KIEAE Journal, Vol. 19, No. 1, Feb. 2019, pp.17-24.

KIEAE Journal

Korea Institute of Ecological Architecture and Environment

95

Cost Benefit Analysis of Adaptive Solar Control and View Management
- Case study of an office building in New York City

Kang, Oscar*

* *School of Architecture, Seoul National University of Science and Technology, South Korea (oscark@seoultech.ac.kr)*

ABSTRACT

Purpose: Commercially available adaptive exterior shading application is evaluated through a cost benefit analysis of a case study office building in New York City. Analysis is performed on an actual project with a client and stake-holders during early phases of design. The purpose of this analysis is to utilize findings from recent research and real cost data from the field and to apply it to everyday architectural practice. By providing general cost information for investors and stake-holders, often a deciding factor on its implementation, an informed decision can be made on the use of adaptive exterior solar control in a office building in New York City. **Method:** The design of the case study building was observed by the author in an architectural design firm in New York City with initial cost data obtained through correspondence with local installers. A key assumption in the analysis was factoring in productivity gains, in addition to reduced energy consumption, peak load reduction, and reduced carbon dioxide(CO_2) emissions based on quantitative results from recent research. **Result:** With recent literature reporting minimal total energy reduction in a similar climate region, the projected return on investment of adaptive solar management is significantly influenced by increased productivity gains.

KEYWORD

Adaptive Solar Control
Automated
Dynamic
View Management
Sustainable
Building
Case Study

ACCEPTANCE INFO

Received Jan 24, 2019
Final revision received Feb 14, 2019
Accepted Feb 19, 2019

1. Introduction

1.1. Research Background and Purpose

Solar radiation has a significant impact on the energy performance of the building and the occupant's visual and thermal comfort often affecting their work productivity1). The purpose of solar shading is to control the amount of incoming radiation while maintaining desired visibility to the exterior. While the term "shading" refers to the protection from solar radiation, there are certain periods of time, dates or seasons, depending on the location, where incoming solar radiation is beneficial to help reduce lighting and cooling loads while increasing occupant comfort. By striking a balance between the need for daylight, visibility to the exterior, lighting, and cooling loads the term solar shading needs to be viewed in the perspective of solar control and visibility management.

In practice, solar control also known as daylighting design is primarily provided by the lighting designer as an additional service2). This was also the case for the design of the case study building observed by the author. Under the AIA B201-2017 Standard form for Architect's Services[12] for design and construction management between the owner and the architect, daylighting design is considered an additional service or supplemental service. Most stake-holders, including the client, would acknowledge and recognize the importance of daylighting, solar control and visibility to the exterior for the well-being and productivity of the occupant. However, it is difficult to quantify and justify the additional cost required to install and maintain an active solar control system, which is considered above and beyond the typical manually operated interior roller shades or venetian blinds. As a result, decisions to implement active solar control in the building design are often dismissed or not even considered in the early phases of design due to a lack of quantitative information about its benefits. Obtaining this information for a bespoke project requires a significant investment of time and effort. Seeking to address this, this paper combines an empirical account of a case study in practice, and findings from previous research combined with real cost data from practice to offer an estimated cost benefit analysis of implementing solar control during the early phases of design.

pISSN 2288-968X, eISSN 2288-9698
http://dx.doi.org/10.12813/kieae.2019.19.1.017

1.2. Methodology and Scope of Research

Findings from previous research on quantitative benefits of adaptive solar control are coupled with data obtained from practice and applied to a case study building in New York, NY. The proposed research methodology is outlined in Fig. 1.

