State of the Art Methodology to Assess Energy Facade Retrofits (EFR)

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ABSTRACT: This paper summarizes findings from existing literature and proposes a methodology to assess facade retrofits. Literature review indicates that research on energy-based retrofits isolates limited factors and does not address the holistic benefits associated with facade retrofits. Many cases of energy upgrades in practice that included facade retrofit describe energy savings, but without any quantification of the facade contribution to those savings. In addition, current practice considers the facade as a last step in the process of energy upgrades, confined to being part of a 'deep' or 'comprehensive' intervention. This is primarily due to the higher initial costs of facade replacement or renovation. An extended understanding of facade retrofit from the perspective of related fields would help to establish a more comprehensive evaluation of its benefits. A proposed methodology to perform life cycle assessment of facade retrofits that are initiated with an energy-based systems retrofit is described in this paper. It recognizes the building skin as the key system in the total building performance. Total performance refers to energy, human and financial parameters. The different perspectives considered in the methodology include Building Science, Human Comfort, and Real Estate fields. Building Science is used to evaluate several energy retrofit alternatives and resulting energy reductions are obtained from energy simulations. A sensitivity analysis assists in evaluating and selecting the most beneficial input facade parameters. Human Comfort responses to environmental factors influenced by the facade are analyzed from existing literature and findings are used as reference. Real estate gains and losses are evaluated based on current market trends to appreciate the influence of facade improvements. A holistic methodology to evaluate overall building performance enhancements of facade retrofit could provide a paradigm shift in the importance of facade retrofit on our existing building stock.

KEYWORDS: Facade, Retrofit, Energy, Human factors, Costs.

INTRODUCTION

Facades were a priority in the design of traditional architecture. They played an important role in the overall building performance prior to forced air and electric lighting. With the advent of economical energy use and the introduction of new building materials, facade designs transformed to aesthetic expressions with less concern about performance. With increased awareness due to an energy crisis in the 1970s, the facade once again was conceptualized as the building skin, becoming a key building system for environmental control. Adapted to specific climatic conditions, it acted as a filter for maximizing the use of free energy and human comfort (Fitch and Bobenhausen 1999). Paradoxically, during the same period, buildings were designed with facades that did not respond to that priority. Sealed glass boxes were developed everywhere under principles of modernity and progress and corporate symbolism. These buildings were inherited in our cities in the 21st century, and now a major target for energy reduction. Most of these buildings possess inefficient envelopes as major contributors to building energy waste. In our current scenario with uncertain energy prices, most of the energy challenges for the upcoming decades relies in the capacity of transforming existing inefficient buildings into high-performance ones.

Energy building retrofit is an emerging area of research. Within this area, very little is known about the development of high-performance facade retrofits from inefficient old ones. Even for new projects, technical references for assisting the design of high performance are scarce (Straube 2012, 2). A preconceived design is settled early in the process without tools to consider the full range of impacts on other performances, and systems are still often design sequentially instead of fully integrated. Consequently, facade interventions are usually based on professional experience or relying on rules of thumb. Measurement and verification is infrequent, and if done, these results are not shared as public knowledge, (Warburton and Kostura 2007, Benson et al. 2011) limiting current and future informed decision making. Moreover, the energy retrofit market works in a 3-5 year payback period (Benson et al. 2011, 1), which makes HVAC and lighting systems the preferred replacements. Due to lower implementation costs than facade retrofits, quick savings on utility bills give more tangible and controlled risk. However, improvements on the energy efficiency of internal mechanical equipment do not reduce the energy flow through an inefficient skin. The owner sees a smaller energy bill but does not realize further energy reductions and other performance benefits of retrofitting the facade.

Facade retrofit is understood as any intervention (modification, addition) in the building facade with the goal of improving energy performance and/or indoor quality in an existing building. Facade retrofit can range from small repairs (weathering) to a total replacement of the original facade for a new system. Generally, the facade is included in what is known as a 'deep energy retrofit', which analyzes the building as a whole with the goal of achieving over 50% energy reduction (The American Institute of Architects and Rocky Mountain Institute 2013, 6).

