The Triple Bottom Line Benefits of Climate-Responsive Dynamic Façades

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ABSTRACT

To achieve net zero energy, façade designs must move from static dark glass monoliths to dynamic, climate responsive layers for balancing daylighting and shading, natural ventilation and mixed mode conditioning. While 5-15 year energy paybacks are sufficient to prompt some level of increased investment in facades, dynamic facades require the addition of triple bottom line (TBL) calculations that capture the economic, environmental and human benefits of high performance buildings. This paper introduces an approach to TBL justifications of climate-specific high performance building façade solutions, to provide professionals and manufacturers compelling arguments for inspiring building investment that will improve the quality of the indoor environment. Given that lighting and space conditioning are 80% of office energy loads in India, arguments for investing in façades that optimize daylighting and shading, natural ventilation and mixed mode conditioning are critically needed. This paper illustrates the triple bottom line of five climate-responsive façade and related system improvements – high visible transmission/ low solar glass, internal light shelves/inverted blinds, daylight dimming, external overhangs/shades, and operable windows - that demonstrate TBL paybacks of less than two years for new and retrofit construction. This ongoing project is funded by the US Department of Energy and LBNL, and undertaken in collaboration with CEPT, India through the Center for Building Energy Research and Development (CBERD).

INTRODUCTION

The development of TBL life cycle data sets for building decision-makers is critical to overcome first-least-cost decision making patterns that prevent owners and tenants from investing in high performance, energy efficient building solutions. While the completion of five to fifteen year energy payback calculations (first bottom line) can prompt increased investments, the addition of environmental and human benefits (second and third bottom line) provides the 'tipping point' for the level of design, engineering and investment needed for high performance facades that save energy and improve the quality of the indoor environment for workers.

The challenge for TBL calculations is the quantification of environmental and human gains, including health, productivity, and organizational performance. This paper develops TBL justifications for five climate-specific building façade solutions that improve the quality of the indoor environment while optimizing energy effectiveness. For each technology, the first bottom line relates to the known Indian costs and literature identified benefits of energy and facility management savings resulting from the investment. The second bottom line relates to the Indian environmental benefits that are directly linked to electric energy savings: reductions in CO2, SOx, NOx, particulates, and water. The third bottom line is based on available international studies that have identified the human benefits directly

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linked to improved indoor environment quality in terms of human health and productivity.

Carnegie Mellon's studies of daylighting/ lighting retrofits in the U.S., completed for the DOE EEBHub, revealed that with energy savings ranging from 13-85%, simple paybacks will be from 2-8 years - if only energy savings are included in the life cycle calculation. However, when the environmental benefits of electricity savings are included, paybacks are much faster, from 1.5-5 years. Most strikingly, when human benefits identified in international research are included - from reduced headaches and absenteeism to improved task performance or productivity - paybacks for investments in daylighting and lighting retrofits in US offices are less than 2 years (Loftness, Srivastava et al, 2013). Building on these earlier studies, through support from the US Department of Energy and Lawrence Berkeley National Lab, this on-going research advances the TBL evaluation of high performance façade investments for office buildings in each of the five Indian climates identified in the National Building Code.

WHY INVEST IN FACADES?

India is the world's fourth largest energy consumer (EIA, 2013) and fifth largest source of greenhouse gas emissions (GOI, 2010). With the building sector contributing 35% of the total electricity consumption (Rawal et al, 2012), and a projected five-fold growth in the constructed area anticipated by 2030 - from a 21 billion square feet in 2005 to 104 billion square feet, building energy efficiency plays a major role in managing energy use in India (Seth, 2010, Figure 1a).

India's national Energy Conservation Building Code (ECBC, 2008) was revised in 2008, but remains voluntary and has not been adopted by most of the Indian states. To encourage adoption of ECBC, a three-tier approach has been proposed which advocates implementation of the ECBC codes in phases, and allows time for training and capacity building (Rawal et al., 2012). Tiers are categorized based on: ease of implementation within current practice, the energy savings potential, and the ROI offered. Tier one focuses on envelope-related measures, tier two on HVAC, while the third tier regulates lighting measures.