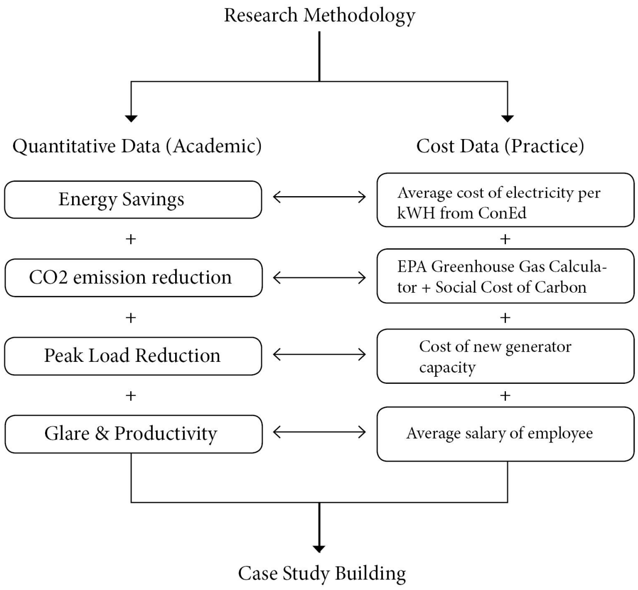

Fig. 1. Research Methodology Diagram

Four categories of quantitative benefits are identified from recent literature: (1) energy savings, (2) carbon dioxide emission reduction, (3) peak load reduction, (4) glare and its impact on productivity. Each quantitative benefit is coupled with cost data obtained from practice and applied to the case study building, described in Section 3, to derive a cost / benefit analysis, see Table 2.

2. Theory

2.1. Overview of Adaptive Solar Control Systems

"Automated", "dynamic", or "adaptive" solar building control systems have been commercially available for the past few decades[5] and installed in more projects in Europe compared to the US due to contrasting expectations in performance, cost and quality, including concerns about operation and maintenance[5]. In residential homes or smaller buildings, the use of traditional manual blinds or shading may be sufficient. But in larger buildings such as an office building, with a multitude of occupants, a more sophisticated building control strategy involving sensors and algorithms that respond to the changing surrounding environment is preferred over manual controls of occupants[6]. Excluding smart window technology, there are two common adaptive solar control systems available, motorized blinds and roller shade systems.

Traditional manually operated venetian blind systems are a viable solution to control solar gain and glare. Wide range of controls are available through the geometry of the louvers which can be tilted manually by the occupant. However, blinds are rarely set up in an optimal manner and in the absence of the occupant or user, allows either excessive heat gain or loss. Automated blinds through sensors and controls allows for enhanced performance and occupant comfort while also providing the option for manual override.

A common alternative to blinds are roller shades which are commonly available with a wide range of fabrics and optical properties. Fabric specifications determine the percentage of visible sun and light transmittance, reflectance and absorbance which affects both visual and thermal quality in the interior environment. While roller shades can be partially or fully lowered, the view will be reduced for those time periods when shading is critically needed. In contrast, venetian blinds control solar radiation through adjustable horizontal louvers, supporting greater visibility to the exterior, of significant value in improving health and productivity for the occupants that could offset their greater first costs and maintenance costs. Common optical properties of shade fabrics include openness factor(OF), solar transmittance(Ts), solar reflectance(Rs), solar absorbance(As), and visible transmittance(Tv). In addition, due to ultraviolet degradation, exterior roller shade fabrics are further limited in availability compared to interior roller shade applications. While simpler in operation compared to blinds, roller shades are limited in optical control.

2.2. Cost / Benefit Analysis in Sustainability

> "Environmental designers often argue for broad sustainability objectives without further detail..."[8]

Investment in sustainable design technologies, such as adaptive solar control systems, are often dismissed or limited due to first cost decision making. Yet, research that assesses the cost benefit or return on investment of a sustainable technology are currently limited. In practice, this type of assessments are rarely performed. In comparison with other disciplines such as automotive or computing industry, every investor is aware of the "component by component quality... including, life cycle benefits..."[8].

In early phases of design, this is exacerbated by the fact that information needed for a sophisticated analysis are often unknown. Ironically, early phases of design often has the most influence in the first cost and performance of the building. As a result, a less time consuming cost benefit analysis is needed to provide a general cost of ownership or return on investment for decision-makers and stake-holders.

