EVALUATING THE CLEANSING EFFICIENCY OF AN EXTENDED LIVING FAÇADE DRAPED WITH *VERNONIA ELAEAGNIFOLIA*

Jacob Thottathil Varghese[1], Sat Ghosh[2], Swetank Pandey[3], Rudranshu Samanta[4]

ABSTRACT

Nature has its own astonishing capability to naturally cleanse the environment. Living green drapes on buildings look elegant and can provide sustainable solutions in congested cities. The Vellore Institute of Technology in India promotes green values within the country. Although the campus is lush and verdant, its ever growing student population precipitated an increase in public thoroughfare causing air pollution. To partially alleviate this problem, walls of a subway connecting the main academic campus and the hostel premises are draped with *Vernonia elaegnifolia* creeper; this is aesthetically elegant and was found to be efficient in capturing much of the vehicular pollution within the subway. An experimental investigation clubbed with an Ecotect analysis helped ascertain the optimal duration of the temperature drop across the subway. The analysis also predicts an annual savings of 36000 USD per hostel block. A detailed Scanning Electron Microscopic analyses coupled with Spectrophotometry established the deposition pattern of sulphates and nitrates. It is expected that the results of this analysis will promote the use of green facades in this sun drenched country.

KEYWORDS

Atmospheric cleansing; Atmospheric pollutants; Ecotect analysis; Green facades; Thermal comfort; Vernonia elaeagnifolia; Vertical Greenery System

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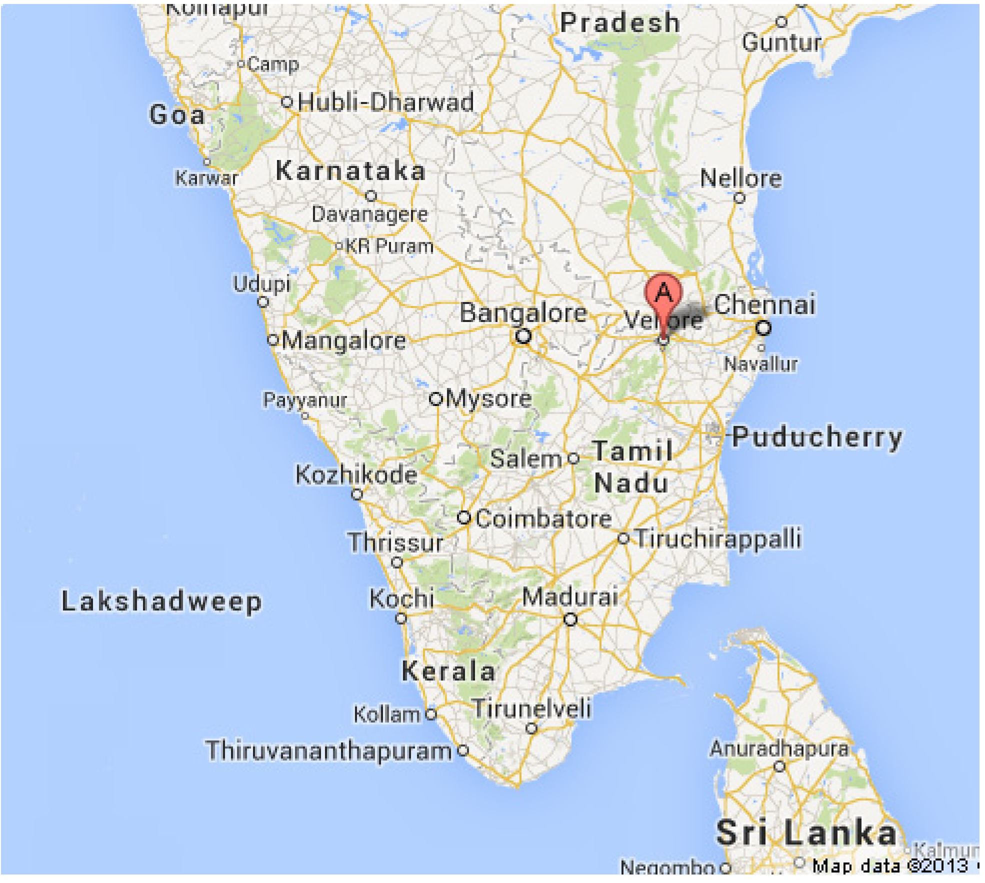
1. INTRODUCTION

Toxic emissions cause hazards to humans. Emissions occur mainly from four different sources: electric power generation, industry, residential sources and transportation. Vehicular emissions, categorised under the mobile polluting sources at the ground level, have the maximum impact on the general population. It accounts for nearly 700,000 deaths per year in South Asia due to changes in $PM_{2.5}$ concentrations (ICCT 2013). Oxides of Nitrogen generated during the combustion of fossil fuel accelerate the formation of Ozone at the ground level, adversely affecting a Nation's economy (USEPA 1998). In major cities of the Indian sub-continent, the annual fuel consumption by road transportation alone is in excess of 3.63 million tons causing deterioration in ambient air quality by 72% (Sengupta 2001). In Chennai, although the total number of vehicles exceeds 3.03 million, only 3.5% are tested and certified for emissions (Sreevatsan 2010). Vellore, situated 122.3 km south west of Chennai (Fig.1), is the 6th critically polluted region in the country with a Comprehensive Environmental Pollution Index of 69.25 (EAVCMC 2011; Sengupta 2011; CPCB 2009). Since vehicular emissions near traffic junctions are at their peak during the day, the atmosphere of Vellore is always polluted with gases like SO_2 and NO_2. These gases are advected by the prevailing winds and the turbulence in the atmospheric boundary layer diffuses the pollutants.

Figure 1: Location of Vellore within Tamil Nadu, India. (Source: http://www.maps.google.co.in)



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With this background, VIT University led a green initiative to improve this situation. At VIT University, Vellore, the vehicular traffic is comprised mostly of the ubiquitous auto rickshaws, two-wheelers and taxis, faring students to and fro from the main gate to hostel premises through an underpass and a subway connecting the two. Auto rickshaws are hired frequently inside the campus owing to their compactness, affordability, and availability. Although practical considerations dictated this arrangement, it came with a price, acting as a channel source of air pollution. These emissions act as a line source, at an average height of 0.3m above the ground level (Fig. 2). Most disturbingly, these three wheelers have an utter disregard for vehicle maintenance, because catalytic converters are rarely used, and if at all used, are rarely functional.

Figure 2: Auto rickshaw emissions acting as a line source near VIT University.

Fortunately, green facades can play a major role towards cleansing the atmosphere in many ways (Bradley 2011). Trees grown within an urban environment considerably reduces the concentration of air pollutants (Rosenfeld et al. 1998; Akbari et al. 2001; Nowak 2006; Scott et al. 1998). The stomata take up gaseous pollutants and intercept soot and particulate matter within it (Baker & Brooks 1998). But in most of the metropolitan cities in India, there is an acute scarcity of open grounds to plant trees. Therefore, in these cities, green vegetation can be grown both on vertical walls and roof tops, which can account for almost 40 -50% of the encroached ground (Dunnett& Kingsbury 2004). Greeneries also create a cool micro-climate around buildings because the external surface temperatures of the building walls are reduced, both through transpirational cooling and shading (Bradley 2011; Wilmers 1990). A reduction in ambient air temperatures can be achieved with both horizontal as well as vertical greenery systems (HGS and VGS). Although the latter, commonly termed as green facades are a relatively new concept in Asian metropolises (SNCCS 2008; Wong et al. 2009). Green façades not only look aesthetically elegant when draped on the building envelope, they also mitigate the urban heat island effect and even reduce the cooling load by imparting a time lag to external temperature fluctuations (Cheng et al. 2010).