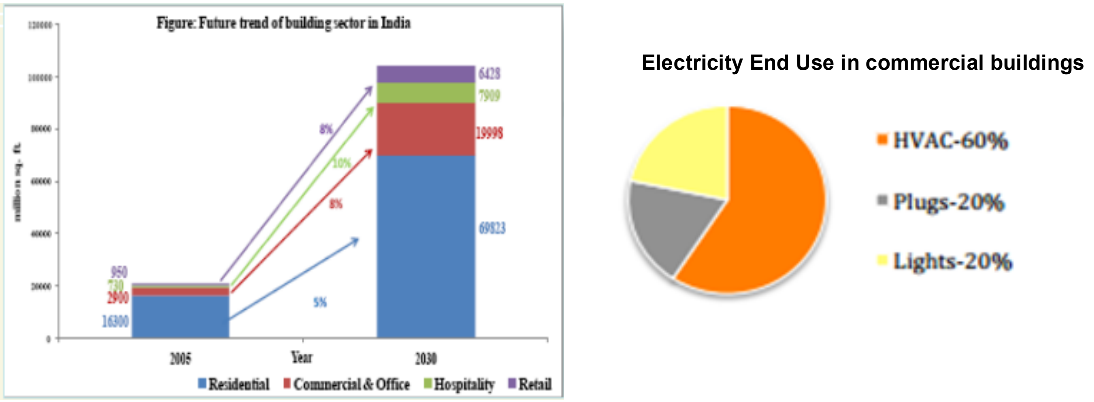


Figure 1 (a)Forecasted five-fold growth for building sector in India; (b) Lighting and Air Conditioning loads account for 80% of the commercial building energy use (Singh et al,2013)

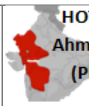
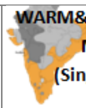
Given the rapid growth in the Indian construction sector, the national government's efforts to improve energy-efficiency in buildings are based on significant reductions in air-conditioning, ventilation, lighting and plug loads. Building façade design and engineering is critical to: air conditioning loads through solar heat control; to natural ventilation and night cooling; to effective daylighting; and even free passive solar heating in cooler climates. High performance, climate responsive facades can significantly reduce both annual and peak electricity demand, and ensure "resiliency" in the face of power outages. Equally critical, high performance facades are critical to occupant health and productivity. This paper explores TBL arguments for five high performance facade measures that can provide up to 25% total energy savings in typical Indian office buildings, reducing the environmental costs of electricity and improving indoor environmental quality for human health and productivity.

Design priorities for new and existing façades

The research team employed a range of techniques to identify climate responsive façade guidelines for Indian climates. A climate analysis using a combination of Koppen climate classifications (Rubel and Kottek, 2010), the National Building Codes (BIS, 2005), Climate Consultant (Milne et al., 2007) and simulation tools (Comfen; NIST Climate Suitability tool; PPG, 2014) supported the identification of representative cities for each of the five Indian climate zones (Table 1) and climatically similar U.S. cities. The companion cities were included to support the development of high performance façade guidelines and provide strong illustrations, quantifications, and product choices. The city of Mumbai was matched with the city of Singapore since there was no climate-comparable city in the US.

The research team then reviewed business-as-usual and advanced Indian office building practices in the five climates, classifying critical characteristics of existing and advanced building facades. Then, the review of existing research, codes and standards, field and simulation studies, was combined with the use of simulation tools to help refine a set of climate specific façade strategies. An illustration of façade design recommendations is shown in Table 1, drawn from a longer list, with 0-3 dots indicating the relative importance of each recommendation for the given climate.

Table 1: Five climatic zones and variations in strategies by climate

Façade Recommendations	 HOT & DRY Ahmedabad (Phoenix)	 WARM&HUMID Mumbai (Singapore)	 TEMPERATE Bangalore (Miami)	 COMPOSITE New Delhi (Dallas)	 COLD Shillong (San Francisco)
Daylighting					
High VLT glass	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
Light shelf/ Inverted blind	● ● ●	● ● ●	● ● ●	● ● ●	
Daylight dimming	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
Shading					
Shallow Building Plan	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
Avoid E/W Glazing	● ● ●	● ● ●	● ●	● ● ●	● ●
Low SHGC	● ● ●	● ● ●	● ●	● ● ●	
Shading Devices	● ● ●	● ● ●	● ●	● ● ●	
Natural Ventilation					
Windows for natural vent.	● ●	● ● ●	● ● ●	● ●	
+ mass for night cooling	● ● ●	●	● ● ●	● ●	● ● ●

From the set of shortlisted guidelines in the above table, five strategies were selected to demonstrate the TBL cost benefit analyses that could be applied across all five climates - with climate specific variations:

1. Invest in high visible transmission glass with climate appropriate shading coefficients
2. Invest in light shelves or light redirection louvers in clerestory glass areas
3. Invest in high performance ballasts with daylight sensors in perimeter office lighting
4. Invest in external overhangs or canvas awnings for summer shading
5. Invest in operable windows for natural ventilation and night cooling

Each of the selected recommendations are outlined in the following sections, alongside preliminary information on product or assembly costs, as well as literature studies on occupant health and productivity benefits, in order to complete Triple Bottom Line calculations for each action.

THE TRIPLE BOTTOM LINE FOR FIVE FAÇADE INVESTMENTS

The TBL calculation approach was refined using the United Nations ICLEI Triple Bottom Line Standards, in which benefits are categorized in one of the three categories – (1) Economic/Profit (2) Environmental/Planet (3) Equity/People. The TBL life cycle benefits for each category are illustrated using successive "return on investment" ratios and NPV calculations. For each façade retrofit, the first cost was evaluated against a 15-year life cycle savings calculation. For the range of selected façade technologies, Indian costs were collected from literature and communications with manufacturers and professionals, acknowledging that there are significant variations in the product and labor market across regions. Where the Indian costs for the technologies were not available, the US market prices were used for this paper. The project team collected average technology and labor costs for each recommendation assuming a medium size office of 50,000 square feet on six floors. The energy savings calculations are based on a national baseline of 200 kWh/sqm-yr (approx. 19 kWh/sqft-yr). Load breakdowns are assumed to be: 60% of the total load for HVAC energy use or 120 kWh/sqm-yr; 20% of the total load for lighting energy use or 40 kWh/sqm-yr; with the remaining 20% of energy used for plug loads (Singh et al., 2013). The long-term objective is to build an on-line calculator for building decision-makers to enable the substitution of their own assumptions and numbers.

The first bottom line calculation includes the economic cost benefits of energy and potentially facility management savings resulting from each of the façade actions. The cost of energy was set at $0.18/kwh, the average all inclusive commercial fixed rate in India (RIL, 2012), which may vary by region (Wilson, 2013). The second bottom line calculations capture the environmental cost benefits that are directly linked to electric energy savings: reduction in CO_2, SOx, NOx, particulates (PM) and water demands. These four pollutants are regulated and even taxed in leading countries to reduce global warming, respiratory illnesses, cancers and developmental impairment. Given India's high reliance on coal fired electric power, the societal costs of environmental abatement could range from $ 0.014 – 0.021/kwh (Table 2), estimated based on EPA (2010), Goodkind and Polasky (2013), Levy (1999) and Ghodke et al. (2012).

Table 2. India's estimated environmental cost impacts of power generation

	CO2	SOx	NOx
India range of emission from coal plant (g/kWh)	783 -1496	5.210 - 9.899	1.612 - 3.490
India Average Emission Coefficients (lb/kWh)	2.18258	0.01907	0.00529
Est. Environmental Cost Premium (/kWh)	**$0.021**	**$0.014**	**$0.016**

The third bottom line captures the human benefits that are linked to improved thermal, lighting and air quality as a result of the building improvement, drawn from the ongoing work of Carnegie Mellon's CBPD to link the quality of the built environment to health and productivity outcomes captured in BIDS: the Building Investment Decision Support Tool (BIDS, 2008). In the absence of Indian field studies that link high performance building systems to health or productivity cost-benefits, the research team relies for now on international laboratory and field case studies to support TBL life cycle decision making.

1. Invest in high visible transmission glass with climate appropriate shading coefficients

20 percent of commercial building energy use in India is for lighting buildings, and much of this is during the daytime when daylight is abundant. Electric lighting also contributes to the air-conditioning demand in Indian office buildings, at a significantly higher cost than solar-controlled daylighting.

Four of the five Indian climates in the codes have cooling dominated seasons, where protection from the sun often becomes a priority. To block solar radiation, use of very dark and reflective glazing is a common practice in Indian buildings. In pursuit of low solar heat gain (low SHGC), designers often mistakenly specify low visible light transmission (VLT). While this type of glazing is effective for shading, it seriously compromises daylight penetration and seated views to the outdoors (Figure 2a). It is imperative for future office facades and façade retrofits to replace yesterday's dark glass (low SHGC and low VLT, see Figure 2a) with today's high performance glass that maintains low solar transmission while maximizing visible light transmission (low SHGC and high VLT, see Figure 2b) in order to lower both lighting and cooling energy while providing views to the outside. Low .30 SHGC with high .65 VLT glass coatings are readily available in India, with incremental costs less than $1/sqft and paybacks of as low as 39 months (PPG, Saint-Gobain, 2014). For the single heating climate in India represented by Shillong (and companion city San Francisco), the low-solar high-visible glass specification should be replaced by a high-solar high-visible glass specification on southern facades to take advantage of the comfort and free heat provided by direct solar gain.

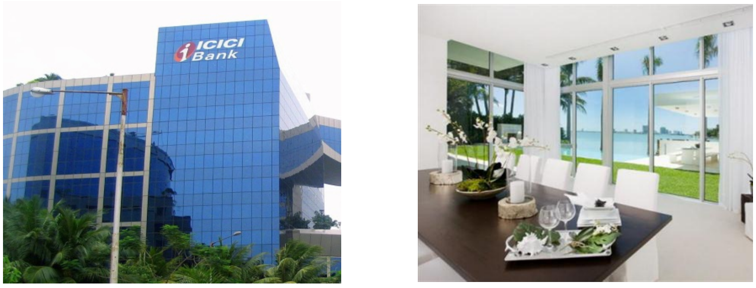


Figure 2: (a) Use of dark glass in I ICICI Bank in Mumbai specified to reduce solar heat gain vs. (b) Shading while ensuring daylight and seated views to the outdoors (Miami vitHouse, 2010)

The CMU team used existing research to calculate the first, second and third bottom lines of high performance glass. In a 1999 multiple building study of 8 office buildings in the UK, the Probe team identifies an average 64% lighting energy savings in buildings with effective daylighting due to clear glass and perimeter access, as compared to buildings with deep floor plans and/or tinted glass (Probe team, 1999). Increasing the effectiveness of daylighting and providing access to views also improves employee productivity and health, also included in the third bottom line. In a 2003 building case study of the Sacramento Municipal Utility District (SMUD) Call Center, Heschong et al. identified an average 6.7% faster Average Handling Time (AHT) for employees with seated access to larger windows and a view with vegetation content from their cubicles, as compared to employees with no view of the outdoors. Other studies reveal the importance of sunshine for health in winter with appropriate orientation and shading for glare control and summer comfort (Benedetti et al., 2001 and Choi, 2005).

2. Invest in light shelves or light redirection louvers in clerestory glass areas

To ensure daylight effectiveness beyond the first few feet of work area, the second retrofit recommendation is to introduce light shelves or inverted blinds/louvers in the clerestory glass area. Light shelves serve critical purposes that include the distribution of daylight deep into the building, glare control and shading. When well designed, they can ensure high levels of daylighting without glare and overheating, and even reduce heat loss on winter nights (CBPD, 2014 a). A study of the existing building stock revealed that a number of Indian offices already have clerestory glass above the view windows (Figure 3a), and the addition of a light shelf or inverted louvers or blinds will greatly enhance daylight effectiveness.

The ideal light shelves would be highly reflective and diffusing. If louvers or venetian blinds are used they should be inverted (curve upwards) to reflect daylight onto the ceiling for diffusion (see Lightlouver™ profile Figure 3b). The inverted blinds can even have a seasonally "smart" W-profile that reflects high sun angles back outdoors, to reduce solar gain in the cooling season, and reflects low sun angles into the space to increase solar gain in the heating season (Retrosolar™). Inverted blinds and louvers in the clerestory, in combination with a highly reflective ceiling, create a daylighting system that can be used on the east, west and the south façade. The most affordable solution for the Indian market is approximately \$20 per sqft of building façade, based on manufacturer estimates, given 20% of the baseline building surface area as clerestory to be equipped with light shelves (Skyshade™, 2014).

Figure 3: (a) Typical Indian office with no daylight redirection device (b)LightLouver units in clerestory to reflect sunlight into the ceiling

Given that 25-100% of workstations may be within 15 feet of a window wall in many Indian office buildings, daylighting without glare can save up to 35% of a medium size office building's total lighting energy (Figueiro et al., 2002; Schrum & Parker, 1996). The electricity savings is calculated in the first bottom line and the environmental benefits of reduced power generation is calculated in the second bottom line.

The human benefits of investing in light redirection/diffusion are related to the spectral quality of daylight, the management of brightness contrast by bouncing light, the improvement of views, as well as the importance of sunshine in winter and shading for comfort in summer. For example, in a 1992 laboratory experiment conducted using 26 subjects, Osterhaus and Bailey found a 3% improvement in visual tasks related to reduced glare (Osterhaus & Bailey, 1992).

3. Invest in high performance ballasts with daylight sensors for perimeter office lighting

The third cost-effective retrofit is the use of high performance ballasts and daylight sensors to support on/off or dimming control of the first and second rows of lights on each building façade (Figure 4a). This investment in new controls for groups of lights ensures up to 30% energy savings through 'daylight harvesting'(Lee & Selkowitz,2006). In a 1984 simulation study supported by meta-analysis, Verderber and Rubinstein identify 64% lighting energy savings in a 30% daylit building given daylight dimming controls, automatic scheduling, tuning, and lamp lumen depreciation, compared to a conventional lighting system with no controls. To ensure that the sensors are not disabled or covered by occupants, critical attributes for the selection of daylight sensors include: programmable thresholds for acceptable daylight minimums, relocatable sensors to address variations in office layout, and assurance of gradual light level changes through dimming or time limited switching. Daylight sensors and switches can be installed without full automation systems, and can be introduced with wireless interfaces to existing fixtures, making them cost effective retrofits.

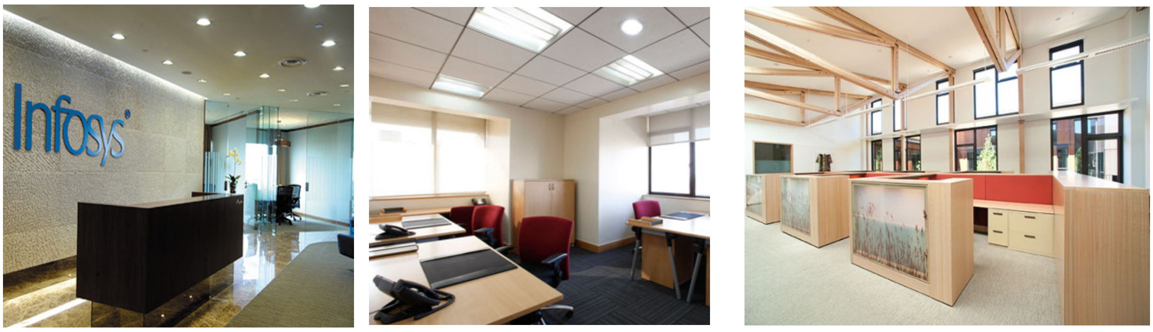


Figure 4: a, b) Electric lighting 'on' most of the time in Infosys and Raheja Tower offices in Bangalore; c) Balanced daylight and daylight harvesting controls in the Packard Foundation offices in California.

Encelium, Lutron, and several other lighting control companies have developed wireless controls that can be added to existing ballasts in combination with well-placed daylight sensors. A web based controller is available for calendar-driven or daylight-sensor-driven switching of each row. Daylight harvesting is a quick and low cost retrofit for the majority of buildings, with costs from $0.45- 0.90/sqft.

In many medium sized office buildings, up to 100% of spaces could be (and have been historically) daylit, saving up to 70% of total lighting energy. In deeper section buildings, daylight harvesting can save 10-35% of the lighting energy. The human benefits of daylight contributions in the workspace are also measurable. In a 1995 building case study of Lockheed Building 157 in Sunnyvale, California, Thayer et al identified 50% savings in lighting, cooling and ventilation energy and 15% reduced absenteeism due to the daylighting design which integrates layout, orientation, type of glazing, and light shelves in combination with reflective ceilings. The full spectrum light inherent in daylight also has an influence on human health, with research revealing that the natural changes in day light is critical for melatonin production that regulates our sleep cycle (Figueiro, 2010). An earlier field study conducted by Figueiro et al. (2002) identifies a 15% increase in time dedicated to visual tasks in daylit workspaces. With visual tasks constituting 25-30% of time spent at work, there is a potential performance improvement of 3.75% linked to the benefits of daylight. Daylighting should be a priority in the workplace, particularly since higher light levels can be achieved at a lower energy cost.

4. Invest in external overhangs or canvas awnings for summer shading

In four of the five climates of India, shading the facade is a high priority to avoid overheating in summer. While modern office buildings in the past century were often sleek glass towers, today's design community is rediscovering the power of facades articulated by static fins, louvers, and screens as well as the highest performing dynamic awnings. These dynamic shading devices can be daily or seasonally adjusted to reflect sunlight when required, while allowing effective daylight penetration and solar gain during the winter (Lechner, 2009). Today, awnings are made of synthetic fabrics which are fade resistant, water repellant and require less maintenance than they have historically. Fixed overhangs, horizontal louvers and fins, and dynamic awnings are each effective additions to modern facades. They provide shade with daylight, without diminishing our views, and should replace yesterday's dark glass, eggcrate shades and scrim layers.

Given that India ranges from 6^o to 37^o north latitude, horizontal devices should be the norm for southern orientations, combined horizontal and vertical or dynamic devices for east west, and vertical devices for north facades (Figure 5b,c). Openings along the top and sides of the overhang or awning should be provided to prevent heat from being trapped at the window wall.

Figure 5: a) DLF Center, Delhi with no shading devices vs. b) vertical awnings on the north face of the Phoenix library, and c) horizontal louvers on south face of Stecalite, Noida.

The cost of installing external louvers and awnings varies dramatically based on material and assembly, with $7.50/sqft assumed in the TBL calculations. The use of adjustable awnings as a shading device can reduce solar heat gain and associated cooling loads in the summer by up to 65% on south-facing windows and 77% on west-facing windows, with a 20-25% total cooling energy savings (DOE, 2012; Nagy et al., 2000). The human benefits of light shelves include the value of glare control for productivity and health, as well as shading for improved thermal comfort in summer by reducing direct and radiant solar heat. In a 1998 controlled experiment, Witterseh identifies a 54% increase in mathematics accuracy and a 3.5% typing improvement when subjects feel thermally comfortable, rather than too warm, in quiet office conditions (Witterseh, 2001).

5. Invest in operable windows for natural ventilation and night cooling

The last recommendation for which triple bottom line analysis was completed was to introduce operable windows for natural ventilation and night cooling. The business-as-usual building illustrated in figure 6a, reveals the rising trend of sealing office facades (Figure 6a). This is a serious disadvantage during brown outs or black outs, as the building runs out of air and starts to overheat. Moreover, sealing building facades eliminates the opportunity to use natural ventilation for cooling and breathing, or night ventilation to pre-cool the building to offer hours of free cooling the next day.

To avoid the possibility of rain coming in, and to ensure controlled air flow, the use of awning, drop-kick, and pop-out windows are emerging in modern offices (Figure 6b and 6c). For hot and dry climates like Ahmedabad, natural ventilation can be pursued on moderate days if air quality and noise are not a local issue. More critically, night ventilation cooling can be pursued on nights that are predicted to be cooler than 70°F and combined with thermal mass or phase change materials to store 'coolth' for conditioning on the following day.

Figure 6: a) Infosys, Bangalore with no operable windows, b) 3i Innfotech EPIP Whitefiled with a modest percent of operable windows, but dark glass c) Deutsche Bank, Frankfurt with high Tvis pop-out windows.

The cost of natural ventilation is related to the additional costs of window hardware and the manual or automated system for control, while night cooling requires the addition or exposure of thermal mass in the airstream. Mechanical engineers should be carefully selected for their commitment to "mixed mode" conditioning (CBE, 2014), and integrated early into the design process. Consideration of natural ventilation should address the site-specific limits of climate, outdoor air quality, noise, security, and local building codes.

On the benefit side of the equation, the annual energy savings of natural ventilation in the climate of Ahmedabad includes up to 15% of ventilation loads (Milne et al., 2007) and up to 35% pre-cooling load (Emmerich, *Climate Suitability Tool*). International studies reveal that the human benefits of natural ventilation can be measured in both employee health and productivity. In a 2003 meta-analysis study, Seppänen et al identifies a productivity increase of 4.9% for an eight-hour workday due to night-time ventilative cooling, an energy-efficient method of reducing daytime indoor temperatures by using night-time air to cool a building's structure and furnishings. In a 1988 multiple building study in Berlin and Heidelberg, Kroeling identifies a 33% reduction in reported headaches, a 28% reduction in reported frequency of colds, and a 31% reduction in reported circulation problems for employees in naturally ventilated office buildings as compared to air conditioned office buildings.

TRIPLE BOTTOM LINE RAPIDLY ACCELERATES PAYBACK FOR DYNAMIC FAÇADES

Given these international studies on the human benefits of high performance façade solutions, the research team completed TBL calculation for five façade investments in the hot and dry Indian climate, to demonstrate the applicability of the framework in the building decision-making process (Table 3). For each facade investment, a 15-year life-cycle calculation is completed with the Indian first costs, energy savings and environmental benefits, and combined with international findings on health and productivity benefits, to generate the triple bottom line results shown in Table 3.

Table 3: TBL calculation for five façade investments

		High VLT Glass	Light Louvers	Dimming Ballasts	Awnings for shade	Operable Windows
Economic Considerations	**First cost per employee**	$45	$114	$70	$330*	$120
	Annual Energy savings:					
	Energy Savings (%)	35%	35%	30%	20%	35%
	Energy savings per employee	$24	$23	$20	$40	$70
	ROI (Economic)	**52%**	**20%**	**28%**	**12%**	**58%**
	Payback in years	**2**	**< 5**	**3.5**	**8**	**< 2**
Environmental Considerations	Given Annual Energy savings in kWh	130	130	113	224	392
	Annual Environmental Benefits:					
	Air pollution emissions (CO2, SOX, NOX = $.051/kwH)	$6.7	$6.7	$5.8	$11.4	$20.0
	Water Savings ($0.002/kwh)	$0.3	$0.3	$0.2	$0.4	$0.8
	ROI (Eco + Env)	**68%**	**26%**	**38%**	**16%**	**76%**
	Payback (Eco + Env) in years	**1.5**	**< 4**	**< 2.5**	**< 6.5**	**< 1.5**
Equity Considerations	**Annual Human Benefits**					
	Productivity increase (1- 4%)	$320	$240	$300	$100	$240
	Reduction in absenteeism (6 -14%)	$24	$24	$24	$24	$10
	ROI (Eco + Env+ Equity)	**825%**	**258%**	**500%**	**52%**	**284%**
	Payback (Eco + Env + Equity) in years	**< 0.5**	**< 1**	**< 0.5**	**2**	**<1**

*Awnings have a lifetime of 5 years; first cost includes prices for three changes

The development of Triple Bottom Line life cycle data sets for building decision-makers is critical to overcoming first-least-cost decision making patterns that prevent owners and tenants from investing in high performance, energy efficient building solutions. For example, the investments in high visible transmission glass with climate appropriate shading coefficients shift from 2 year paybacks based on energy savings alone, to 1.5 years including environmental benefits, to less than 6 months given the human benefits. Investments in the most affordable light redirection louvers in clerestory glass areas, high performance ballasts and daylight sensors, canvas awnings, and controls for operable windows also demonstrate reductions in paybacks from 8 years to less than a year as energy, environmental and human benefits are cumulatively calculated. It is critical for building owners and their design-engineering teams to embrace layered and dynamic facades for daylight, shade, natural ventilation and night cooling to significantly reduce India's lighting and cooling loads in commercial offices and improve indoor environmental quality.

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