2.3. Review of Previous Studies

This research relies on findings from previous research on quantitative benefits of dynamic solar control to derive a cost benefit analysis. Four categories of quantitative benefits are identified from recent research: (1) Energy savings, (2) Carbon dioxide(CO_2) emission reductions, (3) Peak load reduction, and (4) Glare and Productivity. An additional category which relates to daylight / visual connection and productivity is identified but quantitative benefits are not derived and utilized in the calculation of the cost benefit analysis.

Research on energy savings include Littlefair's[7] series of experiments to simulate(using DOE-2 with Equest interface) the performance of various solar control strategies in an office building in London. Five cases are reviewed: (1) no shading, (2) manually controlled internal shading(roller shades), (3) exterior fixed shading(overhang), (4) adaptively controlled internal shading, and (5) external shading device that is moveable and adaptively controlled. Results indicate that in terms of overall energy reduction(heating, cooling, lighting, and ventilation), the best performing solar control strategy is the automatically controlled internal roller shades as it provided a 6.6% reduction in total delivered energy when compared to no shading and 3.8% reduction when compared to internal manual roller shades. In comparison, adaptively controlled moveable exterior shades provided a 1.3% total energy reduction when compared to no shading and an increase of 1.6% when compared to internal manually operated shades. When evaluating energy reduction in terms of cooling load alone, adaptively operated exterior shades provided a 66% reduction when compared to no shading and a 53% reduction when compared with interior manually operated shades. The substantial savings in cooling energy would allow the removal of cooling in portions of the building creating further initial cost savings but this would need to be evaluated on a case by case basis.

Littlefair's[7] analysis extends further into the amount of carbon dioxide emissions for multiple shading options. Results indicate that adaptively controlled exterior shades provide a total of reduction of 7.8% in CO_2 emissions over no shading and a 3% reduction over interior manual roller shades.

Research on peak load reduction include Tzempelikos, Athienitis, and Karava's[10] research which performed an integrated thermal analysis on a 53,000m^2 engineering building in Montreal. Three cases were reviewed, passive lighting control with no shading, active lighting control with shading, and active lighting control coupled with adaptive venetian blinds and roller shades. The main finding of the research indicates a 512kW/37% peak cooling load savings by using adaptive solar control coupled with lighting control strategies. This amounts to a 0.00966kW peak load reduction per m^2.

Research on glare include Zhang and Altan's[11] survey of occupant comfort(thermal, visual, and acoustics) in a conventional high rise block and a contemporary environmentally designed building in Sheffield, UK. Survey results indicated that in a conventional high rise building with high WWR, 65.3% of occupants experienced discomfort from glare.

Research on productivity include Osterhaus and Bailey's[9] lab experiment at the Lawrence Berkeley Laboratory where computer operators were exposed to large area light source of variable but uniform luminance. Results of the experiment include a 3% reduction in visual task efficiency along with a marginally increase in error rate in high glare situations.

Finally, research on productivity tied to view management include Heschong's[2] seminal study on SMUD call center. Findings include a significant increase in productivity(7% to 12% in processed calls and 10% to 25% in mental function and memory recall) with a pleasant visual connectivity to the exterior in comparison to no view. The study was conducted with the use of solar control in the form of perforated vertical blinds which partially screened by the view[2].

Table 1. Summary of Quantitative Findings from recent literature

Category	Research	Finding
Energy Savings	Littlefair[7]	1.3% annual energy savings
CO_2 emission reduction	Littlefair[7]	3% reduction in CO_2 emission
Peak load reduction	Tzempelikos et al. [10]	0.00966kW peak reduction per m²
Glare & Productivity	Zhang and Altan[11]	65.3% of occupants experience discomfort from glare
	Osterhaus and Bailey[9]	3% reduction in productivity

3. Case Study & Analysis

3.1. Context of Case Study Building

The case study building is situated in New York City, NY, USA. New York City like many metropolitan cities is known for its skyscrapers and commercial office buildings with fully glazed facades. Recent studies focused on this trend of highly glazed facades in commercial office space[6]. However, a large segment of commercial retail space within New York City are provided by mid to low-rise buildings with limited glazed fenestrations. In fact, New York zoning laws prohibits and limits the construction of high-rise buildings in certain commercial areas. Representing the reality of building construction in practice, the case study building is a mid-rise new construction, five-story 3,250m^2 (35,000ft^2) commercial office building in New York, NY with approximately 50 employees3). The building is designed to meet New York City 2014 Energy Compliance Code 16 requirements for new construction and ASHRAE 90.1-2007 as a minimum for performance of a standard code-compliant building.