This study is performed on the green walls of the subway in VIT University, Vellore, Tamil Nadu, India (Fig. 3). On a single day, the vehicular density exceeds 1,400 (comprising approximately 1,300 auto rickshaws and 100 other vehicles) through the underpass. The

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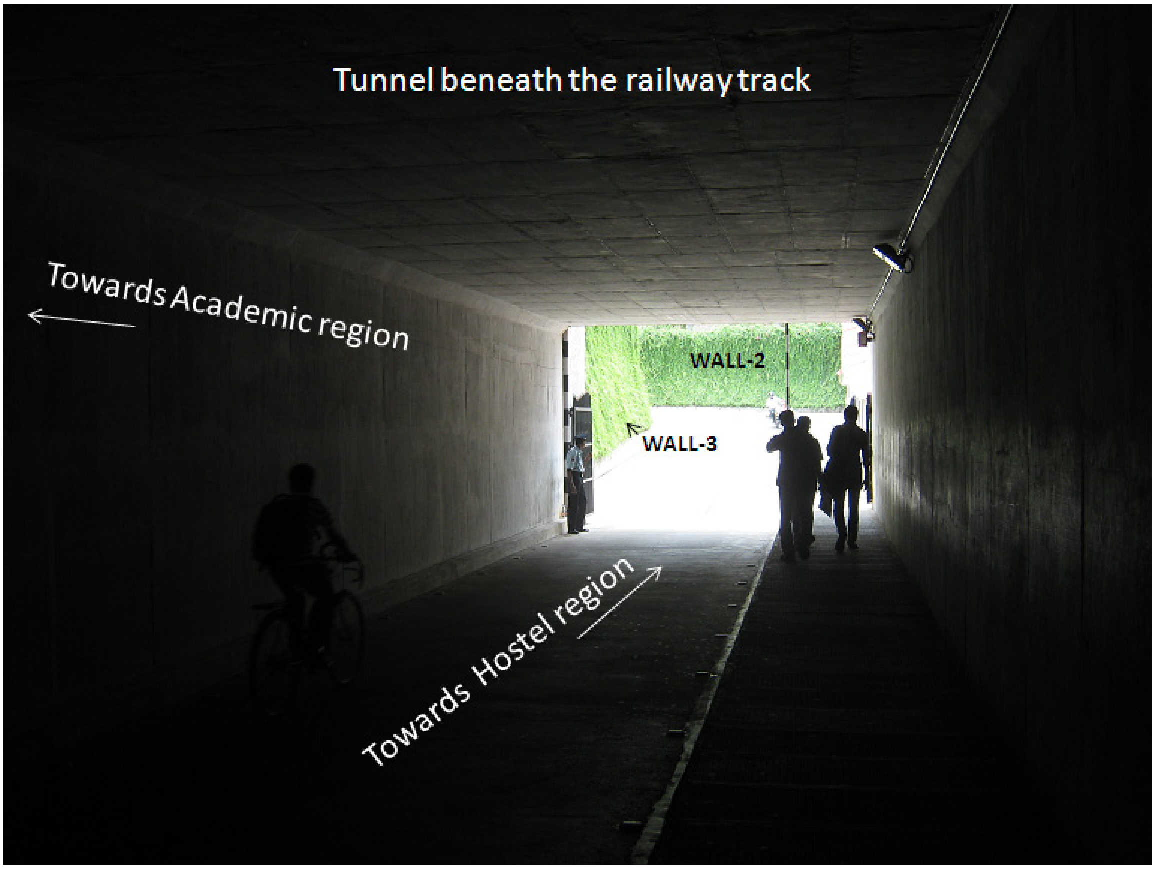
situation is partly ameliorated by draping *Vernonia elaeagnifolia* over the four exposed concrete walls (6m high) of the subway which has a total span and area of 93.7m and 489m^2 respectively (Fig. 3). This subway, along with a tunnel (58.3m), leads out to an inclined road linking it to the hostels area (Fig. 4).

Figure 3: The *Vernonia elaeagnifolia* creeper draped over the subway walls.

Figure 4: Tunnel connecting academic campus with the hostel region.



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Earlier studies on the tropical climber, *Passiflora caerulea*, draped on to a portable façade, required constant maintenance and surveillance to lend full façade coverage (Jacob et al. 2011). Another alternative, the *Vernonia elaeagnifolia* which bountifully flourishes in warm climates, is capable of prolific growth and has the propensity to spread out its verdant leaves on any form of supporting structure with very little maintenance cost. It belongs to the sun flower family (asteraceae) and in the Indian sub-continent, it is commonly known by its vernacular name *Pardabel* (FOI 2005). In Hindi, *Parda* refers to a curtain alluding to a lush curtain like drape. The frilly stems intertwined with the copious elongated oval shaped leaves, typically 5cm long and 2cm wide, provide a natural net, holding the leafy façade together (Fig. 5). The slender stems of this creeper facilitate its free fall over a wall as in this subway and may well drape an entire building. It is easy to grow and is primarily grown for the purpose of forming natural green curtains over building façades, hence the name curtain creeper. The average leaf area is approximately 760mm^2 (0.00076m^2). During the monsoons, there is almost 100% coverage over concrete walls which wanes to about 85% during the hot summer months.

Figure 5: *Vernonia elaegnifolia* can spread out over any form of support structure.

The purpose of this investigation is to broadly provide a quantitative estimation of the cleansing efficiency of these green walls. In addition, the following issues are particularly addressed:

a. During photosynthesis the stomata are fully open, making them efficient sinks to allow the ingress of suspended particulate matter through them. This investigation aims to establish the extent of atmospheric cleansing during the day when vehicular traffic is at its maximum, contrasting it with night time conditions when the stomata are closed or half open allowing only the removal of gases. This diurnal quantification of removal rates has not been undertaken on such a large scale in India with a traditional living wall drape.
b. The study aims to quantify deposition patterns – a zonal separation of the attached pollutants along the vertical extent is also explored. It is important to ascertain whether the pollution is sufficiently well mixed within the adjacent boundary layer to render a uniform gradient.
c. Is there a threshold temperature beyond which the façade's cooling efficiency is limited? This is an important issue and must be ascertained for the erection of other draped facades involving the same species.

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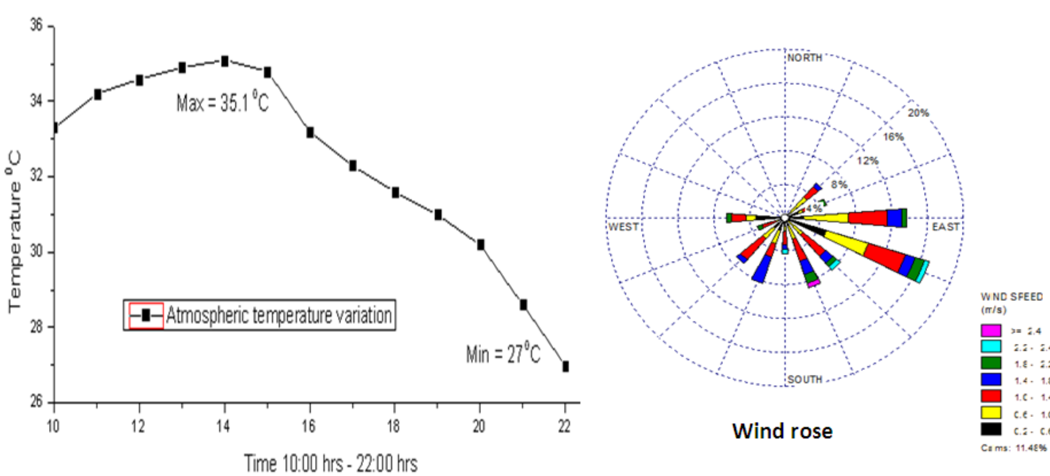
Figure 6: Aerial view of VIT University. (Source: www.vit.ac.in)

2. OBSERVATIONAL AND MODELLING ANALYSES

VIT University's sprawling campus lies on the plains surrounded by low rocky hills (Fig. 6). The temperature dips to a low of 10°C during the winter months of December-February and soars to 43°C during summer (April-June). It has a dry climate for the non-monsoon months. Precipitation usually happens during the months of June-August and October-December. The average solar insolation over Vellore is 5.14 kWh/m^2/day (SYNERGY 2013). Although these are annual temperature trends, in this study, we have recorded temperatures using a TESTO-61° thermometer. The measurements were taken on 29 July 2013 (10:00 hrs. – 22:00 hrs.) for model configuration. A wind rose also was plotted using a CAMBELL SCIENTIFIC – 03301-L wind vane (Fig. 7).

Figure 7: Meteorological parameters (Temperature Wind direction & Wind speed) recorded at Vellore, Tamil Nadu, India.



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In this section, we describe observational results where vehicular traffic is at its maximum at the start of a new academic year. The maximum temperature recorded was 35.1°C (14:00 hrs) whilst the minimum was 27°C at 22:00 hrs, exhibiting an intraday range of approximately 8°C over a time gap of 8 hours. Also, the temperature drop was rather drastic (3°C) soon after 20:00 hrs (Fig. 7). The subway has a southwesterly orientation along the academic region and thereafter has a northeasterly orientation along the hostels area (Fig. 8). The predominant wind direction being west to east, brings in moderate levels of pollution (Fig. 7). However, above the façade height of 6m, the subway is open to the free boundary layer and it enables the free dispersion of air pollutants. This points to the need for other properly placed facades within the campus.

Figure 8: Subway - Photographed from the top of the Hostel Building and Autodesk Ecotect model.