1.0 EXISTING EVALUATION METHODS FOR FACADE RETROFITS

A growing interest in energy performance has been centered on understanding existing buildings from a life-cycle perspective. Some studies have approached the topic from a global point of view of the challenges and opportunities of building energy upgrades, whereas others have focused on specific aspects. For example, research has centered on embodied or operational energy, costs of these interventions, or impact in several aspects of sustainability. Many studies in the area of energy building retrofit have focused on a variety of energy conservation measures (ECMs), such as lighting, Heating, Ventilation and Air Conditioning (HVAC) equipment replacement, incorporation of building controls, and changes in operations or energy generation. Some cases of facade retrofit have been included as just another alternative among these strategies.

Yet, studies focusing on the retrofit of the building envelope are limited. Qualitative studies have looked to map the challenges and opportunities that facade retrofit offers in practice (Patterson et al. 2012). Others investigate the appropriateness of strategies of facade intervention for specific building type or context (Brunoro 2008). Typologies of facade retrofits have been explored according to the magnitude of the intervention in the building. These range from repairs of the original facade to the full replacement (Sanguinetti 2012, 8-9, Patterson and Vaglio 2011). From a broad perspective of sustainability, studies have examined facade retrofit using life cycle assessment (LCA) (Ebbert 2010). Some of these studies include operational energy but many have explored other aspects, such as economic, urban, equity, ecological or social impacts.

1.1. Deterministic methods for evaluation of facade retrofits

In deterministic methods, the results obtained in a model are directly defined by their initial input. In energy analysis, a common practice is to use engineering calculations for predicting future behavior based on physics. Some deterministic methods describe energy flow through the envelope statically (no time variation). Those steady-state calculations are performed for a selected set of rooms on the building with critical conditions, which are assessed under standard design conditions.

More advanced deterministic methods use dynamic simulation models to assist the evaluation of any prediction of the building performance based on spatial-temporal variations. Simulations are considered an important paradigm shift in the assistance of design processes for a faster and cheaper performance prediction before construction (Clarke 2001). Nowadays, hundreds of simulation tools are available with multiple capabilities. Some of them allow whole building analysis and consider load calculations, renewable energy, indoor air quality, ventilation, code compliance and more (US Department of Energy 2013). However, assessments using these tools are not routine in practice yet, not even for new design. If project budgets allow for them, the assessments may be incorporated later in the process, frequently when design decisions have been made already (de Wilde 2004). In addition, fewer of these tools are dedicated to the study of the facade itself, so its analysis is embedded in whole energy analysis.

As part of the use of simulation, facade retrofits have been explored using calibrated energy models. They are extensive, since the goal is to obtain a closer representation of the behavior of the building under study. Because it is a complex procedure, calibration is addressed by some standards such as ASHRAE Guideline 14, International Performance Measurement and Verification Protocol (IPMVP), or the Federal Energy Management Program (FEMP). Some studies such as the one carried out by Güçyeter and Günaydın (2012) integrate envelope retrofit strategies (insulation) with renewable energy technology and climate control using a calibrated simulation model (EDSL software). That model is fed by data from one year of energy monitoring to analyze environmental parameters and annual energy of a campus building in Turkey (Güçyeter and Günaydın 2012). Martinez et al (2012) evaluates single and cumulative effects of facade retrofits on energy consumption using whole-building calibrated energy models (eQuest and Design Builder) for a commercial office building in Los Angeles (Martinez et al. 2012). Singh evaluates facade retrofit strategies among several ECMs intended to bring a building to zero net-energy status (Singh 2012).

Other studies have looked to existing energy simulation tools to evaluate different retrofit packages. NREL modified an existing energy simulation tool (BEopt) for evaluating retrofits of residential buildings from a life- cycle perspective (Polly et al. 2011). The study includes wall insulation and air seal among the alternatives. Ebbert (2010) explores facade retrofits in European office buildings using energy models (ESP-n) integrated in life cycle analysis (LCA). Rosenfeld et al (1999) proposes a computerized semi-automatic tool to assist decision-support for renovation projects (Rosenfeld and Shohet 1999).

