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Can Indoor Plants Reduce Air Pollution Cost-Effectively? An Economic Assessment of Natural Air Purification

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ABSTRACT RESEARCH ARTICLE

Potted plants are encouraged as a low cost, nature-based solution to indoor air pollution, which is one of the most significant environmental health risks. However, the economic viability of phytoremediation has never been evaluated with respect to the physical capacity of leaf uptake of pollutants. This paper translates 196 published chamber measurements into clean air delivery rates (CADR) which are used to rate engineered air cleaners, and then into levelised costs of clean air and cost per disability-adjusted life year (DALY) avoided. A well-mixed mass-balance model is parameterised for a room of 30 m3, three occupants and a room air change rate of 1 air change per hour, a Dhka case being used as an example of a high exposure case. With the median single plant CADR of 0.023 $m^3 h^{-1}$, 1,304 plants are required to replace 1 ACH, at a cost of USD 42,652 annually, or 109 plants per square metre. The levelised cost is USD 0.162 per m^3 of clean air, compared to USD 0.0000689 for HEPA filtration and USD 0.00052 for mechanical ventilation. Passive plants are inefficient in removing the fine particles, while the cost of plant-based PM2.5 abatement is approximately USD 9.4 million per DALY, which is less than 10% of the per capita GDP of Bangladesh. According to the break-even analysis, the potted plant would have to provide 54 $m^3 h^{-1}$ of clean air, which corresponds to some 2,357 times the measured performance, to outcompete filtration. Plants are thus biophilic design elements, not pollution control technology, and claims by regulators or companies that they are the same are not economically justifiable.

Keywords: *indoor air quality; phytoremediation; cost-effectiveness analysis; clean air delivery rate; disability-adjusted life years; HEPA filtration; green building policy*

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1. INTRODUCTION

In industrialised countries and rapidly urbanising economies, people spend almost 90% of their time indoors and personal exposure to many pollutants is driven by the indoor environments in which time is spent. The Global Exposure Mortality Model estimates that ambient fine particulate matter (PM2.5) is responsible for 8.9 million premature deaths per year globally, and the Global Burden of Disease programme estimates about 4.2 million deaths per year due to ambient air pollution, with residential energy use, agriculture, power generation and traffic as the most important contributors to the attributable burden. Much of that exposure is through outdoor pollution that shows up inside the house, and also through volatile organic compounds (VOCs) and products of reaction with ozone and resuspended particles produced inside the house (Morawska *et al.*, 2013; Weschler, 2006). Cooking emissions and a lack of ventilation exacerbate the situation in low and middle-income countries, with mean indoor PM2.5 ~5 times the World Health Organization 24-hour guideline, as measured in 43 households in Dhaka.

In this context, indoor plants have an unusual policy status. Credits are awarded in sustainability schemes for indoor greenery, corporate wellness programmes use green offices as proof of green commitment and the trade and popular media constantly write about potted plants as natural air purifiers. The claim is based on a report by the National Aeronautics and Space Administration (NASA) that examined a few ornamental species in closed containers and found measurable depletion of formaldehyde, benzene and trichloroethylene. This study has been supported by a substantial experimental literature on species-specific uptake, on the relative contribution of foliage and root-zone substrate, on the influence of light, humidity and growing medium as well as field trials reporting lower VOC concentrations after plants were introduced.

The economic question is not the same as the question of the removal of pollutants by the plants. Removing a pollutant is not enough for a technology to be an efficient method of improving health, it must remove a large amount of a pollutant relative to alternatives per unit cost of removal. Source control for indoor air management consists of the use of low-emission materials, more outdoor-air ventilation and particle or sorbent filters with known costs and effectiveness. The BCRs for filtered water consistently fall between 4 and 130 when monetary values are assigned to the impact of mortality reduction; a comprehensive nationwide evaluation of portable purifiers has shown that the cost can be of the order of tens of thousands of yuan per DALY. For potted plants, no such evaluation has been undertaken; promotion of a low price for the product is based on the assumption that a near zero purchase price means a low per unit cost of pollution removal.

The physics of leaf mediated uptake is what that means, and it is a constraint that price cannot do without. Cummings and Waring (2020) converted 196 chamber measurements across 12 studies to the air-cleaner industry metric of clean air delivery rate, yielding a median of 0.023 m3 h−1 per cleaner, and a range over several orders of magnitude. To achieve the same removal as a typical building (which expects to achieve around 1 h−1 through air exchange), 10 to 1,000 plants per square metre would be needed. “This is not a point on horticulture: the constraint applies irrespective of the cost of the individual plant, since the number of plants needed is inversely related to per plant performance.”

The paper is thus comprised of the following four objectives. What is the clean-air equivalent, per square foot of floor space, provided by potted plants, in the same units used to rate mechanical cleaners? How much does that clean air cost on a levelled basis when compared to filtration and ventilation? What are the implicit health benefits per dollar spent in a high-exposure South Asian environment? But, under which circumstances, if any, would plant-based systems be economically viable? The contribution is threefold: a levelised cost of clean air (LCOA) metric making heterogeneous interventions directly comparable; the first break-even calculation identifying the per-plant performance necessary for phytoremediation to compete with filtration; and decision rules separating the justifiable, non-pollution control benefits of indoor vegetation (biophilic amenity and occupant wellbeing) from the indefensible benefits of pollution control.

3. METHODS

3.1 Analytical framework

This assessment happens in four stages: translation of phytoremediation evidence to a clean air delivery rate, scaling to a reference room to determine the plant inventory needed to deliver a ventilation-equivalent, translation of capital and operating costs to a levelised cost per cubic metre of clean air, and translation of the resulting exposure reduction to avoided DALYs. The steady-state indoor/outdoor ratio for a pollutant with negligible indoor source is:

$$C_{in}/C_{out} = Q / (Q + CADR + k_{dep} \cdot V)$$

where V is the volume of the room (m3). A plant assembly with CADR = Q cuts this ratio in half, but does not remove the pollutant. The inventories that are needed for that equivalence are:

$$N = Q / CADR_p$$

The levelised cost of clean air annualises capital and operating costs per unit of delivered clean air:

$$LCOA = (C_{cap} \cdot CRF(r,T) + C_{op}) / (CADR \times 8760)$$

Where CRF is the capital recovery factor at the discount rate r over the life T. The capital component is not considered to be an amortised investment but is considered as an annual replacement charge for plants because the lifetime of plants is not long and is not guaranteed.

Health benefits are calculated in a marginal way without resorting to a counterfactual baseline. Avoided DALYs per year in a room that has n people is:

$$\Delta DALY = n \cdot \Delta C \cdot \beta \cdot m0 \cdot D$$

where β is fractional increase in adult mortality per μg m−3 PM2.5, m0 is the background annual adult mortality rate and D is the DALYs lost per premature death. The break-even per plant performance at which plants are equal to filtration costs is the annual cost per unit of clean air across technologies:

*CADR*p = (annual cost per plant) / (cost per $m^3\ h^{-1}$ of clean air from filtration)*

3.2 Reference environment and case setting

The reference environment (RE) is a 30 m3 room with a floor area of 12 m2 and a ceiling height of 2.5 m, used by three occupants at an air exchange rate of 1.0 h^{-1} (i.e., a small office, seminar room or urban living room) and in the same size scale as in the chamber to the building translation by. So, the outdoor air supply is 30 $m^3\ h^{-1}$.

The health-economic case is Dhaka, Bangladesh due to the high level of outdoor concentrations, high indoor exposure and low health-system expenditure, making it a situation where air-quality interventions should be most attractive. The mean value of indoor PM2.5 is assumed to be 75 μg m−3, five times higher than the 24-hour guideline value set by WHO (2021) for Dhaka households . The baseline level of adult mortality is 0.007 per person-years, and the number of DALYs per premature death is 12, which is based on the age distribution of cardiopulmonary mortality in South Asian countries. The cost-effectiveness threshold is one to three times GDP per capita per DALY, which ranges from the conventional lower limit of the WHO to the Bangladeshi GDP in 2024 of USD 2,593.

3.3 Cost parameterisation

Plant costs represent indicative market retail price for commonly grown ornamental plants in urban markets of South Asian countries and a central value of USD 15, ranging between USD 8 and USD 30. Annual maintenance consists of 20 minutes of watering and care per week (17.3 hours per year) valued at USD 1.50 per hour; water and fertiliser (USD 3 per plant-year) and 25% of plants replaced annually (typical attrition) (USD 32.70/plant-year). Since a lot of plant care takes place within the household, a zero-wage variant is added to the sensitivity analysis.

The filtration comparator is a portable HEPA filtration unit that has a smoke CADR of 250 m3 h−1, capital cost of USD 250, life of 8 years, annual filter cost of USD 60 and continuous fan power of 45 W, thus amounting to USD 150.81 annually. The incremental outdoor air supply of 30 $m^3\ h^{-1}$ is the ventilation comparator (enthalpy difference 39 kJ kg^{-1}, COP 3 and the same tariff, 1,139 kWh and USD 136.66 per year). Ventilation is also included to indicate pollutant dilution overall; in Dhaka it wouldn't consistently lower indoor PM2.5 levels since the outdoor concentration is often higher than the indoor concentration, as mentioned below.

Table 1. Model parameters, central values and ranges.

Parameter	Symbol	Central value	Range	Basis
Room volume	V	30 m^3	20–60	Reference room
Floor area	A	12 m^2	8–25	Reference room
Occupants	n	3	1–6	Reference room
Air exchange rate	ACH	1.0 h^{-1}	0.3–3.0	Typical building stock
Single-plant CADR	CADRp	0.023 $m^3\ h^{-1}$	0.010–0.060	Cummings and Waring (2020)
Plant purchase cost	Cp	USD 15	8–30	Market scan
Plant replacement rate	δ	25% yr^{-1}	10–50%	Assumption
Care time	h	17.3 h yr^{-1}	0–35	20 min week-1
Wage for care	w	USD 1.50 h^{-1}	0–3.00	Assumption
Water and fertiliser	m	USD 3 yr^{-1}	1–6	Assumption
HEPA CADR	CADRh	250 $m^3\ h^{-1}$	100–400	Equipment specification
HEPA capital cost	Ch	USD 250	120–500	Market scan
HEPA life	T	8 yr	5–12	Equipment specification

Parameter	Symbol	Central value	Range	Basis
Filter cost	F	USD 60 yr^{-1}	40–100	Market scan
Fan power	P	45 W	20–80	Equipment specification
Electricity tariff	e	USD 0.12 kWh^{-1}	0.05–0.25	Commercial tariff
Discount rate	r	8%	3–12%	Standard practice
Indoor $PM_{2.5}$	Cin	75 µg m^{-3}	35–120	Yasmin et al. (2024)
$PM_{2.5}$ reduction, HEPA	ηh	60%	40–80%	Well-mixed mass balance
$PM_{2.5}$ reduction, plants	ηp	3%	1–10%	Budaniya and Rai (2022)
Mortality slope	β	0.8% per µg m^{-3}	0.4–1.2%	Burnett et al. (2018)
Baseline adult mortality	m0	0.007 yr^{-1}	0.005–0.010	Assumption
DALYs per death	D	12	8–15	Assumption
GDP per capita	—	USD 2,593	—	World Bank (2024)

3.4 Scenarios

Four scenarios are compared and contrasted. S1 is passive potted plants to provide a CADR equivalent to the outdoor air supply into the room. S2 is a portable HEPA purifier and was tested on a per-unit-of-CADR basis, as it is significantly oversized for this room and such a per-room test would not look negatively on S2. S3 is the same mechanical ventilation at an increased rate of 30 m3 h−1. S4 is an active botanical biofilter, qualitatively evaluated due to lack of standardised cost data, as reported by. Where possible, source control is assumed to be the dominant option out of the three engineered options and is not costed as a separate option.

3.5 Sensitivity and uncertainty

A one-way sensitivity analysis is conducted on the most sensitive parameters: per-plant CADR, opportunity cost of care labour, plant purchase price, PM2.5 reduction due to plants, mortality slope, indoor concentration and capital cost of HEPA. In addition, a combined best case is calculated where the plants are priced at USD 8, opportunity cost is zero, the plants provide 0.060 m^3 h^{-1} each, and 10% of PM2.5 is removed from indoors, to counteract the criticism that the headline results are "pessimistic" in their assumptions.

There are intentional restrictions on the approach. It is a steady-state, one-zone analysis without any spatial gradients, intermittent operation or substrate saturation/re-emission. It only monetises health benefits associated with death; morbidity and productivity/cognitive benefits are also important but are not monetised in this approach and are examined independently , and it does not monetise amenity value of vegetation which is addressed separately as it is the most robust defensible argument for indoor plants. The figures for cost are indicative of the market and not audited procurement prices, which impacts the level of the estimates but would not affect the orders of magnitude comparison that underpins the conclusions.

4. RESULTS

4.1 The physical scale of plant-based clean air

With the median single plant CADR of 0.023 m^3 h^{-1}, 109.7 plants per square metre are needed to match the 30 m^3 h^{-1} supplied to the reference room by one air change per hour. The figure is within the range of plants per m² (10–1,000) reported by Cummings and Waring (2020) and is arrived at by arithmetic and not horticultural assumption! It is also impractical up front: a 12 m^2 room will not fit 1304 pots in a room, and the irrigation, lighting and humidity needs associated with this density will change the function of the room.

Table 2 is a scaling of the result. For a 1,000 m^2 office floor, the amount of plants would be around 108,700 plants (USD 15 per plant) which would cost USD 1.63 million to install and USD 3.55 million per year to operate, of which the majority will be the labour associated with the care. The reference room, per occupant, represents USD 14,217 of annual plant cost for air cleaning, versus USD 50 for the HEPA comparator. The purchasing demand represents the number of plants required to be alive to produce a desired volumetric flow equal to that vented by the room; more efficient pots cannot close the gap.

Table 2: Physical and cost scale-up of plant-based air cleaning.

Scale	Plants required	Plants per m^2	Installed cost (USD)	Annual cost (USD)
Reference room (12 m^2, 30 m^3)	1,304	108.7	19,565	42,652

Scale	Plants required	Plants per m^2	Installed cost (USD)	Annual cost (USD)
Apartment (75 m^2)	8,152	108.7	122,280	266,575
Office floor (1,000 m^2)	108,696	108.7	1,630,440	3,554,359

4.2 Levelised cost of clean air

A common way to express these costs is shown in Table 3. The cost of clean air from potted plants is levelised at USD 0.162/m3 or approximately USD 162000/Mm3. Portable HEPA Filtration costs USD 0.0000689 per cubic metre (USD 69 per million cubic metres) for the same service, and USD 0.00052 (USD 520 per million) for incremental mechanical ventilation. The cost of plants per $m^3\ h^{-1}$ of clean air per year is USD 1,422 per unit of capacity, compared with USD 0.60 per unit of capacity for the filtration and USD 4.56 per unit of capacity for the ventilation.

The ratios are relatively insensitive to reasonable parameter uncertainty: plant-based clean air is ~2,357 times more costly per unit delivered than filtered clean air and ~312 times more costly than ventilated clean air. Fig. 2 shows a summary of the comparison, on a logarithmic scale. The lower the air exchange rate in the room, the higher plant density needed, and it is very sensitive to per plant performance as can be seen in Fig. 1, even at the high end of the range studied in this paper (0.060 $m^3\ h^{-1}$), a room at 1 air change per hour still needs about 42 plants per square metre.

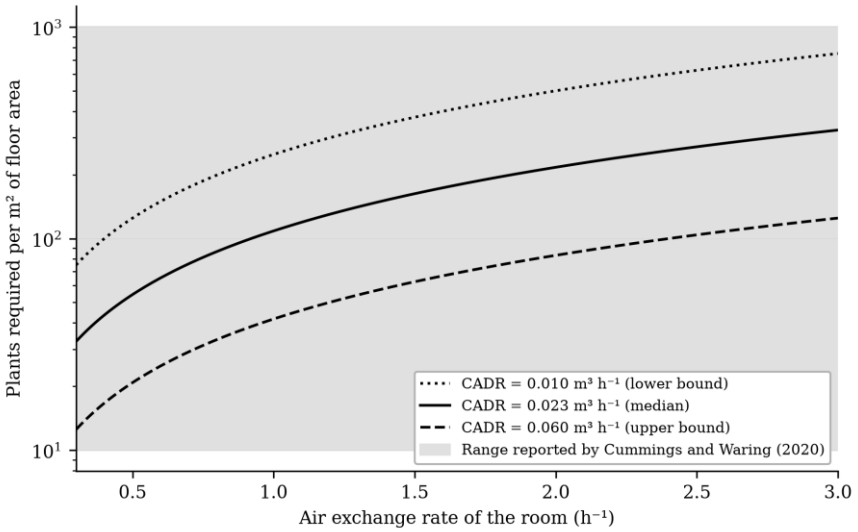


Fig. 1: Plant density required to match a room's air exchange rate for low (0.010 $m^3\ h^{-1}$), median (0.023 $m^3\ h^{-1}$) and high (0.060 $m^3\ h^{-1}$) per-plant clean air delivery rates. The shaded band is the 10-1000 plants per m^2 range reported by Cummings and Waring (2020). Note the logarithmic ordinate.

Table 3: Cost and cost-effectiveness of alternative indoor air interventions.

Metric	Potted plants (S1)	HEPA filtration (S2)	Mechanical ventilation (S3)
Annualised cost (USD yr^{-1})	42,652	151	137
Clean air delivered ($m^3\ h^{-1}$)	30	250	30
Cost per unit capacity (USD per $m^3\ h^{-1}\ yr^{-1}$)	1,422	0.60	4.56
Levelised cost (USD per m^3)	0.162	0.0000689	0.00052
Levelised cost (USD per million m^3)	162,299	69	520
Reduction in indoor $PM_{2.5}$ (µg m^{-3})	2.25	45.0	not applicable
Avoided DALYs per year	0.00454	0.0907	not applicable
Cost per DALY (USD)	9,403,037	1,662	not applicable
Multiple of GDP per capita per DALY	3,627	0.64	not applicable
Cost relative to HEPA (per unit clean air)	2,357	1	7.6

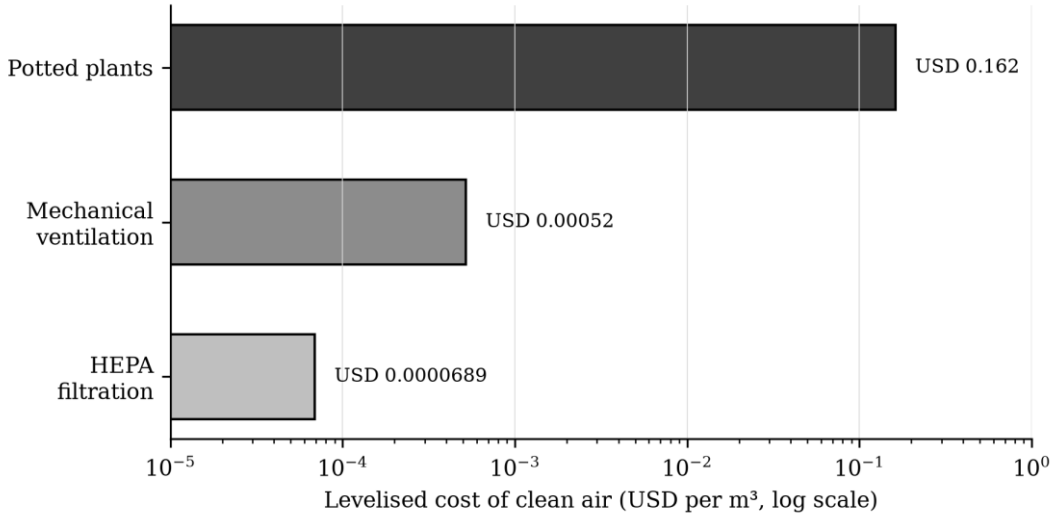


Fig. 2. Levelised cost of clean air (USD per m^3) for potted plants, mechanical ventilation and portable HEPA filtration, plotted on a logarithmic scale.

4.3 Break-even performance

The break-even calculation helps identify the per-plant CADR at which plants would match the filtration cost. If full costs were charged, a potted plant would have to produce 54.2 $m^3 h^{-1}$, about 2,357 times the median measured value. The threshold is 4.0 $m^3 h^{-1}$, 172 times the median, when only purchase price is used and the plant life is assumed to be 5 years without maintenance; and 0.0 $m^3 h^{-1}$, 0 times the median, if care labour is assumed to have no opportunity cost. To match the cost of clean air from a purpose-built plant, a potted plant then would need the ability of a small portable air cleaner.

It is an economic statement of a physical constraint. The few tenths of a square metre of leaf area per plant coupled with the metres per hour deposition velocities for VOCs and fine particles means that the CADR is necessarily small. There is no reasonable way of reducing the price of a pot and reducing the valuation of unpaid housework by two or three orders of magnitude.

4.4 Health-economic results

The health-economic translation is also given in Table 3. A HEPA unit supplying 250 m3 h−1 to the reference room reduces the steady-state concentration by 60% (45 µg m−3) and saves an estimated 0.0907 DALYs per year for three occupants, at USD 1662 per DALY. This is about 0.64 times the GDP per capita of Bangladesh, well within the range considered to be highly cost-effective, and of the same order of magnitude as reported benefit–cost ratios from residential filtration ranging from ~4 to ~130.

Passive plants was assumed to reduce PM2.5 by 3% inside the room as there was evidence that plant leaves and substrate are not able to remove particles effectively in rooms with occupants . The corresponding reduction, 2.25 µg m−3, will avert 0.00454 DALYs per .year at USD 9.40 million per DALY, or some 3,627 times GDP per capita and 5,657 times the cost of filtration. Granting plants the credit for the much greater VOC reductions that some chamber studies report does not materially improve the comparison, as there is no change in cost per unit of clean air; plants provide the same volumetric flow at 2,357 times the unit cost of filtering.

4.5 Sensitivity

The one-way sensitivity is given in Table 4. The plant-to-filtration cost per DALY varies between 1,168 with care labour free and 16,969 with a 1% reduction in indoor PM2.5 by the plants. A change in the mortality slope or in an indoor concentration change will affect both technologies' absolute cost-effectiveness proportionally, and hence their ratio will not change, but will be important for filtration: at a mortality slope of 0.4% per µg m−3, filtration costs USD 3,325 per DALY and is no longer clearly cost-effective by the GDP-based threshold, while at 1.2% it costs USD 1,108.

The combined best case (USD 8 plants), which results in 0.060 m3 h−1 per plant and 10% reduction in indoor PM2.5, shows USD 165,344 per DALY or 64 times GDP per capita. That's not to say the conclusion is an artefact of any one pessimistic assumption, because even under assumptions all at the most generous end of published evidence, plant-based air cleaning remains two orders of magnitude more expensive than the conventional alternative.

Table 4: One-way sensitivity of plant-based cost-effectiveness.

Parameter varied (range)	Plant cost per DALY (USD)	Ratio to HEPA filtration

Parameter varied (range)	Plant cost per DALY (USD)	Ratio to HEPA filtration
Base case	9,403,037	5,657
Single-plant CADR (0.010–0.060 $m^3 h^{-1}$)	21,626,984–3,604,497	13,010–2,168
Wage for care (USD 0–3 h^{-1})	1,940,994–16,865,079	1,168–10,145
Plant price (USD 8–30)	8,899,816–10,481,366	5,354–6,305
$PM_{2.5}$ removal by plants (1–10%)	28,209,110–2,820,911	16,969–1,697
Mortality slope (0.4–1.2% per µg m^{-3})	18,806,073–6,268,691	5,657
Indoor $PM_{2.5}$ (40–120 µg m^{-3})	17,630,694–5,876,898	5,657
HEPA capital cost (USD 120–500)	9,403,037	6,654–4,390
Combined best case	165,344	99

4.6 Conditions under which plant-based systems could be justified

Three qualifications emerge. First, engineered botanical biofilters are a different technology: single-pass removal efficiencies and throughput on a per unit of CADR basis should be compared to mechanical filters. Their ability to compete is dependent on the capital cost per unit of airflow, and on fan energy which is not standardized in the literature.

Second, plants can be rational, if the goal is localised protection in the vicinity of a point source, e.g. printer alcove, newly installed furniture etc. and the alternative is no action. Still, the cost of the decrease in exposure per unit is substantial compared to sealing the source.

Third, and most importantly, the case for 'indoor vegetation' is based on benefits, which this model does not appreciate: aesthetic amenity, perceived restoration, and psychological effects, which have been documented, albeit inconsistently, in experimental studies. Such benefits do exist, but they do not represent the benefits of pollution control; they represent interior design benefits, and the mixture results in the misallocation mentioned above.

5. DISCUSSION

5.1 Why the economics are so unfavourable

The results are not dependent on the price of the plants, but on the ratio of the clean air a plant can process to the clean air required in the room. A potted plant is a low-cost object with very small volumetric flow; a purifier is a moderate-cost object with large volumetric flow. