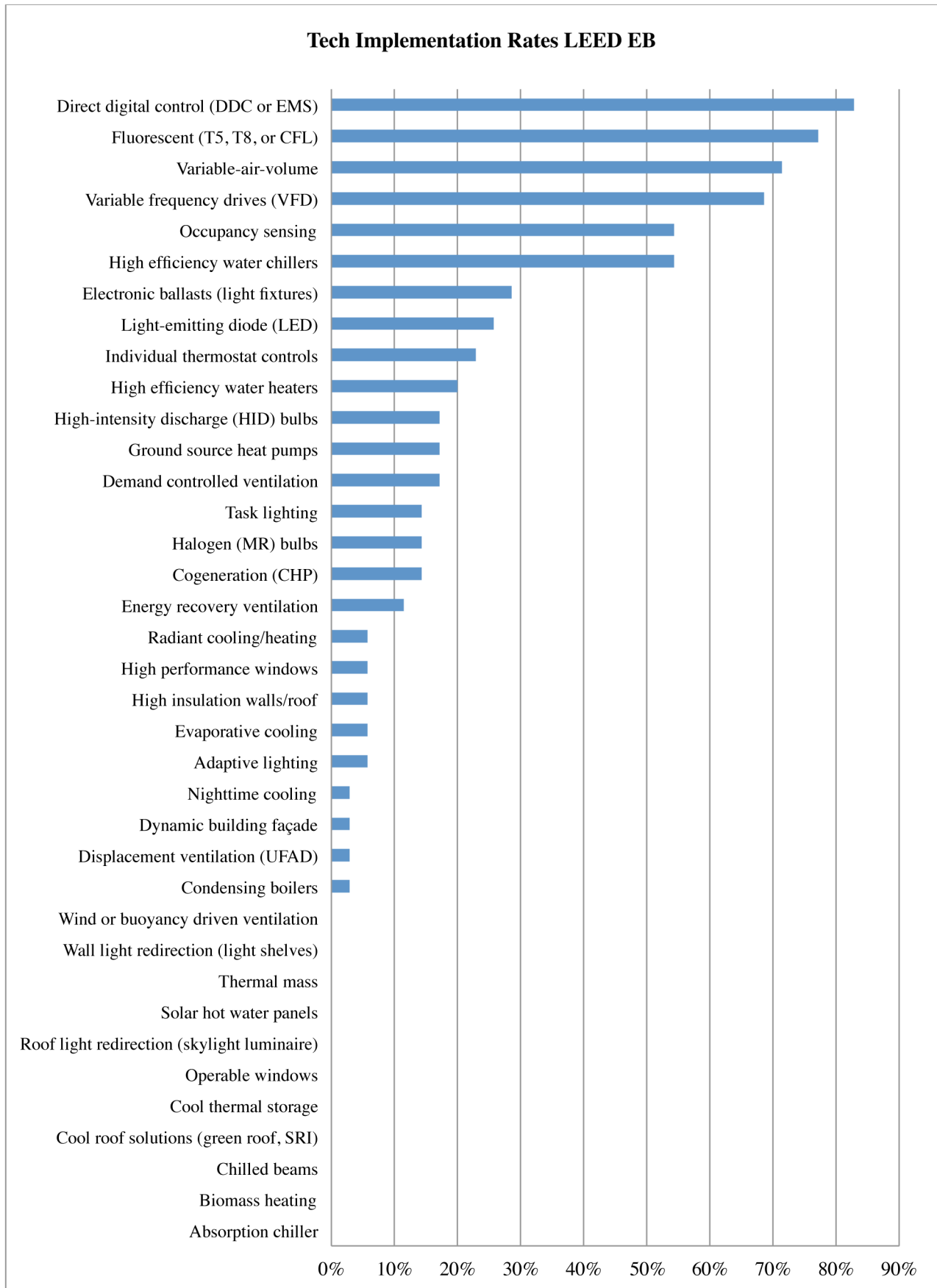
VI. APPENDIX B: LIST OF LEED PROJECTS STUDIED (CONTINUED)

Project ID	Project Name	City	State	LEED System	LEED Score	Estar Score
I000000190	560 Mission Street	San Francisco	CA	EBOM 2009	88	98
I000005773	Highlands Ranch Office Center I	Highlands Ranch	CO	EBOM 2009	54	98
I000000186	The Berkshire	Dallas	TX	EBOM 2009	42	97
I000001070	Qwest Tower	Phoenix	AZ	EBOM 2009	55	97
I000005574	2882 Prospect Park	Rancho Cordova	CA	EBOM 2009	60	96
I000003261	2555 Ponce	Coral Gables	FL	EBOM 2009	57	95
I000000473	IFC Headquarters Building	Washington	DC	EBOM 2009	82	94
I000001499	M E Group Office Building	Omaha	NE	NC 2009	84	93
I000008689	1400 Smith Street	Houston	TX	EBOM 2009	61	
I000001662	Meredith 1615	Des Moines	IA	EBOM 2009	41	79
I000001491	Resnick - 250 Hudson	New York	NY	EBOM 2009	53	77
I000005206	1120 Avenue of the Americas	New York	NY	EBOM 2009	51	77
I000001764	Key Center	Cleveland	OH	EBOM 2009	60	76
I000000083	Mercy Ridge Retirement Center	Timonium	MD	EBOM 2009	57	73
I000001108	Wacker Randolph Building - Transwestern	Chicago	IL	EBOM 2009	44	73
I000002920	Textron Tower	Providence	RI	EBOM 2009	43	73
I000000978	GRBCC LEED CERTIFICATION	Houston	TX	EBOM 2009	51	71
I000004030	111 Huntington Avenue	Boston	MA	EBOM 2009	60	71
I000005620	MJ Wilkow 20 S Clark Street Chicago	Chicago	IL	EBOM 2009	51	71
I0220328	100 First Street	San Francisco	CA	EB 2.0	52	93
I000000231	Two Twenty Two Berkeley By EOP	Boston	MA	EBOM 2009	65	
I000008877	1828 L St NW	Washington	DC	EBOM 2009	67	
I000005018	150 California Street	San Francisco	CA	EBOM 2009	67	
I000000450	3003 Perimeter Summit	Atlanta	GA	EBOM 2009	55	
I000001804	Four Chasewood	Houston	TX	EBOM 2009	52	
I0507779	Pittsburgh Opera	Pittsburgh	PA	EB 2.0	45	
I000000736	Rose Garden Arena	Portland	OR	EBOM 2009	62	
I0099424	JCPenney Home Office	Plano	TX	EB 2.0	49	
I000006052	55 West Monroe	Chicago	IL	EBOM 2009	66	
I000007651	131 South Dearborn	Chicago	IL	EBOM 2009	50	
I000008276	120 S LaSalle Street Building	Chicago	IL	EBOM 2009	60	

VII. APPENDIX C: FULL TECHNOLOGY BREAKDOWN: LEED NC AND EBOM



VII. APPENDIX C: FULL TECHNOLOGY BREAKDOWN: LEED NC AND EBOM (CONTINUED)



REFERENCES

1. Hayter, R. (1999). The Future of HVAC. Presented at the Netherlands Technical Association for Building Services, June 11, 1999.
2. Howard, R.A. (2000). Decisions in the Face of Uncertainty. In Alexander, C. (Ed.) Visions of Risk. London: Pearson Education Limited.
3. Marshal, H & Norris, G. (1995). Multi-attribute Decision Analysis Method for Evaluating Buildings and Building Systems. National Institute of Standards and Technology, September 1995.
4. Sheffer, D. (2011). Innovation in Modular Industries: Implementing Energy-Efficient Innovations in US Buildings. Stanford University, August 2011.
5. U.S. Energy Information Administration, 2010 Commercial Buildings Energy Consumption Survey, September 2008.