1.2. Stochastic methods for evaluation of facade retrofits

As an alternative to deterministic methods, some studies have assessed energy retrofit decisions incorporating stochastic models. In those approaches, random component selections represent the behavior of building performance. As is characteristic of stochastic models, multiple simulations using uncertain inputs and processes defined by appropriate probability distributions develop a range of probable outcomes. Asadi et al (2012) develops a simulation-based multi-objective optimization scheme (TRNSIS, GenOpt, Matlab) to include facade retrofit strategies for a residential building in Portugal (Asadi et al. 2012). Sanguinetti (2012) uses a statistical model to compare a series of energy retrofits with a traditional energy simulation for a residential building. With three performance parameters (environmental, delivery process and financial), she evaluates different combinations of new layers and infiltration control (Sanguinetti 2012).

Even though the facade is not considered within the strategies, Heo (2011) proposes a scalable and adaptable framework for analysis of building retrofits under uncertainty. The study covers physical properties, equipment performance, and costs. In a scalable method (individual building or portfolio), a normative model is calibrated using Bayesian theory and probabilistic analysis. This model assesses feasible ECMs to select the optimal mix of retrofit technologies in a modeling process described as transparent and easy to use (Heo 2011).

1.3. Financial evaluations of facade retrofits

Several studies have indicated insufficient data and methods to assess investments on retrofits. Consequently, one of the many myths regarding sustainability is that any action for greening an existing building is not a worthwhile investment (Kubba 2012, 2). Investments in energy retrofits that do occur are commonly measured by single payback calculations. The payback method emphasizes initial costs of implementation, and only accounts for future energy savings as returns on the investment. It fails to integrate indirect benefits derived from improved facade performance. In addition, these calculations do not incorporate other factors such as interest rate, inflation, energy price fluctuation, happening overtime. To consider the facade as part of an energy retrofit, studies need to be framed on a period adequate for financial evaluation longer than the typically 3-5 year payback owners expect for retrofits that only upgrade internal systems. Many complexities appear with systems in the building that have different life spans. Studies have estimated those life spans: the structure could last the whole life of a building, while equipment would be updated every 8-15 years (Kats 2003, 10). Some facade components need to be replaced every 20 years to maintain a longer overall lifespan for the facade system (Giebeler et al. 2005).

Life Cycle Cost (LCC) method has been used to serve decision analysis. It considers initial cost, actual initial savings, and persistence of savings over time. Some of these studies have included facade in the retrofit strategies have used different time periods for analysis: 20 years (Gilligan 2009, Sanguinetti 2012); 30 years (Kats 2003, 10, Polly et al. 2011); 50 years (Maleki 2009);. A recent modification of the California Energy Commission extended the evaluation time period of analysis from 25 to 30 years (California Energy Commission 2011). Financial analysis models should not only consider that facade retrofits extend the life of buildings, but also a series of other benefits.

Among other financial benefits of green buildings are higher rental and building values. A study found rental rates in green-certified buildings are roughly 3% higher per sq. ft. than otherwise identical buildings, and selling prices are about 16% higher (Eichholtz, Kok, and Quigley 2009), whereas a study also reports rents about 35%higher than other local properties(Northwest Energy Efficiency Alliance and National Buildings Institute 2011, 2). Another study found that certified buildings reported between 31-35% higher sales prices (Kubba 2012, 31-32). A survey in Seattle by the Building Owners and Managers Association (BOMA) reported that 61% of real estate owners believe green buildings enhance their corporate image and many of them believe that 'green' buildings will be a factor in the selection of a lease space in the short term (Kubba 2012, 3). A survey reported that green buildings have better financial performance compared to other similar buildings including higher building values, higher asking rents, higher return on investment and higher occupancy rates (Turner Construction 2010). A report analyzing LEED buildings suggests that the greener the buildings, the longer their lifespans are compared to conventional buildings (conventional Certified building: 40 yrs; Silver: 60 yrs; Gold: 80 yrs; Platinum: 100 yrs) (Kubba 2012).