3.2. Case Study Building

The case study building was designed by an architectural design firm along with a group of consultants4) in New York City as the new headquarter for a private company. The author was involved directly in the design of the building enclosure with input from consultants and with access to local contractors, fabricators and suppliers who were bidding on the project (project sensitive information including the names and addresses of stake-holders have been withheld).

Due to the high cost of land and space, like most buildings in New York City, the case study building maximizes it's allowable buildable area based on local zoning laws and setbacks. The building dimension corresponds to the plot dimension of 22.8m in width and approximately 30.4m in depth with a 6m rear yard setback applied from the second floor. The overall building height is 35.4m which includes five floors and a mechanical penthouse above the roof, see Fig. 2. for a schematic building massing of the building. The ground floor of the building is an open plan commercial space while the upper floors(floors two to five) are typical office spaces for employees.

The structure of the building is primarily concrete(concrete beams, columns and slabs). While steel was briefly considered, due to financial reasons, concrete was chosen as the primary structure of the building. Heat and cooling is primarily provided by two air handing units located above the mechanical penthouse and distributed through centrally located shafts. Lighting is provided by a combination of LED track lighting, recessed down lights, and suspended light fixtures controlled by an overall building management system with local controls provided in central locations throughout the building.

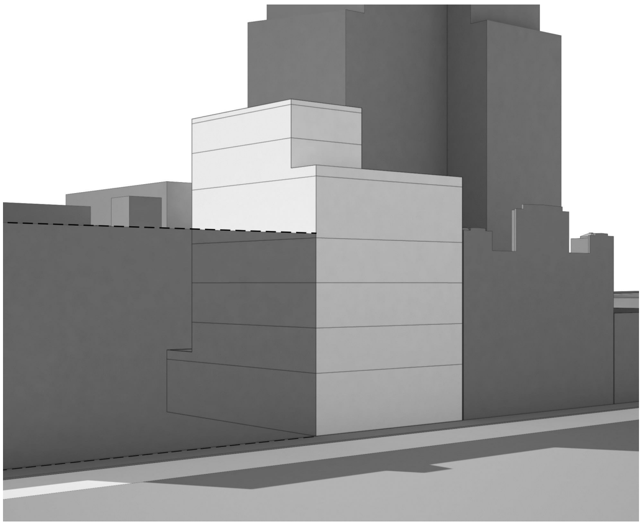

Fig. 2. Schematic Building Massing

The case study building's facade(see Fig. 3.) is the basis for analysis. The facade design consists of colored concrete block and horizontal stone bands with individual windows5) from levels two to five. A large opening is provided at the ground level resulting in a total window to wall ratio(WWR) of 35%. From the limited choice6) of commercially available exterior roller shade fabrics, White / White color shades are selected with a 5% openness factor, a key criterion which balances the need to control glare while maintaining visibility through the shade. Other solar optical properties of the shade fabric include: solar transmittance(Ts) of 22, solar reflectance(Rs) of 62, solar absorbance(As) of 16, and visible transmittance(Tv) of 23.

Fig. 3. Case Study Building Elevation

Another recent specification criteria of roller shades include the View Clarity Index formula developed by Konstantzos et al.[4]. The range of values of the View Clarity Index ranges from 0 to 1 where 0 represents full blackout and 1 referring to fully visible.

The proposed shade fabric has a View Clarity Index(VCI) of 0.2389 when put into perspective closely correlates to the a typical white Lutron interior shade. For a graphic representation of the proposed exterior mounted adaptive solar control and its components, see Fig. 4.

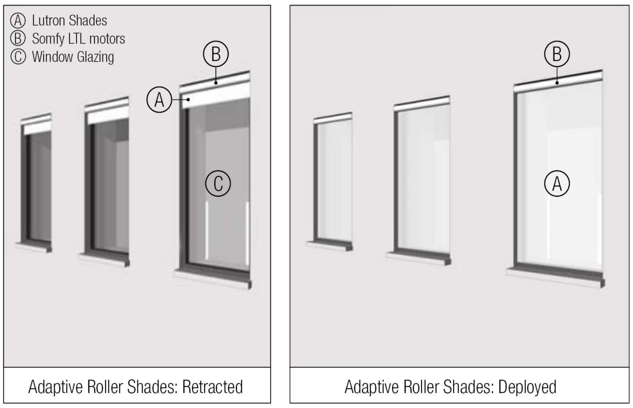

Fig. 4. Image of proposed exterior adaptive solar control and its components in both retracted and deployed state

3.3. Cost Benefit Analysis

A cost benefit analysis is performed for the 3,250m^2(35,000ft^2) case study building with fifty employees in New York City. Quotes for fabrication and installation of adaptive solar shades are obtained from local installers in New York. The quote provides an initial cost of adaptive shade control(exterior roller shades) for the case study project to be $646 per m^2 of window area. With 24 windows, each with an area of 4.5m^2, and a total window area of 108m^2, this results in a total initial installation cost of adaptive roller shades at $69,788. With 50 employees in the case study building within 6m of the enclosure, the installation cost per employee is approximately $1,395, refer to Table 2.

Estimated total electricity consumption(cooling, lighting, water heating, and misc.) of a 3,250m^2 commercial office building in New York is approximately 441,256kWh7) at an average electricity cost of $0.2217 per kWh. Heating is provided by natural gas and the approximate annual consumption is 551.5 MMBtu at $0.16 per MMBtu. This results in a total electricity cost of $97,822 and a total heating cost of $8,769 for an annual total combined energy cost of $106,591. Applying a 1.3% savings from recent research[7](see Table 1.), total annual energy savings gained from installing exterior adaptive solar shading amounts to $1,385, with a benefit per employee of $27.70, refer to Table 2.

The cost of peak demand reduction can be calculated by reviewing the cost to purchase a new generator. Banting et al.[1] calculated the cost of bringing in new generation capacity at $600 per kW while evaluating environmental benefits of implementing green roof in the city of Toronto. The total estimated peak load reduction for the case study would be 31.5kW(0.00966kW/m^2. x 3,250m^2). With the cost of bringing new generator capacity at $600 per kW, the initial cost savings of avoiding the construction of new generator capacity would be $18,900(31.5kW x $600), a savings of $378 per employee, see Table 2.

Calculating the cost of reduction in CO_2 emissions is a three step process. First, the amount of CO_2 emissions is calculated based on energy consumption(electrical + heating) of the building. The Greenhouse Gas Equivalencies Calculator from the United States Environmental Protection Agency(EPA)8) estimates 50kg of CO_2 is release per 0.1MMBtu of natural gas. For electricity, an average of 0.7kg CO_2 is released per kWh according to the United States Environmental Protection Agency(EPA). By applying the amount of annual natural gas and electricity used to the factors provided by the EPA, results indicate a total of 27,300kg of CO_2 emission from natural gas(551.5MMBtu x 50kg CO_2) and 304,000kg of CO_2 emission from electricity (441,256kWh x 0.7kg of CO_2) for a combined total of 331,300kg of annual CO_2 emission.

Second, the cost of CO_2 emissions is calculated. The attempt to quantify the social cost of carbon dioxide emissions has been documented in a 2010 report by multiple agencies within the United States Government[3] including but not limited to the Department of Energy, Commerce, Agriculture, Transportation, and Office of Energy and Climate Change. The intent was to "incorporate the social benefits of reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions"[3]. The report provides four estimates based on three methods of calculation and a fourth calculation that accounts for "higher than expected impacts from climate change". Under the 2015 calculation, per 1,000kg of carbon dioxide emissions, the cost varies from $5.7(5% discount rate), $23.8(3% discount rate), $41.7(2.5% discount rate) and $72.8 based on a higher than expected impact from climate change. By applying these rates to the total CO_2 emission, the annual social cost of carbon dioxide emission for the case study building is estimated anywhere between $1,888 to $24,118 annually.

Third, findings from previous literature, see Table 1., is applied. 3% CO_2 emission reduction is quantified based on recent literature[7], see Table 1., resulting in an estimated annual cost savings of $57 to $723 annually, a savings of $14.46 per employee, see Table 2.

Calculating the cost benefit of glare and its resultant impact on productivity, 3% productivity gain[9] from 65.3% of employees [11] can be projected based on recent literature, see Table 1. Applying this to the case study building with 50 employees at an average salary of $40,000 this amounts to total potential productivity benefit of $39,180($783.60 per employee).

Table 2. Cost/Benefit Analysis of incorporating exterior adaptive solar control

Description	**Area (m^2)**	**Cost/ Benefit per m^2**	**Project Cost/ Benefit**	**Cost/ Benefit per employee**
Installation/First Cost of Adaptive solar control	108m^2	\$646 per m^2 of glazing area	(\$69,788 initial cost)	(\$1,395)
Total Energy Savings(annually)	3,250m^2	\$0.43	\$1,385	\$27.70
Peak demand reduction	3,250m^2	\$5.82	\$18,900	\$378
Reduction in CO_2 emission(annually)	3,250m^2	\$0.22	\$723	\$14.46
Productivity gain from glare control	3,250m^2	\$12.06	\$39,180	\$783.60
First Year Cost Benefit	-	-	**(\$9,600)**	**(\$192.00)**
Five Year Cost Benefit	-	-	**\$231,152**	**\$4,623.04**

Factoring in all the cost benefits from reduced annual energy use, peak demand reduction, reduced carbon dioxide emissions, and productivity gains from glare control, a five year cost benefit analysis is represented in a graph in Fig. 5.

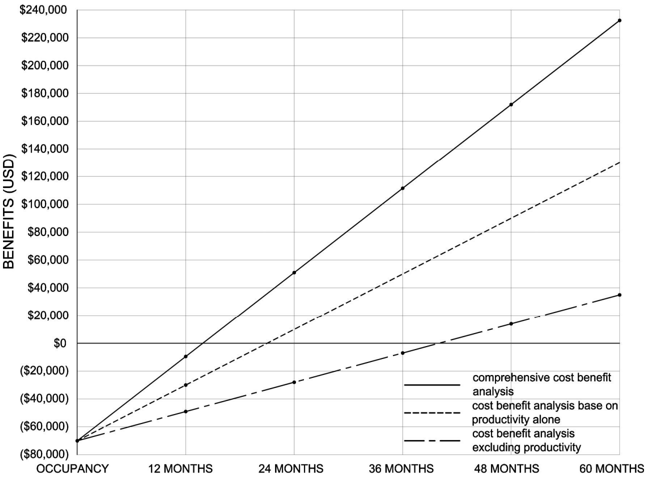

Fig. 5. Five Year Cost Benefit Analysis

3.4. Analysis of Results

Analyzing the results, first year(12 months) return on investment(ROI) is projected to be 86%. A key finding in the analysis is that productivity gains account for 65% of the first year return on investment(ROI). Full return on investment is projected to occur in the 13th to 14th month(first quarter of Year 2). To further illustrate the significance of productivity on the return on investment, a separate analysis is performed based on productivity alone, represented in a dashed line in Fig. 5. Based on productivity alone(excluding all other benefits), full return on investment is projected to be slightly lengthened(22nd month or third quarter of the Year 2). Excluding productivity benefits, full return on investment is extended by more than 2 years resulting in a projected return on investment occurring in the 38th month(the first quarter of Year 4), represented by the center line type in Fig. 5.

3.5. Limitations of Research

Results from the cost benefit analysis portray an estimated return on investment and a general indication of its financial feasibility. Based on this information, clients and stake-holders are able to make an informed decisions on viability of exterior adaptive solar control during early phases of design. However, there are a few limitations with the proposed research, methodology and analysis to be considered.