2.1 Ecotect analysis

Although measurements of temperature suggest times when cooling efficiencies are optimal (12:00 hrs – 16:00 hrs), a modelling analysis was undertaken to yield a deeper insight. Autodesk Ecotect analysis, a sustainable design software, is used to compute the temperature difference between the draped and the undraped facades for the subway. The Autodesk Ecotect analysis helps conceptualize the optimal thermal gains and losses over a 24 hour period for any chosen day and for our purposes, 29 July 2013, was chosen. This helped understand optimal energy consumption patterns vis-a-vis façade form, fabric and the orientation. In Fig. 8, we first show an aerial view of the subway along with an Ecotect reconstruction.

TABLE 1: The input parameters for Ecotect analysis.

Façade Specifications	U – Value (W/m^2K)	Admittance Value (W/m^2K)	Solar Absorption
Subway – walls – Concrete block plaster	2.83	3.63	0.506
Subway – floor – Concrete slab on ground	0.88	6.00	0.467
Hostel block – walls – Brick plaster	2.62	4.62	0.418
Green drape over concrete walls and brick plaster	0.192	6.380	0.75

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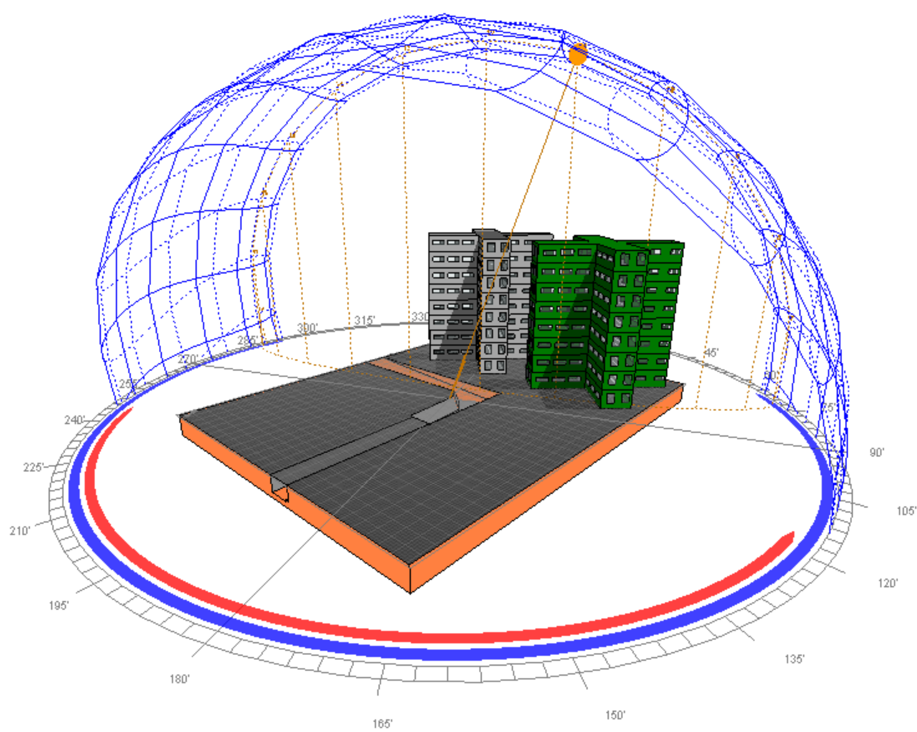
The simulation engine in Autodesk Ecotect analysis uses the admittance method to evaluate the internal temperatures and heat loads. The input parameters enlisted in Table 1 show the façade specifications, the fabric U -values, the admittance coefficients, and the solar absorption values explicitly, directly loaded from Ecotect's main library. The analysis used the weather file for Chennai, Tamil Nadu (13.080 N, 80.27° E). This was a reasonable proxy for Vellore (12.92° N, 79.13° E). The modelled subway has a volume of 311.068m^3 against the actual volume of 314m^3.

Autodesk Ecotect analysis generates sun path diagrams providing detailed annual trajectories of the sun over VIT campus. Fig. 9 shows a screen shot of such a diagram which includes the modelled tunnel, the subway and the two hostel blocks – one with the existing building material and the other with a green drape over the outer fabric facilitating an easy inter-comparison of draped and undraped façades.

Figure 9: Annual sun path over the modelled Tunnel, Subway and the Hostel buildings "H" and "J".



First, we investigate the cooling within the subway. In order to gauge the cooling efficiency with the original façade height of 6m, we show the modelled temperature distributions separately with and without the *Vernonia elaeagnifolia* drape as a function of the time of day (Fig. 10). During prime hours of the working day (07:30 - 16:45hrs), although the nearby hostel blocks ("H" and "J" blocks) do not cast shadows over the subway (Fig. 10), the green drape induces a maximum drop of 1.80C at 14:00 hrs. Until 07:30hrs, the undraped wall is slightly cooler than the draped one – this is true also after 16:45hrs. This implies that the cooling efficiency is optimal only when the stomata are fully open during the sunny hours (07:30 - 16:45hrs), the most uncomfortable part of the day and the crossing over of temperature occurs within 32°C - 34°C.

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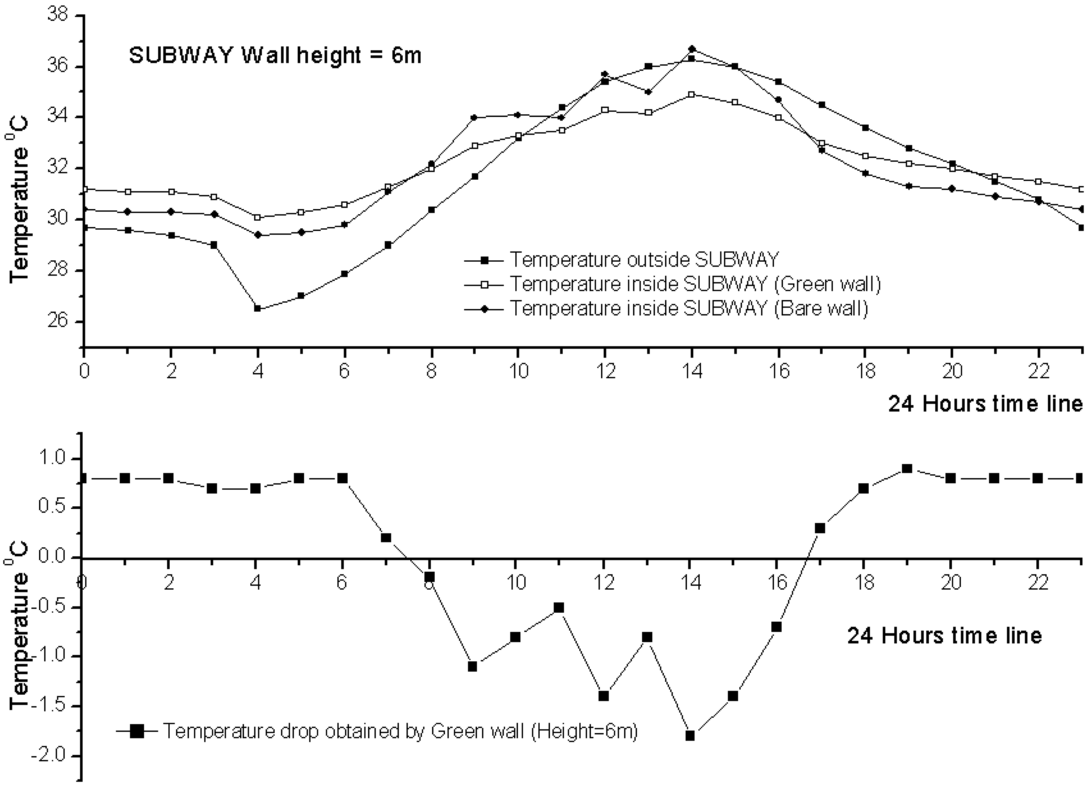
Figure 10: Temperature variation inside the Subway (Original Height, H) – Bare wall vs. Green wall - Temperature dip.



The amount of subway temperature drop (cooling) obtained with 6m tall green drape was of the order of approximately 2°C. This was corroborated with actual temperature measurements. Therefore, it is expected that a greater temperature drop can be achieved if larger façades are draped with the same creeper. The Ecotect model predicts the temperature drop of the order of 4°C by doubling the façade height. First, the extant subway height of 6 m is doubled to 12m with the expectation that when the exposed façade area increases, the temperature drops are even more substantial. This expectation is indeed obtained for a façade height of 12m (Fig. 11). The temperature drop has now increased to 3.9°C, almost by a factor of 2.

For a 12m tall facade, the maximum temperatures occur during 11:00-13:00hrs. This is mainly due to the increased built area of the walls that absorbs and radiates heat. During these hours, the sun's position is such that the majority of the rays fall on to the concrete floor, which in turn absorbs and radiates heat (Fig. 9). The entire subway is akin to a duct restricting the free entry of cool outer air from circulating inside. This renders much higher inner temperatures - almost 6°C higher than the outer temperatures (Fig. 11). Upon comparing Fig. 10 and 11, one notices subtle differences – the cooling efficiency is the highest during mid-afternoon, just as before. But the flipping over of the temperature occurs at later times (08:00hrs and 17:00hrs). Optimal cooling happens over a 9 hour period with almost a double temperature drop.

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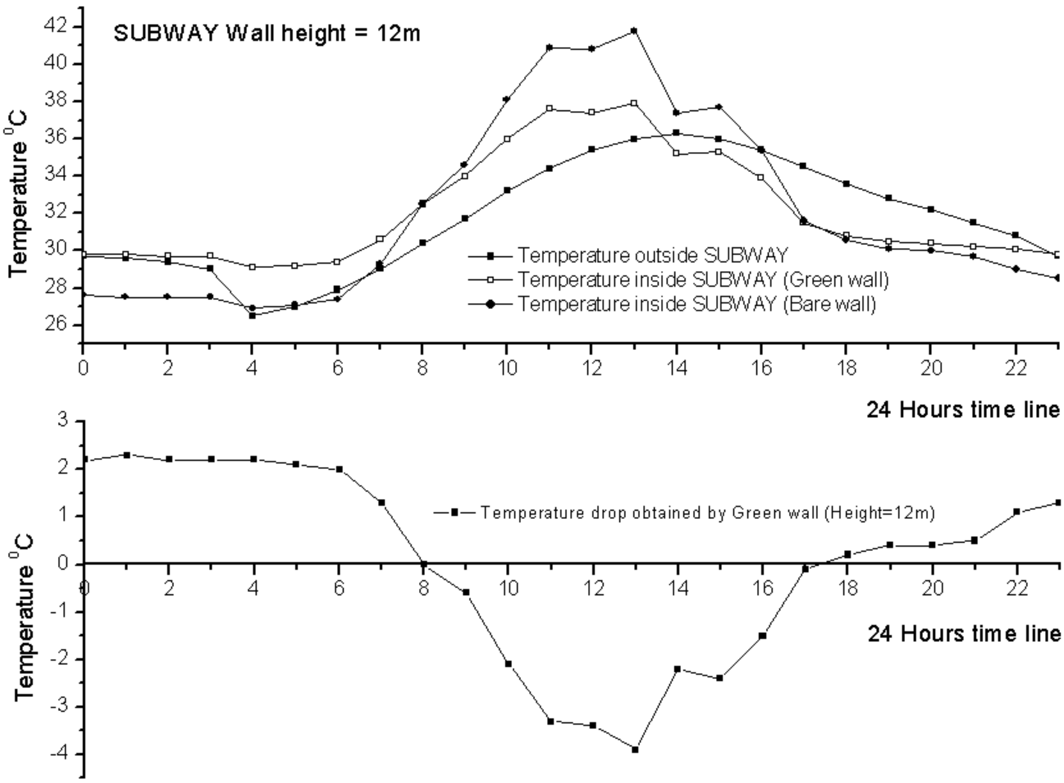
Figure 11: Temperature variation inside the Subway (Height Doubled, 2 x H) – Bare wall vs. Green wall - Temperature dip.



The crossing over of the temperature between the bare wall and the green wall happens within a band of 32°C - 34°C (Fig. 10 and 11). This suggests that the green drape has a threshold limit beyond which it is warming (rather than cooling) inside the subway. The threshold value is also a function of the maximum outside temperature.

2.2 Pollution distribution patterns over the subway façade.

In this section we shall establish the deposition pattern of sulphates and nitrates over the façade's vertical extent spanning 6m in order to find out the most vulnerable zones. A three tier zonal analysis is undertaken (Fig. 12). The subway consists of four walls that are oriented differently from the predominant directions (See wall terminology - Table 2). In this table, we show the orientation and area of the walls constituting the entire subway length of 93.7m. A rectangular grid size of 24m x 6m is identified on each wall except WALL-4 which is the shortest in length (Fig. 12). The first two walls (WALL-1 & 2) are located opposite to each other and the pathway enclosed by these two walls has a steep gradient reaching 22.5°N towards the hostel region. Therefore, the area of the green facade also decreases gradually in the aforesaid direction (Fig. 3).

On each of these four walls, three sampling zones, Zone-1(top zone), Zone-2 (middle zone), and Zone-3 (bottom zone) are mapped by dividing the wall height every 2 meters,

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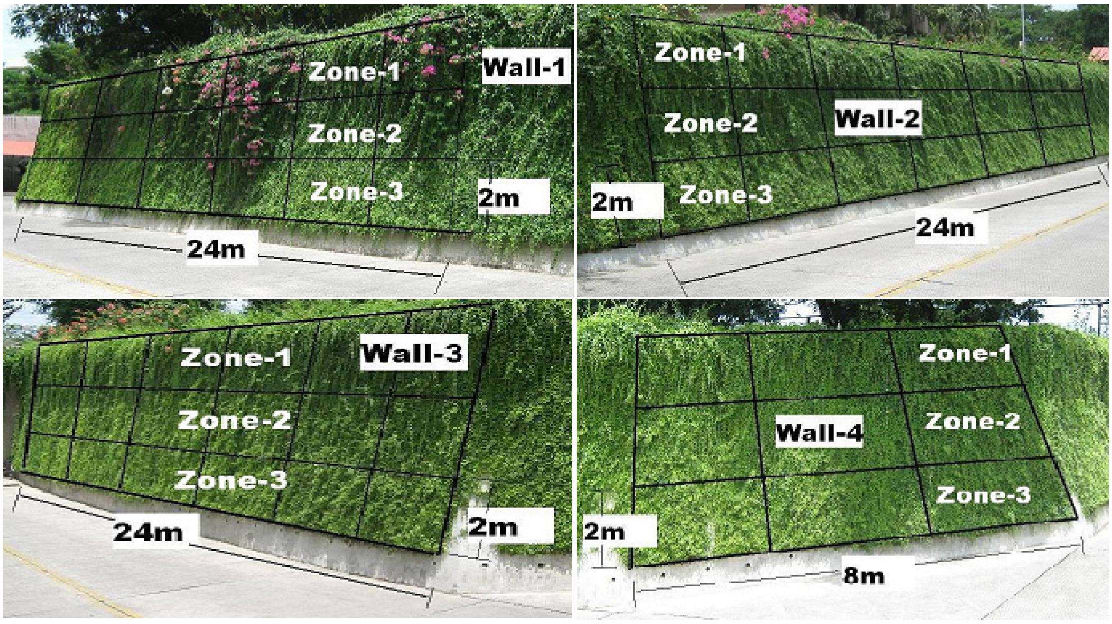
TABLE 2: Draped wall characteristics.

Wall Numbers	Orientation	Area	Zone-1 (Top Zone)	Zone-2 (Middle Zone)	Zone-3 (Bottom Zone)
WALL-1	22.5° South	124.315 m^2	6	6	6
WALL-2	22.5° North	157.093 m^2	6	6	6
WALL-3	22.5° West	158.349 m^2	6	6	6
WALL-4	West	48.943 m^2	3	3	3

measured from the bottom. The zones on WALL-1, 2 & 3 are further sub- divided lengthwise into 6 regions, each measuring 4m, whilst WALL-4 has only 3 regions (Fig. 12). This allows uniform distribution of the leaf samples for experimental analysis with 63 sampling regions on all the four walls (Table 2) which is a sizable sample for a rigorous and conservative analysis.

Figure 12: Subway walls draped with *Vernonia elaeagnifolia* creeper. Sampling regions are identified zone-wise.



A measure of the cleansing efficiency of the green façade is obtained by comparing the amounts of sulphates and nitrates in the plant tissues vis-à-vis airborne SO_x and NO_x. We present conservative estimates spanning a sampling period over 16 hours and have refrained from looking at local spurts of air pollutants causing transient high concentrations. The high volume sampler with the specifications indicated in Table 3 was positioned near WALL-4, midway between the subway, where the available mixing volume for all the pollutants was the highest (Fig. 13). An extended sampling period of 16 hours (09:15 hrs on 29 July to 01:15 hrs on 30 July 2013) was chosen to contain the entire vehicular load for the day and also to establish the cleansing efficiency of any residual pollution.

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TABLE 3: Technical specifications of the High Volume Sampler Envirotech APM 460 DXNL attached with Envirotech APM 411.

