



Figure 1: Some principles used in the design of traditional building façades in India are finding their way into modern architectural practice.

High Performance Building Façade Solutions

BY ASHISH RAKHEJA, MEMBER ASHRAE; AND ANCHAL AGARWAL

The architectural façade has long been a compelling focus of interest for building physicists and designers, combining attributes of both appearance and performance in a holistic manner. Façades as building envelopes form the outer skins of buildings, portraying the project image and creative intent. Interestingly, they are also important environmental moderators. A thoughtfully designed skin can make a building work more effectively for its owners, occupants and the environment. The technology has gradually emerged in recent decades, driven largely by the pursuit of transparency in the building façade among designers.

Façade plays an important role in influencing energy consumption in a building and the Indian Energy Code (ECBC) as well as Green Building rating systems (IGBC/GRIHA/LEED) lay emphasis on its optimization. However, traditionally, the façade design has been considered the responsibility of Architects and Façade Consultants who are driven largely by aesthetic considerations. As India begins its journey towards 'Net Zero Energy Buildings', it is important that the air

conditioning engineers' fraternity starts playing an active role by providing inputs on thermal considerations. In India, with a predominantly hot climate, there is a need to regulate heat gain through the skin as it influences the total air conditioning load of a building.

In this article, the importance of façade design has been covered under three segments. In the first part, a building

About the Authors

Ashish Rakheja is a B.Tech. in Mechanical Engineering from REC University, Allahabad and M.Tech. in Thermal Engineering from IIT Delhi. He has work experience of over twenty years in design and coordination of multi-disciplinary engineering activities, has worked on writing codes and standards with various Government agencies, and has handled design activities of services for thirty six LEED Platinum rated green building projects in India. He is spearheading the green building movement in India as Chairman, Technical Committee of IGBC and is a certified LEED India Trainer. He heads the sustainability division at AECOM India. He is a Past National President of ISHRAE, and has won several national awards and recognitions.

Anchal Agarwal is an M.Sc. in Building Performance and Sustainability from National University of Singapore and a Bachelor of Architecture from Punjab Technical University, Bathinda. She has five years' experience in the field of sustainable building design, and has been working on international projects to optimize building design and energy efficiency and achieve LEED-USGBC Green Ratings.

located in a composite climate (Delhi) has been optimized following a step-by-step approach to treat every element of the façade, thereby reducing energy demand at the source itself. The second section quantifies the energy benefits achieved by installing new technologies available in the market. Finally, the last section addresses how the façades in future will transform buildings. The various parameters of the selected building are given in *Table 1*.

Table 1: Parameters of selected building.

S. No.	Parameter	Description
1.	Usage	Midrise commercial building
2.	Location	Delhi (composite climate)
3.	No. of floors	9
4.	Wall	230 mm thick brick work (U= 1.8 W/m ² K)
5.	Roof	150 mm concrete (U = 2.3W/m ² K)
6.	Glazing	6 mm thick single clear glass
7.	Built-up area	30,000 sqm

In order to quantify the energy guzzling consequence of a non-treated façade, the initial estimates revealed that 25% of the space heat gain was contributed by internal loads and occupancy demand, 28% heat gain came from treatment of ventilation air, and the envelope contributed the remaining 47% (*Figure 2*.) The envelope was further categorized in façade elements and the roof element. The façade elements contributed almost as high as 90% gains in the building, of which, nearly one fourth was contributed by poorly-selected wall material and three fourth was from ill-treated windows. Hence, the study quantified the fact that various elements of the façade make a significant contribution towards energy gains, and optimizing each of them could help in achieving a well-designed building. For instance, *Figure 3* highlights how radically rethinking / reassembling/ redesigning buildings as systems offers new pathways of increased environmental performance and value creation at lower cost, while providing more comfort. The integrated façades component design in Singapore-ETH Centre Future Cities Laboratory reduces the building volume by 33% while providing the same useful floor space. This, not only reduces the conditioned volume, but also façade and glazing areas and their heat gains, structural loads and consequently all materials and cost associated with these elements, thus demonstrating that design integration can make façades function more than an envelope.

Façade Optimization through Passive Strategies

A simulation model was created using e-Quest software to compute the energy consumption and to study the effect of various improvements planned in the design. The annual energy consumption of the untreated building worked out to 9,120 mWh with a cooling load of 2000 TR generating 7,843 Tons of carbon every year.

As a matter of interest, the building was modeled in four different climatic zones of India and the energy

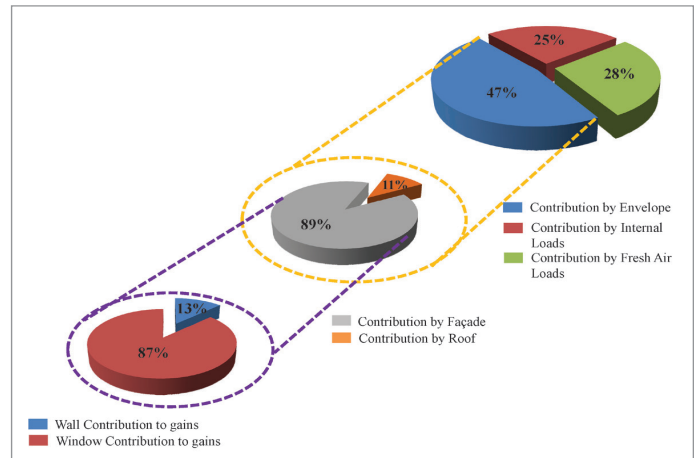


Figure 2: Pie chart highlighting contribution of façades in building envelope.

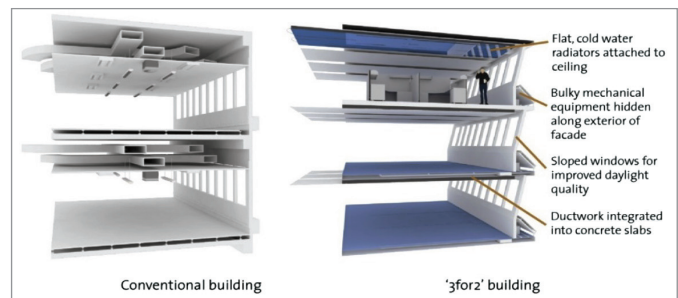


Figure 3: Singapore-ETH Centre Future Cities Laboratory façade design.

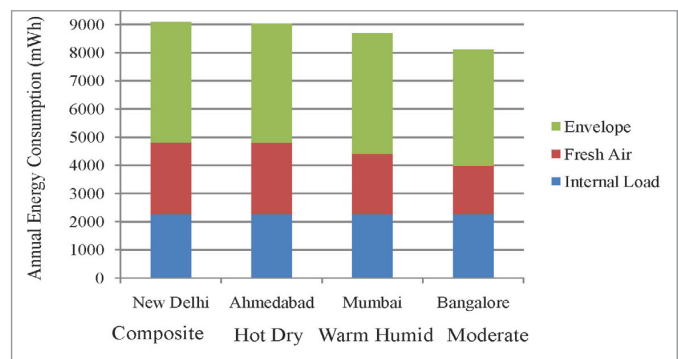


Figure 4: Façade performance in various climate zones.

consumption pattern at different locations was quantified. The study revealed that, whereas the internal heat gains due to lighting/occupancy/equipment were largely the same, there was a variation in ventilation and façade heat gains depending on the location. Thus, with the use of heat recovery devices (wheels/heat exchangers, etc.) in the ventilation air stream and by treating the façade to get an optimized performance, it is possible to ensure that any building will have nearly similar performance irrespective of the climatic zone (*Figure 4*).

As a first step, the following fundamentals of green design were adopted in terms of optimizing façade performance:

Building Orientation Optimization

External surfaces of the building experience varying solar heat gain as direct radiation is greatly dependent on azimuth, e.g. the building roof gets heated by solar radiation continuously from sunrise to sunset; the external building walls can be mutually shaded or subjected to radiation depending on sun orientation and angle.

The intensity of direct solar radiation on any surface is expressed as follows:

$$I_{A_n}^\perp = I^\perp \cos(A_n - A_s),$$

Where A_n is the azimuth angle of the wall and $I_{A_n}^\perp$ is the intensity of direct solar radiation on the wall. Thus, the intensity of direct solar radiation on the wall is at a maximum when $A_n = A_{s0}$, that is, the wall with the solar azimuth A_{s0} relative to I_{max} has the strongest direct solar radiation gain. The solar azimuth A_{s0} varies with the season. It moves from the south in the winter to the east and west in the summer, which accounts for the strongest solar radiation on the external walls being on the south wall in winter and on the east and the west walls in summer.

Thus, south is the optimum orientation of building both for winter - for solar heat gain - and summer. Hence, the larger surfaces of wall should face south with the least exposure on west and east.

Thus, in the selected building, north-south orientation contributed up to 2% saving on the annual energy consumption, reducing it from 9,120 mWh to 9,020 mWh per year (Figure 5).

It is important to note that the flexibility of modifying building orientation may not be possible in all cases and hence there are other means of protecting the building from direct solar gains.

Window-to-Wall Ratio Optimization

The next step is to establish the optimum openings area on the façade in order to cut down unwanted heat gain without compromising on the daylight quality within occupied spaces.

The building façade or envelope is often the first line of defense against undesirable external elements. In a country like India, where cooling of the building is the primary requirement in summers, minimizing direct solar radiation helps reduce heat gains. Thus, it is important to determine the area and type of glass and create a balance with aesthetics in order to minimize solar heat gain, giving due consideration to both capital and operation costs. Although glazing technology has advanced significantly in recent years, a typical high performance glazing unit (U value of 1.7 W/m²K) still has five times the heat transmission of an insulated spandrel panel (U value of 0.35 W/m²K). Glass should, therefore, be placed and orientated to optimize views and day-lighting whilst avoiding heat gains.

In the case study, adjusting the window-to-wall ratio (WWR) of the building envelope affected the amount of heat entering the space, as opaque enclosures generally resist heat transfer better than glass (Figure 6).

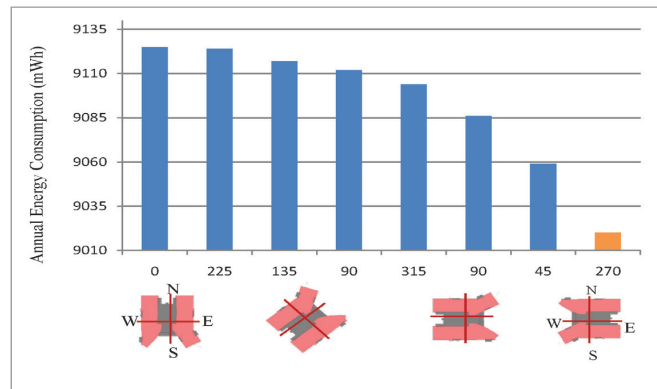


Figure 5: Graph highlighting impact of building orientation on energy consumption.

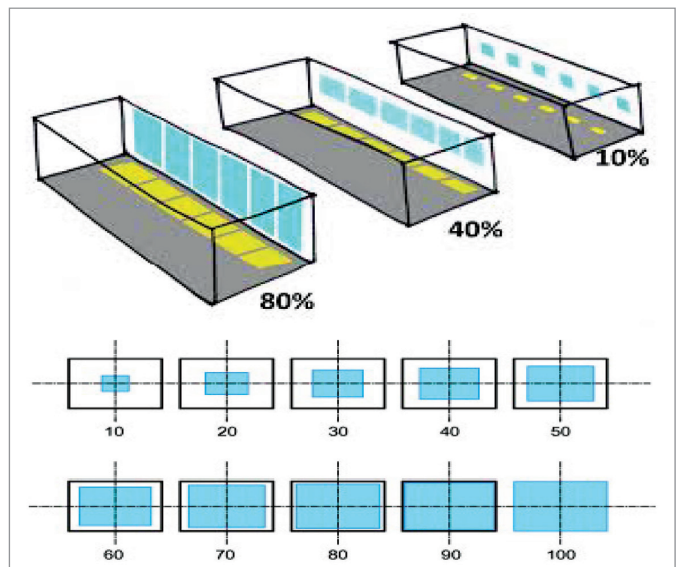


Figure 6: Impact of WWR on building loads.