1.4. Integrating human value

Over the last few years, the importance of the connection of human comfort to the concept of sustainability has been brought to the foreground. Americans spend 80-90% of their time indoors (US Department of Labor 2013). Concepts such as the Sick Building Syndrome (SBS), Building Related Illness (BRI), and Multiple Chemical Sensitivity (MCS) are consequences of poor indoor quality, generally detected in enclosed, mechanically-conditioned spaces. As a direct influence on indoor environmental quality, a proposed facade intervention must evaluate restoring ventilation and lighting levels that will favour human comfort. However, considering human parameters for evaluation under quantifiable criteria is a complex task. The nature of thermal comfort derives from subjective evaluations (Carlucci 2013, v). Several other human factors are influenced by facade retrofit- noise, glare, daylight availability, visual contact with the outside environment and other factors can all be influenced by facade in working environments. Not only listed as one of the reasons by doing retrofits, the cost of people is highlighted by several studies. Analysis focusing on office building costs shows that the cost of employees is 72 times the cost of energy (Zobec, Colomban, and Kragh 2001); or the costs of California's State employees as 10 times the cost of property (Kats 2003, 54). Current research recognizes that strategies to maximize occupants wellbeing would quickly offset the costs of implementing well-done energy retrofits (Zobec, Colomban, and Kragh 2001, citing Romm and Browning 1998).

2.0. A PROPOSED METHODOLOGY

An integrated approach, rather than energy-based evaluation that is commonly done with simple payback, would allow visualizing a range of usually hidden benefits. This method is intended to demonstrate that implementing a facade retrofit could yield a net gain that a single payback approach accounting only for energy savings does not assess. Even though energy and economic performances have been integrated in life cycle context, the integration of so called 'soft benefits' is less explored. These benefits are usually described qualitatively, since they are highly complex to quantify and lack empirical data. Some of these benefits are improved human comfort, urban regeneration, improved corporative image, enhanced historical value, and increase curb appeal. This paper recognizes that facades have a direct relation with indoor quality and real estate, and uses previous researcher's estimations in these areas.