Envirotech APM 460 DXNL (for Particulate Matter sampling)	
Flow rate	1.0 m3/min with Filter Paper installed. Sampling time : Maximum 28 hours
Particle size	Particles of ≤ 10 microns collected on Filter Paper. SPM > 10 microns collected in separate sampling bottle.
Power requirement	Nominal 220 V, Single Phase, 50Hz AC mains supply Size: 400 x 300 x 650mm., 60Kg
Envirotech APM 411 (for gaseous sampling)	
Flow rate	0.3 to 2 Liters per minute. Flow Control: Four inlet, one outlet with needle valves for flow control of each unit
Sampling train	4 Nos. of 35ml Borosilicate glass impingers. Size: 240 x 125 x 350mm

A gaseous sampling attachment (Envirotech APM 411) was also paired with the sampler to monitor the SO_x and NO_x concentration. The flow rate of the gaseous sampler was set at 1.0 liters per minute (lpm) throughout the experiment. Since most of the vehicular emissions inside the subway happened within 0.3m height from the ground level, the coarse particles circulated and settled well within 1.0m, whilst the fine particles were buoyed upwards to eddy 2.5m above the ground level. Therefore the sampling was also done at two different heights: 0.75m and 3m respectively from the ground level (Fig. 13). The expected deposition pattern is depicted in Fig. 14. However, as we shall see later (section 2.4), there are subtleties in the deposition pattern that are often not intuitive.

Figure 13: Particulate matter and gaseous sampling in the subway on 29th July 2013, using Envirotech APM4 60DXNL with APM411.

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A visual examination revealed that *Vernonia elaeagnifolia* traps particulate matter (both coarse and fine) effectively onto the leaf surfaces. This aspect is explored further through scanning electron microscopy (Fig 16). A subsequent chemical analysis also indicated the presence of nitrates and sulphates (Figs 17 and 18), which in turn revealed that gaseous pollutants SO_x and NO_x are indeed present in the subway.

Figure 14: Schematic diagram - dispersion of particulates and gases throughout the height profile of the subway wall.

2.3 SUSPENDED PARTICULATE MATTER, SOX AND NOX ABSORPTION.

Figure 15 summarises the ambient air quality near WALL-4, at two different heights, 0.75m (SLOT-1) and 3m (SLOT-2). The most obvious inference from Figure 15 is that the residual pollution is effectively cleansed by the green façade. Past studies on the cleansing of air pollutants by tropical trees suggest the removal rate within an advective diffusive system is substantial only when continuous sources of pollution are switched off (Picardo and Ghosh 2011). Picardo and Ghosh established that shifts in the wind directions moved a pollutant plume around. What remains in an earlier segment corresponding to an earlier wind profile is only the presence of residual pollution. This pall is very much present for time durations of several hours, particularly when the atmosphere is calm. Botanical cleansing mediated by the presence of evergreen foliage then acts as effective sinks for the removal of airborne gaseous pollutants left over from an earlier plume.

During the entire sampling duration of 16 hours, even though 1,472 auto rickshaws and 488 other vehicles passed through the subway, because of the presence of green facade, the concentration of Total Suspend Particulate Matter (TSPM), Respirable Particulate Matter (RSPM), SO_x, and NO_x never exceeded the 8 hours ambient air quality standard limits (see the 3 dashed lines in Fig. 15). A mass transfer analysis predicts a cleansing time of 6 hours through the subway. However, when the source is turned off (during the late nights when there is no vehicular pollution in the subway), there is still a chance of residual pollution hanging in the air, which is removed by the green drapes. The TSPM concentration is almost 53% higher in SLOT-1 than at higher altitudes. The RSPM value for the lower altitude was 47μg/m^3, whilst it was 16μg/m^3 for the second slot. The TSPM being coarse easily settles at lower altitudes.

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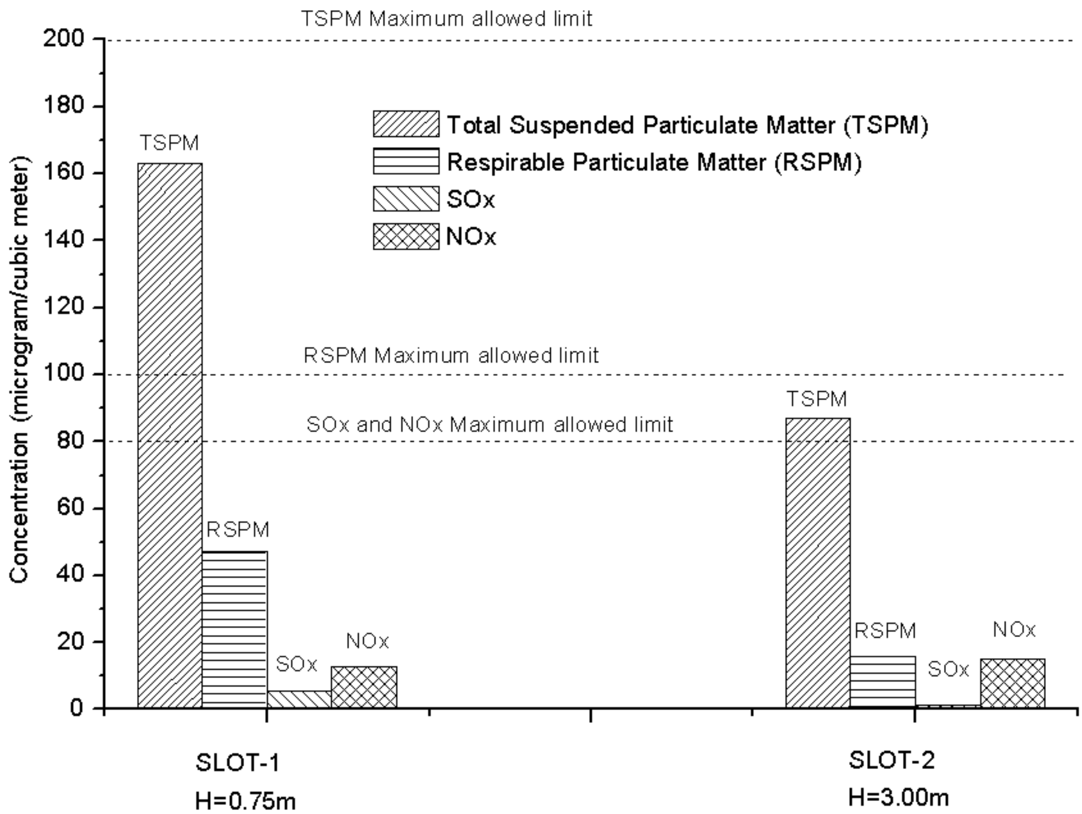
Figure 15: Particulate Matter sampling performed near WALL-4 on 29th July 2013.



In both the Slots, the concentration of NOx is nearly double the concentration of SOx (Fig. 15). This is to be expected since vehicular emissions contain more NOx than SOx (Blumberg et al. 2003) - the level of sulphur is regulated at the fuel refining stage itself. NOx is usually produced when the nitrogen in the air reacts with oxygen at higher temperatures. This reaction normally takes place during combustion of fuel inside the IC engines. Therefore, over regions of higher vehicular traffic, the amount of NOx emitted is approximately 8 times higher than SOx (Blumberg et al. 2003). Sulphur dioxide (SO_2) once emitted from the vehicular exhaust, owing to its higher molecular weight, settles to a greater extent at lower levels. Measured SOx concentration near the ground level is therefore 3.5 times higher than in SLOT-2. Conversely, NO_2 being 28% lighter than SO_2, eddies rapidly upwards in the atmosphere and accumulates at a faster rate (15% higher) and over greater altitudes. Gravitational separation clearly played a major part and this led to the higher concentration of the pollutants in SLOT-1, closer to the ground than in SLOT-2. This qualitative deposition pattern of air pollutants in the freeway between the draped facade walls prompts us to investigate the transformation of these gaseous pollutants into sulphates and nitrates as they penetrate through the stomatal pores, oxidizing and then dissociating deep within the plant tissues.

Leaf samples from all 12 zones (3 Zones per Wall) were processed further for SEM analysis (Fig. 12 and Table 2). The leaf, being a biological sample, had to be desiccated properly to eliminate all moisture content. An auto fine coater (JEOL JFC-1600) was used to prepare the specimen for SEM observation. This effectively coated biological and other nonconductive specimen with metals in a short time resulting in an accurate film thickness up to a maximum

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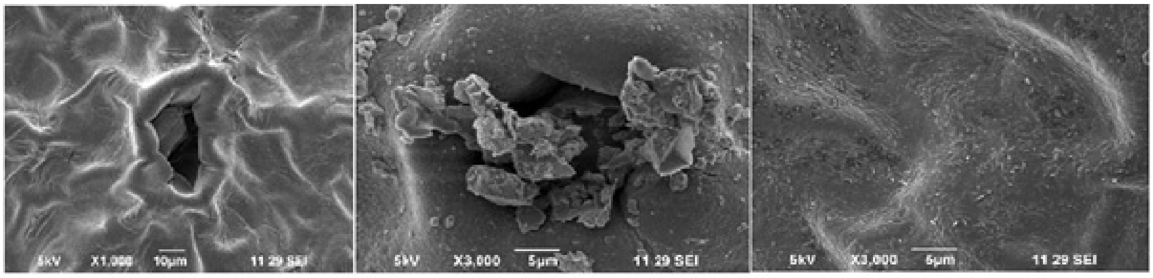
TABLE 4: Technical specifications of Scanning Electron Microscopic analysis.

Model	JEOL JFC - 6390
Magnification	5 – 300000x
Electron gun accelerating voltage	0.5 – 30kv
Admissible specimen size	8 – 150mm
Degrees of freedom	Movement in XYZ, tilt 100 to +900 and 3600 endless

of 10nm (Jacob et al. 2011; JEOL). The SEM that photographed the images had the following specifications (Table 4).

SEM images for the randomly plucked leaf samples (Table 2) clearly illustrate the deposition pattern over the façade height. WALL-4 was chosen for this purpose because it received the direct onslaught of the incoming flow (Fig. 16). The stomatal openings of the leaves on WALL-4 are clearly visible without any signs of clogging (Fig. 16). The bottom zones are more prone to clogging- in fact, the zonal demarcation vis-à-vis the extent of clogging is clearly evident; Zone-3 is most clogged and Zone-1 the least.

Figure 16: SEM images of WALL-4 (clearly visible, partially clogged and fully invisible stomata in Zones-1, 2 & 3 respectively).



The main atmospheric pollutant gases from the vehicular emissions (SO_x and NO_x) are absorbed through the stomatal openings of the creeper and soot and black carbon particles are advected directly on to the foliage. A chemical analysis of these leaf samples collected from 63 sampling regions, uniformly distributed throughout the four walls (Fig. 12 and Table 2), was undertaken. The entire methodology adopted for the chemical analysis is in accordance with standard procedures (Muralikrishna 1997; Bhargava 2009). The leaf samples collected for both SEM and chemical analysis had experienced at least three consecutive climatic seasons. The subway is fully operational since 2010 and it took almost two years for the creeper to provide 100% coverage.

To quantify the concentration of atmospheric pollutants trapped by stomata and mesophilic tissues, the collected leaf samples are oven dried (24 hours at 95°C), and powdered and mixed properly with distilled water in a conical flask. After a settling time of 24 hours, the solution is filtered using Whitman 42 filter paper. Sulphate and nitrate concentrations were

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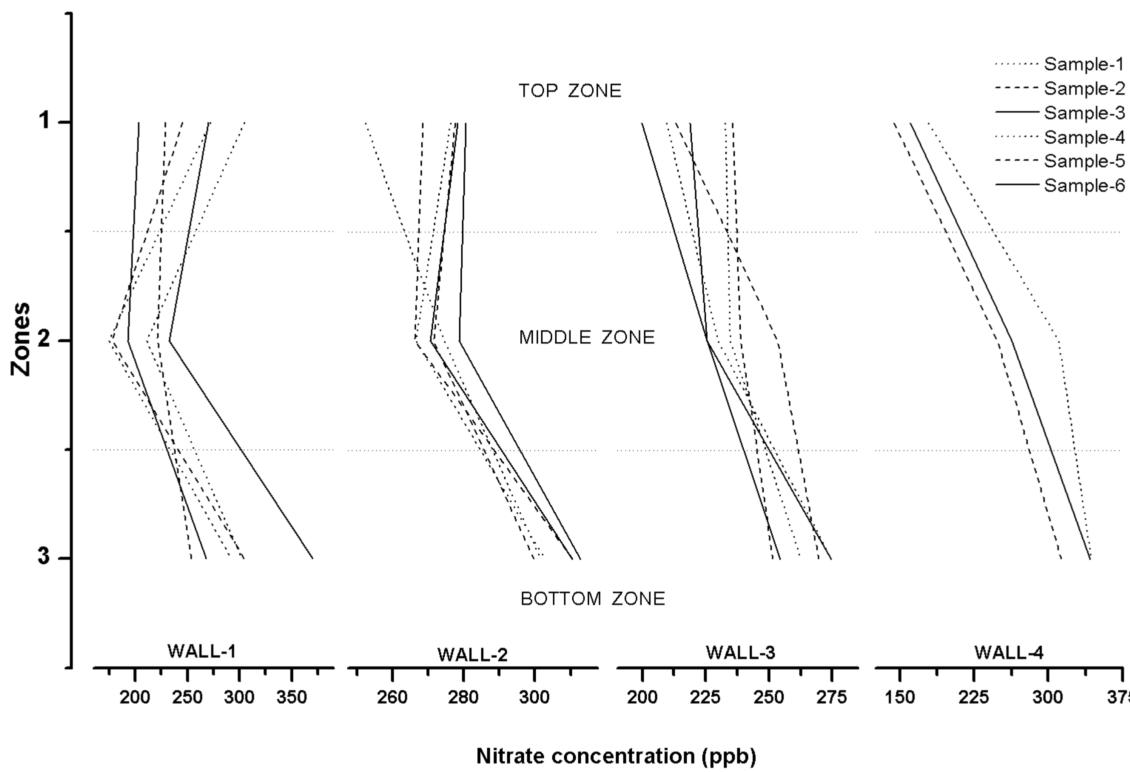
calculated using UV spectrophotometric analysis by setting the absorbance at 420nm and 220nm respectively.

Fig. 17 and 18 describes the deposition pattern of nitrate and sulphate concentration respectively over the three zones on all the four walls. For all the three walls, there is a steady decline of the nitrate species from the high of 300ppb, well within Zone-3, to a value of 200ppb midway in Zone-2. Over wall-1, there was a sharp increase of the nitrates with a discernible change of slope. This trend though visible, fades as one proceeds from WALL-1 to WALL-4. In fact, over WALL-4, there is a continuous decrease of nitrate concentration vertically.

Figure 17: Nitrate concentration on all four walls of the subway.



Interestingly, the nitrate concentrations on WALL-1 & 2 are almost in the same range and also follow a common trend from top to bottom (Zone-1 to Zone-3). The manner in which the façade is draped influences the concentration of pollutants trapped in its stomata. These are planted at the top surface of the walls in such a way that it hangs over the subway from the top to the bottom. Therefore, the fresh leaves are always formed in profusion at the bottom region than at Zones-1 & 2. Also, the periodical pruning of these greeneries over Zone-3 (bottom region) enhances the formation of fresh leaves over this region. The stomatal opening thus remains clear and wide open, particularly when sunny.

The vehicular emissions are higher over this part of the subway – after negotiating the sharp curve near WALL-4, the engine has to generate higher power (which in turn results in higher emissions) to maneuver the uphill slope towards the hostels.

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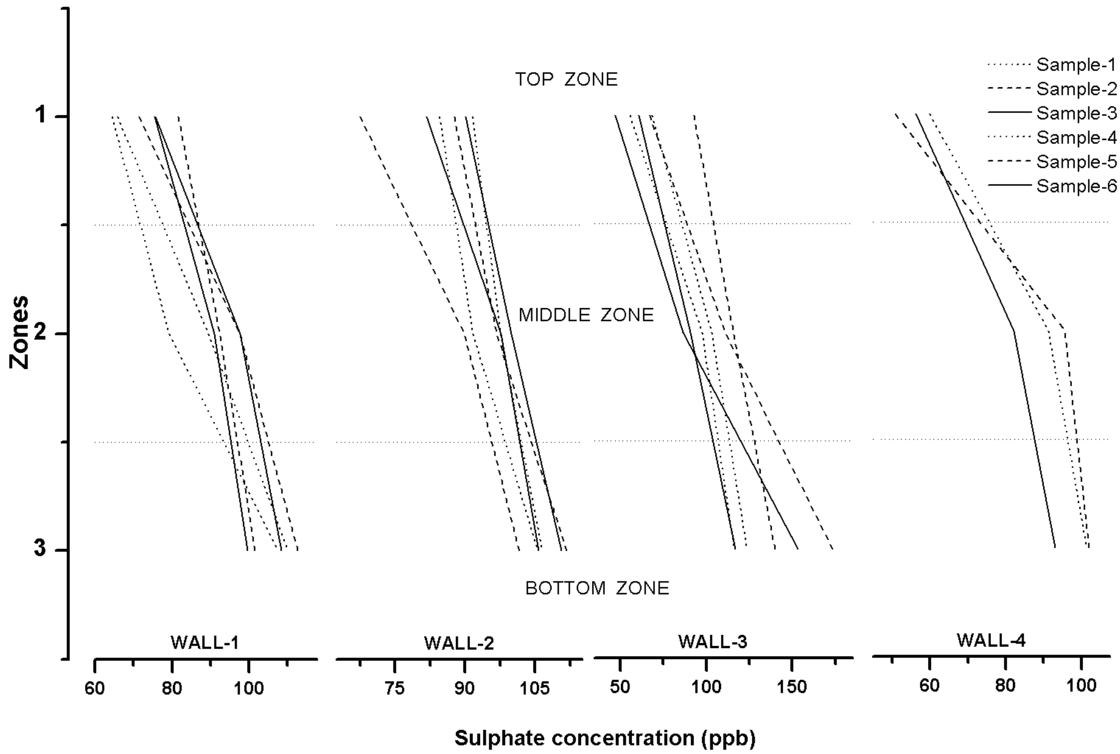
Figure 18: Sulphate concentration on all the four walls of the subway.