A key component of the research is in the proposed methodology of utilizing quantitative benefits from recent literature. By utilizing existing research, a significant amount of time and effort is saved at the expense of obtaining an estimated quantitative finding. This approach, relies on the assumption that the referenced research, see Table 1., has a high correlation to the proposed research. To ensure this correlation, a significant amount of effort was undertaken to identify reliable existing research with similar characteristics to the case study building. Yet differences which may have an impact on the quantitative results are inevitable. For instance, Littlefair's[7] research is used to derive energy savings and CO_2 emission reduction findings by utilizing exterior adaptive solar control on a three story office building located in London. While the topic, function(office building) and the climate conditions9) may be similar, the geometry, orientation of the building, its surrounding context, and environmental conditions may sufficiently distinct to question its applicability to New York City. However, this tradeoff may be worthwhile when considering the following alternatives.

The most common approach is to undertake simulations to obtain quantitative findings based on project specific information. This alternative has its own shortcomings during early phases of design. In early phases of design(pre-design and schematic design), the design is in its inception and still evolving. As a result, information used in performing simulations are often undecided or unknown. Therefore, even with the added investment of time, the results obtained may be equally questionable.

To avoid this issue, simulations in most cases are performed in latter phases of design(design development and contract documentation). However in the latter phases of design, many of the design decisions are already in place and therefore the results of the simulations are simply a verification of the design decisions and not a tool to evaluate its performance or financial feasibility.

Weighing the overall benefits and its shortcomings, the use of quantitative benefits from existing research, if carefully chosen to correlate with the subject of the research, may not be the most reliable option but the most optimal in balancing time and effort invested while maintaining a reasonable amount of reliability.

Cost data presented in this paper also has a few limitations based on location. Installation and first cost information was obtained from correspondence and interactions with local suppliers and non-union local installers during the design and bidding phases of the project between the years 2013-2015[10]. Energy cost was obtained from publicly available information provided by a local energy service provider in New York City. The main limitation of the collected cost data, is in its applicability to other locations. New York City is known for its high labor rates[11] and cost of energy when compared to other metropolitan cities. As a result, the cost data information is not representative of a typical urban condition and therefore to apply findings from this research to another geographical location, local cost information needs to be obtained and factored in.

4. Conclusion

This paper presents a cost benefit analysis of implementing exterior adaptive solar control to a building in New York City through a case study. An overview of adaptive solar control is defined and the need for a detailed financial analysis for sustainable technologies are presented. Quantitative findings from recent literature in addition to cost information for materials and installation obtained by the author through correspondence from local vendors in New York City are used as a basis for a cost-benefit analysis of exterior adaptive solar control. Furthermore, a review of the proposed research methodology, including strengths, weaknesses, and limitations, for its use in early phases of design are presented.

The cost benefit analysis concluded that while there are benefits associated with implementing adaptive solar control and view management, the high initial cost of installation may become a deciding factor in its implementation. By factoring in productivity gains from glare control, the return on investment is significantly improved resulting in a positive return on investment starting from first quarter of the second year. Furthermore, the benefit of productivity alone outweighs the combined performance benefits of energy savings, CO_2 emission reduction, and peak load savings, see Fig. 5., Five Year Cost-Benefit Analysis.

The author's interest is in obtaining quantitative information to be used in the early phases of design as a decision making tool. As a result, an estimated potential benefit from recent literature is used as a basis for a derived cost benefit analysis. For a more comprehensive cost benefit analysis, total energy savings would need to be further broken down into energy savings and increases for heating, cooling, lighting, and ventilation. Productivity gains and deficiencies would also need to be evaluated further. The impact of solar shades on daylighting and visibility needs to be quantified and presented in the cost benefit analysis.

Next steps include a cost benefit analysis of alternate solar and view management technologies including smart glazing and integral glazing to identify the highest return on investment(ROI) across the various types of solar control systems. The case study focused on a single widely available technology and product to avoid limiting the number of qualified installers and vendors for the project.

Acknowledgement

This study was supported by the Research Program funded by SeoulTech(Seoul National University of Science and Technology).

This paper draws from research developed for Professor Vivian Loftness' Productivity, Health and Quality of Buildings at the Doctor of Professional Practice program at Carnegie Mellon University School of Architecture. The author is grateful for Professor Vivian Loftness and to his advisor, Dr. Daniel Cardoso Llach, for their guidance and advice.

Reference

[1] Banting D, Doshi H, Li J, Missious P, Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto, OCE-ETech, 2005, pp.1-88

[2] Heshong L, Windows and Classrooms: A Study of Student Performance and the Indoor Environment. California Energy Commission, 37(4), 2003, pp.414-435

[3] Interagency Working Group on Social Cost of Carbon, Technical support document: Social cost of carbon for regulatory impact analysis -under executive order 12866, United States Government, 2010

[4] Konstantzos I, Chan Y, Seibold J, Tzempelikos A, Proctor R, Protzman J, View clarity index: A new metric to evaluate clarity of view through window shades, Building and Environment, 90, 2015, pp.206-214

[5] Lee E, Selkowitz S, Hughes G, Market Transformation Opportunities for Emerging Dynamic Facade and Dimmable Lighting Control Systems, ACEEE, 2004

[6] Lee E, Selkowitz S, Bazjanac V, Inkarojrit V, Kohler C, High-performance commercial building facades, 2002

[7] Littlefair P, Ortiz J, Bhaumike C, A simulation of solar shading control on UK office energy use. Building Research & Information, 38(6), 2010, pp.638-646

[8] Loftness V, Hartkopf V, Gurtekin B, Hua Y, Qu M, Snyder M, Gu Y, Yang X, Building Investment Decision Supports(BIDS), 2005 Report on University Research, 2005, pp.12-31

[9] Osterhaus W, Bailey I, Large Area Glare Sources and Their Effect on Discomfort and Visual Performance at Computer Workstations.

Proceedings of the 1992 IEEE Industry Applications Society Annual Meeting, 1992, pp.1-5

[10] Tzempelikos A, Athienitis A, Karava P, Simulation of facade and envelope design options for a new institutional building, Solar Energy, 81(9), 2007, pp.1088-1103

[11] Zhang Y, Altan H, A comparison of the occupant comfort in a conventional high-rise office block and a contemporary environmentally-concerned building, Building and Environment, 46(2), 2011, pp.535-545

[12] American Institute of Architects, B201-2007 Standard Form of Architect’s Services: Design and Construction Contract Administration, https://www.aiacontracts.org/contract-documents/19341-architects-services---design-and-construction-contract-administration, 2015.12.20

---

1) Relationship of glare and productivity has been studied by Osterhaus and Bailey[9].

2) Also known as supplemental services, the term refers to services beyond “Basic Services” that arise during a course of a project[12].

3) Number of employees used in the analysis was provided by the client

4) Consultants involved in the design include Structural, Mechanical, Electrical, Plumbing, Fire Protection, Civil, Lighting, and Vertical Transportation Consultants.

5) Project utilizes 1" glass assembly of ¼" clear glass, ½" airspace and ¼" clear glass with specifications of visible transmittance Tv) at 70% and a Solar Heat Gain Coefficient(SHGC) of 0.38.

6) Compared to interior applications, the choice of exterior roller shade fabrics are limited due to ultraviolet degradation.

7) Figure calculated utilizing ConEdison Commercial Energy Calculator, http://www.coned.com/customercentral/calculators/EC_bus_Calc.html, 2015.12.20

8) Calculated utilizing EPA, Green House Gas Equivalencies Calculator, http://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.html, 2016.01.04

9) Both New York City and London have a temperate climate and are often categorized under the same type of climate classification category.

10) The cost information is representative of labor rates in New York, and may differ based on location. Also, construction cost inflation needs to be factored for calculations beyond the years of 2013-2015, the time of date when the data was collected.

11) According to Turner & Townsend’s 2018 International Construction Market Survey, New York City has the second highest cost of labor worldwide(only Zurich, Switzerland is higher than New York City). Labor rate calculation is based on union-workers.