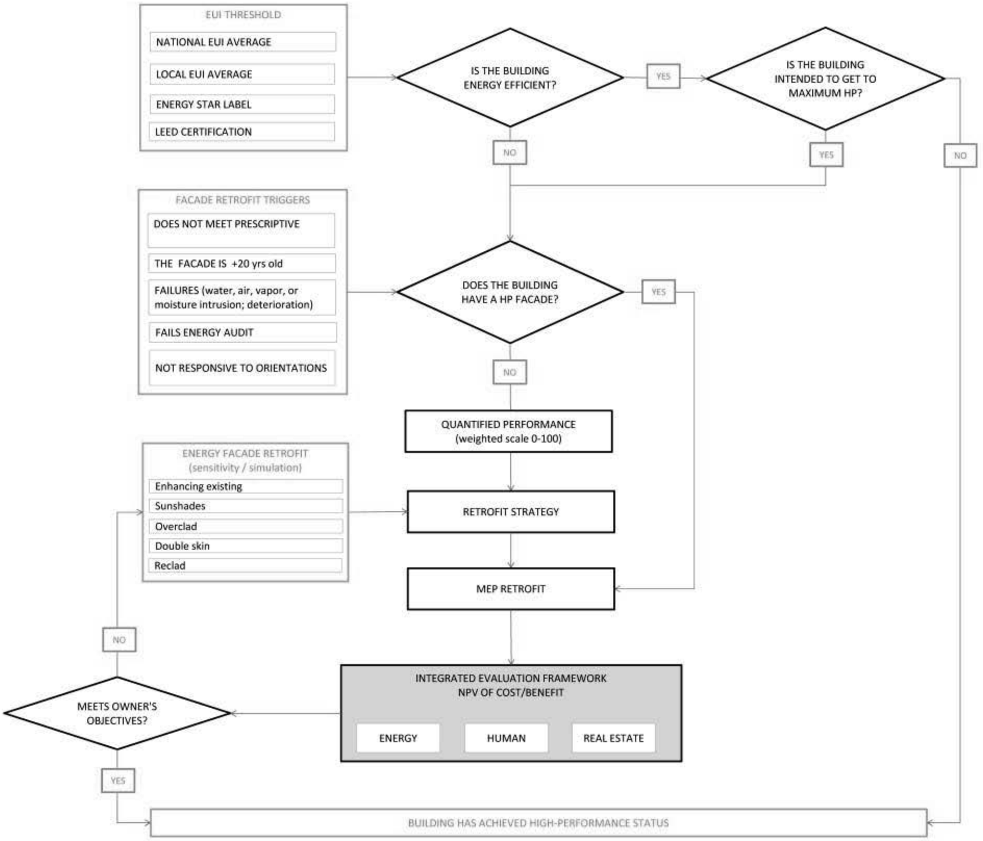

Figure 1. Methodology for assessing energy facade retrofits

The general framework is described in Figure 1. The methodology starts with the evaluation of benchmarking the building Energy Use Intensity (EUI) to some of the commonly used thresholds in practice. Facade evaluation is assessed when the building does not meet these energy performance levels, or the building is intended to achieve a higher performance status. In this methodology, a high performance facade is understood as one that at least achieves high levels of adaptation to climate, orientation, durability (related to age and maintenance) and code compliance. Buildings with deficient facades then follow a quantification of that performance that would determine an appropriate level of retrofit, which could be assisted by energy simulation. Once the best strategy of retrofit is predicted, it must study the synergies with internal systems such as HVAC and lighting.

The evaluation is based on cost-benefit analysis, which accounts for positive and negative consequences of a facade retrofit in monetary terms (Figure 2). Benefits are classified as direct, indirect and intangible (CDC 2013). Direct benefits are evaluated in terms of savings on operational energy. For example, daylighting strategies reduce artificial light when coupled with photo sensors; as including passive strategies, the need for mechanical systems for internal conditioning is reduced. Indirect benefits are gains related to employee costs, such as reduced absenteeism and turnover that are a result of better indoor environment quality. Indirect benefits related to real estate include the increased value on rents or in the value of the building due to the improved status of the building performance.

A timeframe is needed to identify the occurrence of different money flows at different times. A high initial cost is considered in the implementation phase. The operational phase is representative of the life cycle of the renovated facade. This duration will depend on the type of retrofit being evaluated (film in windows have a shorter lifespan than a total new facade).

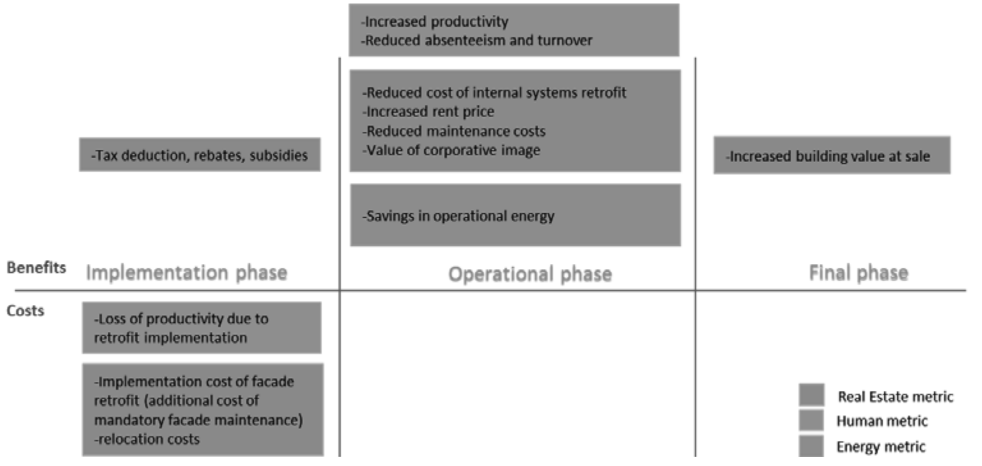

Figure 2. Cost and Benefit diagram and performance metrics

3.0. EXAMPLE-TESTING METHOD

The proposed methodology is tested in two existing office buildings in L.A. and compared with the common practiced payback period. Building-1 has received only maintenance, while Building-2 had a total facade retrofit in 2009. These buildings allow a comparison of predicted energy performance with real measured results for facade retrofits. The measured data in the first case is used to build the baseline for simulations.

Case Building-1 (simulated facade retrofit): Built in 1972, the building is 18,506m^2 (199,199ft^2) over 12 stories. The building maintains its original curtain wall facade, with vertical bands of 6.35mm (¼") single pane glass (clear glass in vision areas and tinted in spandrel) mounted in black neoprene in a non-thermal broken aluminum frame that are engaged in painted steel columns. Drawings show 25mm (1") insulation with no specification of the material. At some point in the past, a reflective solar film was added to the glass. The Window Wall Ratio (WWR) is less than 30%. The building obtained EnergyStar status in 2009. The building housed 531 office employees in 2010.

Case Building-2 (real facade retrofit): Built in 1973, the 9,964m^2 (108,300ft^2), 6-story building, received a total facade renovation in 2009. The building was gutted to its structural frame and mechanical system. The single tinted paned curtain wall facade was replaced for low-E insulated glass. The new facade is a good solution responding to orientation and integrating interior sunshades. Interior finishing and lighting renovation were done at the time of the facade. In addition, the building grew 93 m^2 (1,000 ft^2) in the renovation due to extensions of the concrete slabs that also provide some solar shading. The facade retrofit was reported to have a cost of \$1450/m^2 (\$135/ft^2).

Average energy consumption for large office buildings (>= 2787m^2 (30,000ft^2)) in Los Angeles area is 262KWh/m2yr (82.3KBtu/ft^{2}yr) (California Energy Commission 2006, 8). Both building perform better than average; Building-1 with a EUI of 150KWh/m2yr and a predicted energy reduction of 19% based on energy simulation. Building-2 has a EUI of 222KWh/m2yr and 30% energy reduction (assumed a typical energy use before the facade retrofit).

3.1. Parameters and assumptions

Existing literature and average values for the Los Angeles area serve as a basis for the method in data that has not been obtained by measurement or existing documentation. Parameters and conservative assumptions for the calculation of the costs and benefits for both buildings are detailed by performance area (Table 1). The period used to estimate future benefits and cost is 20 years

Table 1: Parameters and assumptions

Item		Value used analysis
Period of analysis		20yrs
Discount rate		10%
Cap rate		7%
Implementation time		5 months
Energy		
Total Energy savings after retrofit	*Building-1 predicted (energy simulation)* *Building-2 reported (monthly bills)*	19% 31%
Energy prices (no escalation)	*(US Bureau of Labor Statistics 2013a)Electricity* *(US Bureau of Labor Statistics 2013a)Nat. gas*	0.203 $/KWh 1.23 $/therm
Human		
Salaries(weekly)	*(US Bureau of Labor Statistics 2013b)*	$1,185
Productivity gain / loss	*15% increase to work dedication (Figueiro 2002)* *Up to 15% in offices (Loftness et al. 2003)*	5%
Real estate		
Implementation cost of EFR	*Bldg-1 estimated* *Bldg-2 reported cost*	$100 / m2 $135 / m2
Rent price	*(Loopnet Inc 2013)*	283
Increased rent price	*3% higher (Eichholtz, Kok, and Quigley 2009)* *35%higher(NEEA +NBI 2011)*	3%
NOI	*Increased rents (-)energy use (+)energy savings*	---
Building increased value	*31-35% higher sales prices(Kubba 2012)* *16% higher (Eichholtz, Kok, and Quigley 2009)*	5%
Building gained area	*Reported for Building-2*	92.9m2(1000sf)

The value of the building at sale is estimated on year 20 and calculated based on the Net Operative Income/ cap rate. An increased on 5% is estimated over that value due only to the facade improvement.

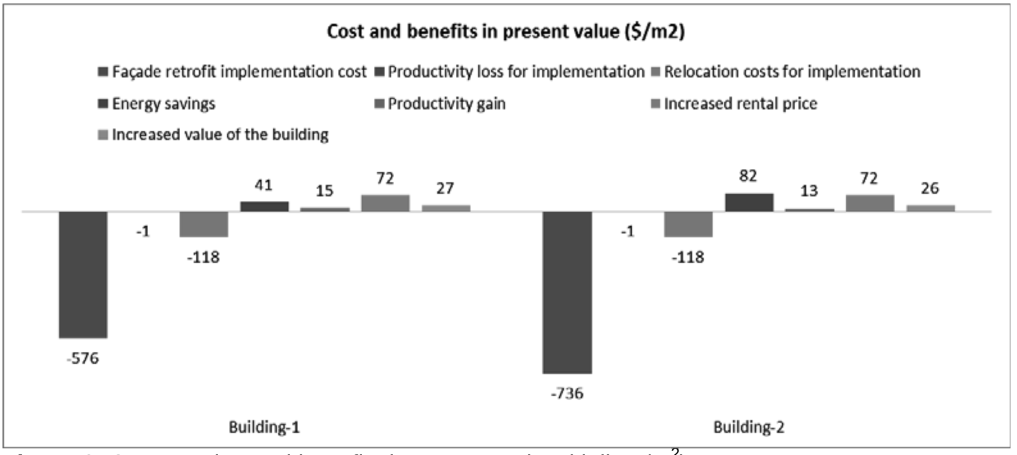

Figure 3. Comparative and benefits in present value (dollars/m^2)

Table 2: Comparison between single payback and proposed method.

Stakeholder		
	Building-1	Building-2
Traditional single pay-back	**120 yrs**	**76 yrs**
	$5	$10
	$576	$736
Proposed method		
Owner (leased building)	**5.8 yrs**	**7.5 yrs**
benefit: (increased rent + building add value)	*$99*	*$98*
cost: (implementation EFR)	*$576*	*$736*
Tenant	**1.3 yrs**	**0.8 yrs**
benefit:(productivity gains + energy savings)	*$56*	*$95*
cost:(increased rent price + productivity loss)	*$73*	*$73*
Owner (occupied by owner)	**8.4 yrs**	**7.1 yrs**
benefit:(energy savings +productivity gains +building add value)	*$83*	*$121*
cost:(implementation FR +relocation +productivity loss)	*$695*	*$855*

From an owner's perspective, there is an estimate of at least 10 times between the traditional payback and the proposed method for both buildings. Considering more than energy in the evaluation allows an increased awareness and understanding of why these are valid benefits to include in a financial analysis when considering the initial investment of retrofitting the facade. Even though this method requires more research and quantification, the range of the adjusted payback years in these studies shows that different stakeholders might consider investing in façade retrofit. Further research needs to find the best ways to quantify all the soft benefits considered here from previous references.

CONCLUSION

This paper proposes an integrated methodology for facade retrofit evaluation, recognizing adjacent fields to architecture. The synergetic approach includes areas that contemplate human and real estate performance criteria in addition to energy performance. The associated research summarized in this paper helps to understand and appreciate the complex interactions in facade retrofit decisions.

The method described in this paper evaluates the costs and benefits of the facade retrofit including areas that are not usually visualized to define the convenience over a limited method used in practice. The method keeps the decision making process open to the richness of interactions, avoiding premature concentration only on initial costs, and allows quantitative consideration of non-energy impacts (such as occupants or building increased value) earlier in the decision process. It incorporates the costs of people under conservative assumptions for increased productivity and the value of the building as extended benefits of energy savings. Extending the period of analysis to 20 years allows these future benefits to be compared to present values. This analysis resulted with an adjusted payback period of less than 5 years when considering all the benefits for both cases than resulted with paybacks of 120 and 76 years using the simple payback method.

This paper recognizes the urgent need for more shared data about building performance to gain a better understanding of the real impacts of facade retrofit. Future work needs to test this methodology with real data for all the performance measures mentioned. Even though actual data is collected (commissioning of new systems, utility bills, sick days, etc.), it is hardly accessible due to the proprietary nature of retrofit designs. Further sources such as post occupancy data from existing retrofitted buildings could help in the foundation of a platform of knowledge for future existing buildings energy interventions. A great opportunity exists in exploring how a facade retrofit affects the building value and how that affects the depreciation of the building. Moreover, optimum facade retrofit solutions and opportunity costs could be determined to help building owners make more informed decisions about energy reductions.

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