Over WALL-3, the nitrate concentration is lower than over WALLS-1 & 2. This wall, being at the entrance of the subway, is the tallest wall. The vehicles moving towards the hostel block have to travel through a straight tunnel before entering the subway near WALL-3 (Fig. 4). Though the height gradient of the pathway near this wall is same as that between WALL-1 & 2, the presence of the straight tunnel encourages the vehicles to ply at top gear until they reach the sharp end near WALL-4. As a result, the vehicular emissions near WALL-3 are lower than compared near WALL-1 & 2. The top regions of this wall are directly exposed to the open railway track resulting in a higher mixing volume for the lighter pollutants. In contrast, at lower altitudes, once the presence of the tunnel keeps the pollutant mixing volume low, the concentration of sulphates over Zone-3 is higher. The available mixing volume of the pollutants play an important role in the pollutant concentration present in the region. The upper space adjoining WALL-4 offers the highest mixing volume as compared to any other region inside the subway. Hence, at higher altitudes (Zone-1), the concentration of both sulphates and nitrates absorbed by the green drape is the least.

3. WIDER IMPLICATION AND CONCLUSIONS

Thus far, we have only explored temperature drops in the immediate vicinity of a subway wall of modest height and have elucidated the benign properties of *Vernonia elaeagnifolia* as a creeper on walls with its ability to absorb Suspended Particulate Matter and Oxides of Nitrogen and Sulphur. Now we come to the issue of draping walls with the same creeper on multi-storeyed buildings.

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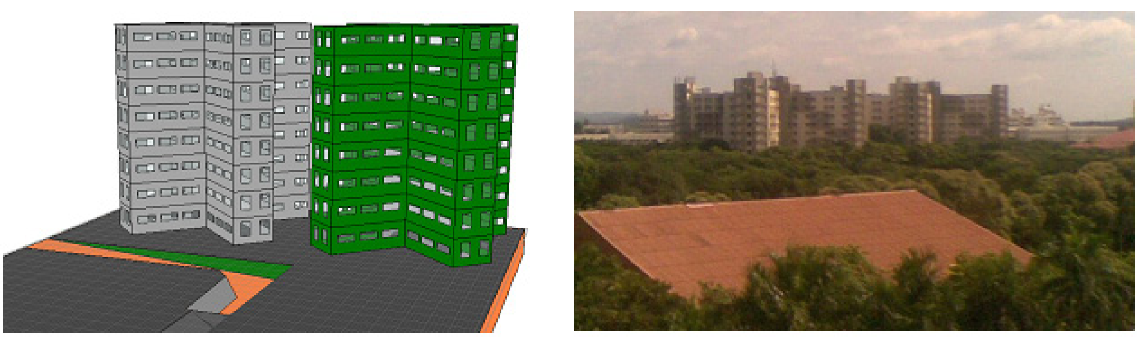
The profusion of growth of this species promises to be a good solution for draping not just walls and roofs, but also walls of high rise buildings that being built at an increasing rate in India. While sunshine is plentiful (averaging over 300 days a year), it is ironically underutilized. Excessive solar gains are perceived as a nuisance because the primary emphasis among India's building occupants is to have air conditioned interiors and artificial lighting without any consideration for ethical and green issues. However, the new India is getting increasingly environmentally conscious in terms of energy efficiency. In particular, the state of Tamil Nadu has several green buildings- the Anna University centenary library at Chennai. Tamil Nadu is just one example. VIT University is attempting to carve itself a niche among an elite group of universities that consider themselves energy conscious. To this end, the VIT University campus, sprawling over 142 hectors, has been designated as one of the greenest university campuses within the Indian subcontinent. Being primarily a Technological Institute, energy courses are tailor made for the study of heat and mass transfer processes, thermal efficiencies, and HVAC across a plethora of situations. Computational Fluid dynamical software is extensively available within the VIT University. This paper therefore made extensive use of such applications of CFD software for future projected gains achieved by draping some of its tallest building with *Vernonia elaeagnifolia*.

Figure 19: "H" and "J" Blocks - ECOTECT modelled and photograph.



In fact, in Figure 19, we have shown VIT hostels "H" and "J" blocks of height of 60m having an exposed façade area of approximately 13920m^2, with and without the green drape. These hostels house 1,400 students and for optimal cooling each block requires 3191KW of electricity every day. Figure 20 shows both the diurnal temperature variations and the temperature drop when the entire exposed façade is draped with the green creeper. We noticed that during the hot mid-afternoon when the HVAC loads are at their highest, outer walls of the draped "J" block are refreshingly cooler by 1.8°C. The HVAC load reduction in Figure 21 shows that in energy terms, the daily savings are estimated in the order of 592KW, translating to a total annual saving of 36,000 USD!

In this paper we have explored the effects of *Vernonia elaeagnifolia* as a versatile façade draping for walls along passageways and over high rise buildings. Results are presented for an "L" shaped street canyon with a road width of 8 m and canyon height ranging between 1 to 7 m. The detailed analysis for thermal cooling and HVAC load reduction is presented. VIT University's green façade along a street canyon showed a remarkable level of efficiency byadding a kinder microclimate. On the hottest day, the street canyon temperature fell by 1.8°C. Apart from adding a verdant elegance to the otherwise nondescript concrete walls, it lent

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Figure 20: Hostel Building – Temperature variation with and without green façade and the temperature dip obtained.

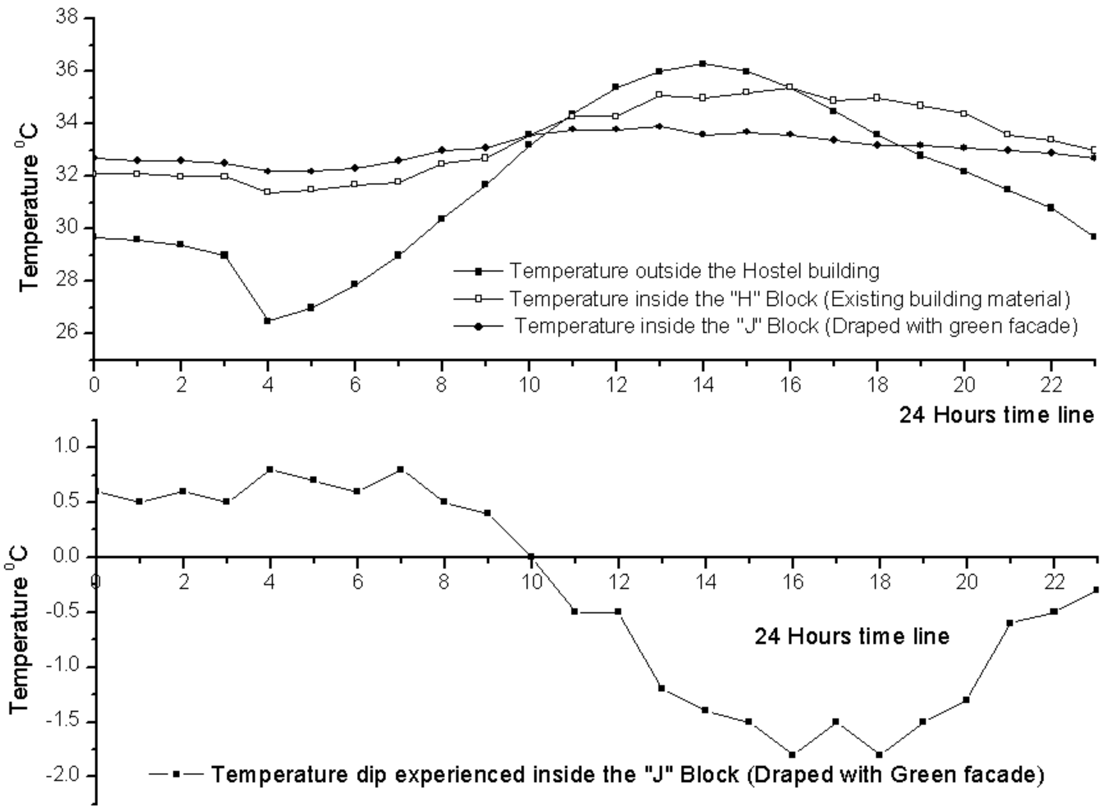
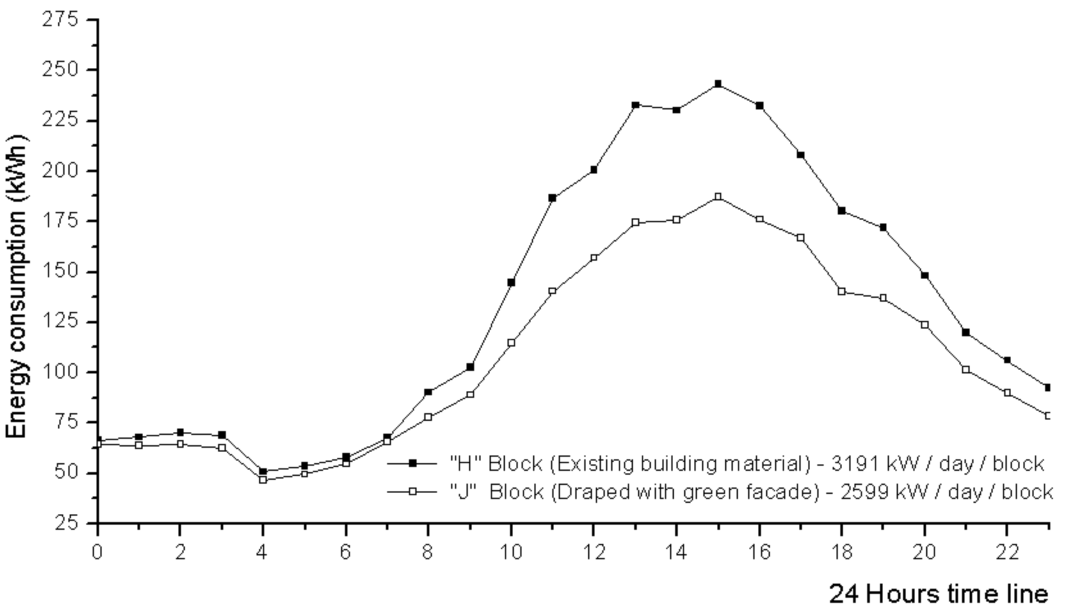


Figure 21: Diurnal energy consumption of "H" and "J" Blocks.



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some measure of cooling and helped cleanse the ambient air over the surrounding to acceptable levels prescribed by the Pollution Control Board.

This first study combining scanning electron microscopy, high volume sampling, UV spectrophotometric analysis of absorbed pollutants along with a versatile architectural software demonstrates the thermal as well as the cleansing efficiency of *Vernonia elaeagnifolia*. It is anticipated that this study will inspire many other green architects within the subcontinent and the rest of Asia where this creeper can easily flourish and cover building surfaces.

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REFERENCES

Akbari H., Pomerantz M., Taha H. 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy. 70 (3): 295- 310.

Baker A.J.M., Brooks R.R. 1989. Terrestrial higher plants which hyper accumulate metallic elements - a review of their distribution ecology and phytochemistry. Biorecovery 1 (2): 81 - 126.

Bhargava S.K. 2009.Practical methods for water and air pollution monitoring.New Age International private Limited.India.

Blumberg K O, Walsh M P, Pera C. 2003. [Internet].Low-Sulfur gasoline and diesel; the key to lower vehicular emissions.ICCT -The International Council on Clean Transportation. Available from:
http://www.unep.org/transport/pcfv/pdf/publowsulfurpaper.pdf. or
http://www.theicct.org/low-sulfur-gasoline-and-diesel-key-lower-vehicle-emissions

Bradley Rowe D. 2011. Green roofs as a means of pollutant abatement. Environmental pollution. 159: 2100 – 2110

Cheng C Y, Ken Cheung K S, Chu L M. 2010. Thermal performance of vegetated cladding system on façade walls. Building and Environment. 45: 1779 – 1787

CPCB [Internet]. Central Pollution Control Board – India. Available from:
http://cpcb.nic.in/divisionsofheadoffice/ess/NewItem_152_Final-Book_2.pdf.

Dunnett N., Kingsbury N. 2004. Planting Green Roofs and Living Walls.Timber Press Inc. Portland. OR.

EAVCMC 2011[Internet]. Environmental assessment for Vellore city Municipal Corporation. Ward 2. Vellore North.Tamil Nadu. Available from: vellorecorp.tn.gov.in/velugd.pdf.

FOI 2005 [Internet]. Flowers of India. Available from: http://www.flowersofindia.net.

ICCT 2013 [Internet]. The International Council on Clean Transportation. Available from:http://www.theicct.org/sites/default/files/publications/ICCT_Briefing_IndiaPolicySummary_20130703.pdf.

Jacob Thottathil V, Balamuralikrishna C, Ghosh S. 2011. Role of green facades in creating sustainable environments: Comparing chemical analyses and SEM images to quantify the atmospheric cleansing by green creepers. World Academy of Science Engineering and Technology. 77: 343 – 46

JEOL [Internet]. Serving Advanced Technology. SEM Question and Answers. JEOL Ltd. JEOL DATUM Ltd. Tokyo. Japan. Available from: http://www.medicine.mcgill.ca/femr/SEM%20Sample%20Prep%20JEOL.pdf.

Muralikrishna KVSG. 1997. Chemical analysis of water and soil- laboratory manual. Reem publications private Limited. India.

Nowak D.J. 2006.Air pollution removal by urban trees and shrubs in the United States.Urban Forestry and Urban Greening. 4: 115 - 123.

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Picardo J.R and S. Ghosh. 2011. Removal Mechanisms in a Tropical Boundary Layer: Quantification of Air Pollutant Removal Rates Around a Heavily Afforested Power Plant, Air Pollution - New Developments, ISBN: 978-953-307-527-3, InTech.
DOI: 10.5772/18348
Rosenfeld A.H., Akbari H., Romm J.J., Pomerantz M. 1998. Cool communities: strategies for heat island mitigation and smog reduction. Energy and Buildings 28: 51 - 62.
Scott K.I., McPherson E.G., Simpson J.R. 1998.Air pollution uptake by Sacramento's urban forest. Journal of Arboriculture. 24: 224 - 234.
Sengupta B. 2001. [Internet].Vehicular pollution control in India - Technical & non-Technical measure policy. Paper presented at: Regional workshop on transport sector inspection & maintenance policy in Asia. ESCAP/UN(DESA). Bangkok Dec 10-12. Available from:http://www.un.org/esa/gite/iandm/senguptapresentation.pdf.
Sengupta B. 2011. [Internet]. Current air quality issues in India. Paper presented at: The Workshop on Vehicular air pollution and its impact on human health. MoEF/ CPCB / EPCA / ICCT. Sept 1-2. Available from: http://www.theicct.org/sites/default/files/BSengupta_0.pdf.
SNCCS 2008 [Internet]. Singapore's National Climate Change Strategy.
Sreevatsan A. 2010 Mar 9.[Internet]. Marked fall in ambient air quality. The Hindu (Chennai Edition). News/ cities/ Chennai. Available from google search: http://www.thehindu.com/news/cities/chennai/marked-fall-in-ambient-air-quality/article221339.ece.
SYNERGY 2013.[Internet].Synergy Enviro Engineers (India) Private Limited. Available from: http://www.synergyenviron.com/tools/solar_insolation.asp?loc=Vellore%2C%20Tamil%20Nadu%2C%20India.
USEPA 1998. United States Environmental Protection Agency. NOX.EPA-456/F-98 - 005.Environmental Protection Agency Office of Air Quality Planning and Standards Research, Washington, D.C.
Wilmers F. 1990. Effects of vegetation on urban climate and buildings.Energy and Buildings. 15: 507–514.
Wong N H, Alex Yong K T, Puay Y T, Wong N C. 2009. Energy simulation of vertical greenery system. Energy and Buildings. 41: 1401 - 1408

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