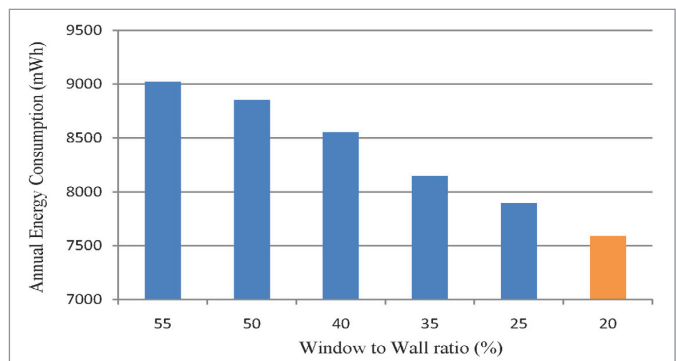


Figure 7: Graph highlighting impact of WWR on energy consumption.

Hence, an optimized WWR of 20% contributed up to 15% saving on the annual energy consumption of the building, reducing it from 9,020 mWh to 7,590 mWh per year and

simultaneously reducing cooling load by 25% and saving 1,228 tons of carbon emission every year (Figure 7).

Shading Devices Optimization

An external sunshade can often be used as a design feature, but its primary purpose is to reduce solar heat gains. Besides, shades also serve the purpose of controlling views into and out of a building, reducing solar glare, providing rain protection for openable windows and serving as a part of the maintenance strategy. Thus, sunshade design should always be influenced by solar geometry and sun-path studies to ensure its effectiveness.

Keeping in mind the above considerations, shading devices with varying widths were simulated for analyzing their effectiveness in cutting down direct solar radiation into the habitable zone. This helped in cutting down the direct solar radiation, reducing solar ingress and allowing the diffused component of light to enter the building, illuminating it uniformly.

Optimized building designed with shades extending nearly 600 mm demonstrated reduction in energy demand from 7,590 to 7,099 mWh, shaving off 7% annual energy consumption (Figure 8).

Fenestration Optimization

Fenestration refers to openings in a building envelope, primarily windows and doors. Fenestration plays a vital role in providing thermal comfort and optimum illumination levels

in a building. Glass performance can be indicated through a number of properties, such as Visible Light Transmittance (VLT), Shading Coefficient (SC) and Thermal Conductivity (U-value). In recent years, there have been significant advances in glazing technology that include solar control glasses, insulating glass units, low emissivity coatings, double glazed units, etc.

For the selected case study, simulation was carried out for three glazing types including single glazed units, double glazed units and double glazed unit with low e-coating wherein a low U-value glass with a low SC (to negate the harsh effect of direct sunlight) provided best results, fetching another 6% reduction in the annual energy demand of the building (Figure 9).

Wall and Roof Assembly Optimization

Walls are generally a predominant fraction of a building envelope and are expected to provide thermal and acoustic comfort within the spaces, without compromising the aesthetics of the building. The thermal resistance (R-Value) and thermal conductivity (K) of the wall/roof is crucial as it influences the building energy consumption heavily, especially in high rise buildings, where the ratio between wall and total envelope area is high.

Wall and roof assembly consisting of building material with high thermal mass and thermal insulation plays a vital role in energy savings and thermal comfort in composite climate conditions. Thermal insulation plays an important role in reducing the conductance or U value of walls/roofs, while high thermal mass helps in achieving thermal comfort conditions by providing a time delay. It is important to note that thermal mass is not a substitute for insulation; in fact, a high thermal mass material is usually not a good thermal insulator. Buildings should, therefore, employ insulation in combination with heat storing materials. The insulation should preferably be placed on the hotter side of the surface.

Therefore, maximum saving was achieved by using wall and roof assembly with R24 (U Value=0.23 W/m²K) resulting in another 3% savings on the annual energy consumption (Figure 10).

Thus, the combination of these five basic steps, i.e. optimized orientation, window wall ratio, shading devices, glazing type and insulation in wall/roof resulted in 34% saving in annual energy demand, and up to 45% saving in the peak

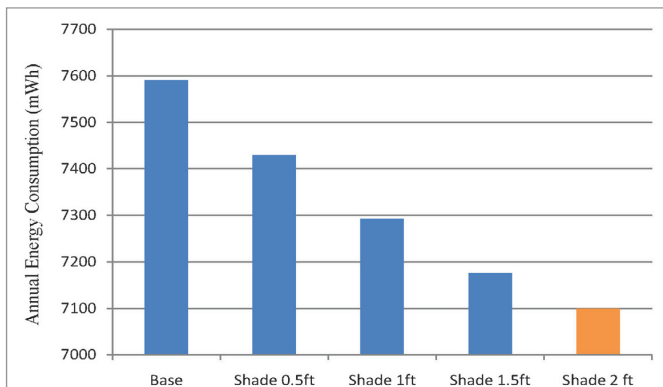


Figure 8: Graph highlighting impact of shading device width on energy consumption.



Figure 9: Graph highlighting impact of glazing unit assembly on energy consumption.

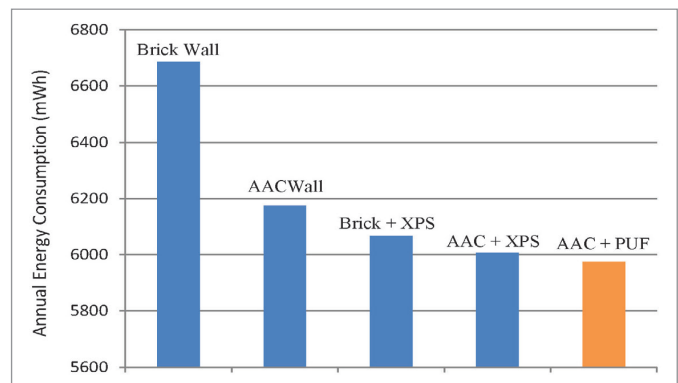


Figure 10: Graph highlighting impact of wall assembly on energy consumption.

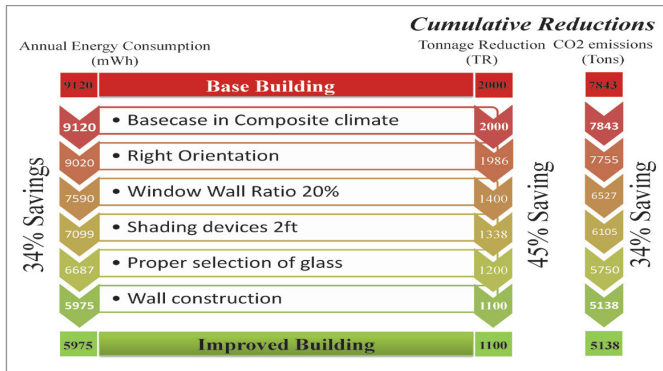


Figure 11: Cumulative reduction in energy consumption by applying basic passive strategies.

air conditioning load as demonstrated in Figure 11. This analysis clearly indicated that there is no substitute for a correct fundamental design and these interventions in early stage of design can help cut down the annual energy bills of a building and also optimize the initial cost.

Minimizing Façade Gains through Innovations

As a next step, state-of-art glazing material and technologies that are aimed at providing high performance insulation (HPI) or solar gain control (SC) or day-lighting (DL) solutions or a combination were evaluated for analyzing possible further reduction in building energy consumption.

An extremely high performing glass assembly double glazed unit with aerogel filling (U value of 0.5 W/m²K), when simulated on this optimized building, only provided further 1.5% savings in the annual electricity bill, thereby reinforcing the finding that a well-designed façade following the basic fundamentals of design is more cost effective and provides a good performance compared to using expensive materials like high-performance glazing solutions.

Green Wall Technology was also simulated to evaluate the enhancement in the wall performance. Living green walls are natural air filters, creating a cleaner, more invigorating work environment that lead to better overall employee health and production. By incorporating living wall technology, further 3% energy reduction was achieved on the already treated façade.

The final strategy included Ventilated Double Façades consisting of two panes of glasses and separated by a cavity through which air flow is encouraged. The driving force for the air flow is natural or mechanical ventilation which helps in reduction of the indirect solar gains. The technology helps in achieving further 5% annual energy saving on an already improved building.

Similarly, buildings often have aluminium frame-work to support the glazing. These frames can add up to a significant percentage in the overall façade area. Providing thermal breaks in these non-insulated frames or using non-conducting materials like plastics also yielded up to 5% savings in the annual operating cost.

Thus, an out-of-box innovative thinking presented a potential of additional 4-5% savings on the energy requirement on an already optimized façade.

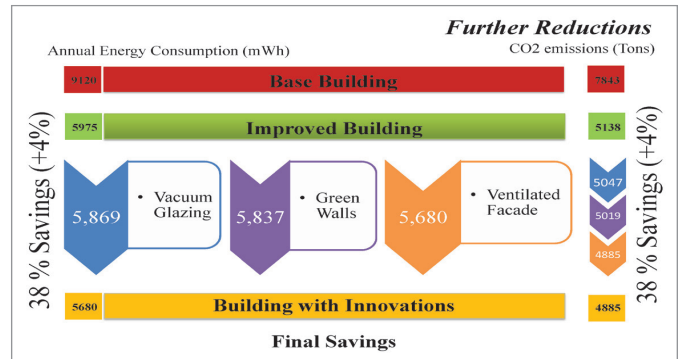


Figure 12: Energy consumption reduction using innovative technologies.

Façades of the Future... the Trendsetters

Some of the technologies on the horizon are:

Façades Generating Power—Photovoltaic Glass Unit (PGU)

Building integrated photovoltaic (BIPV) captures solar radiations and turns them into usable energy. With current efficiencies up to 12%, they have a long way to go before being commercially viable. The advantage of this technology is that it does not compromise the fenestration quality as PGUs provides transparency up to 70% to the human eye.

Energy Generation Potential: For the Indian climate, electricity produced by Photovoltaic Glass Unit system (PGU) in just 1 sqm of area can vary between 40-60 kWh per annum – sufficient energy to supply up to 20,000 hours of light from 20W energy saving light bulbs.

Thermally Dynamic Façades—Phase Change Materials (PCM)

Thermally, dynamic façades uses phase change material wherein a layer of salt crystals captures the heat radiated by the sun and releases it back to the environment during non-operational hours. They basically function as a thermal mass and accomplish that by liquefying as they absorb heat, preventing the heat from reaching the conditioned space and releasing the heat when the outside temperature decreases, typically at night.

Bio-mimicry in Façades—Living Buildings

Just like the surface of a leaf, the 'skin' of future buildings may react to external stimuli, opening, closing and breathing throughout the day through a system of 'cellular' openings that allow light, air and water into the apartments contained within.

The 10 storey building was designed by DesignInc in conjunction with the City of Melbourne and obtained the six green star, in part, because of its many innovative and technological features including photovoltaic cells. The most striking features of CH2 are its recycled timber louvers controlled by photovoltaic cells and the five shower towers, 1.4 meters in diameter and 13 meters long, that draw air from over 17 meters above street level, in which water droplets evaporate slightly as they use up energy and, thus, cool the air. Shower towers lower air temperature to around 21°C (from around 35°C) and water temperature to 20°C.

Façades Enhancing Outdoor Environment—Micro-climate Impact

Growing vegetation on the façade can potentially create a positive micro-climate around the built form. A micro-climate is a local atmospheric zone, where the climate differs from the surrounding area. Studies suggest that a reduction of approximately 2°C can be achieved by using green vegetation around buildings compared to the surrounding ambient in composite climates like Delhi.

Solaris stands as a dramatic demonstration of the possibilities inherent in an ecological approach to building design. With its extensive eco-infrastructure, sustainable design features and innovative vertical green concept, Solaris strives to enhance its site's existing ecosystems, rather than replace them. In September 2009, Solaris was awarded a Green Mark Platinum rating, the highest level of certification granted by BCA's Green Mark, Singapore's sustainable building benchmark.

Façade Addressing Fuel Crisis—Building Powered by Algae

Vertical gardens, solar panels and smart glass have become popular façade materials for their green credentials, but bio-façades take things a step further, generating energy for their buildings. The trend towards bio-materials is being driven by the depletion of fossil fuels. Buildings are responsible for 30-40% of the world's total energy consumption, and the façade industry is responding through the new form of building exteriors.

The new gas and receiving station of the Agro and Food Cluster (AFC), New Prinsenland, located in the Netherlands, has been recognized as the world's first bio-façade.

Another benchmark project is the world's first algae-based bioreactor façade, which was unveiled at the International Building Exhibition in Hamburg last year. The façade features make up the exterior of The BIQ House, which is clad in 200 square metres of integrated photo-bioreactors. Micro-algae are then cultivated

into the glass elements of the façade to make up the building's 'bio skin'.

The façade system, known as Solar Leaf, generates micro-algae biomass and heat to create a renewable energy source while providing shade for the building, offering insulation, interior thermal comfort and acoustics.

Façades Addressing Food Crisis—Hydroponics

The idea that fruits and vegetables can grow with water, light and nutrients is the basis of hydroponic: one of the innovative systems of making the building self-sustaining. There have been other numerous advantages of this system as well. A reduction is seen in street level concentrations up to 40% for NO₂ and 60% for particulate matter. They potentially contribute to an increase in biodiversity in urban areas by providing a habitat for insects and birds. The most important is their 'rejuvenating effect' on the living creatures around as they contribute to softening of the urban landscape and allowing buildings to seem more 'natural' and pleasing for the people. It is a great design concept to integrate hydroponic gardens into tall sky scrapers which give apartment dwellers in urban communities an opportunity to join in on the joy of some gardening and purify the polluted city air to a certain extent. The underlying advantage is reduced solar heat gains, thereby bringing down the annual energy bill of the building.

Conclusion

Energy efficiency is a primary challenge in today's commercial construction industry. How important are energy efficiency gains from a building envelope is a topic that is gaining momentum amongst industry-leading architects and design firms. In order to address a few paramount issues in the industry, with ever-increasing pressure for the dual objectives of higher performance and improved payback to stakeholders, innovative trends and forces shaping the future of building skin contain the answer of many unfolded domains. However, as we continue the



Figure 13: Building Integrated Photovoltaic (BIPV Solar Glass skylight) at Centre for Interactive Research on Sustainability - designed to be the most sustainable building in North America.



Figure 14: Floating Balls of Rotterdam cooled (air conditioned) by PCM.

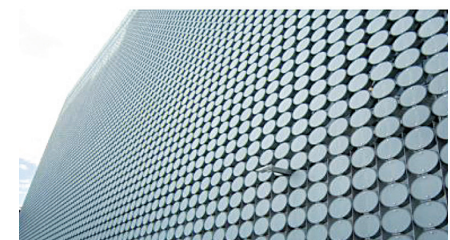


Figure 15: The second, outer skin of RMIT University's Design Hub in Melbourne, Australia, features thousands of operable PV discs that turn to face the sun, improving solar energy collection and providing a unique shading strategy.

journey down the realization of the dream for a perfect façade, there is an underlying statement that adhering to the basics of building design provides the maximum benefit and becomes the foundation for adopting better technologies, providing a cost effective solution. ●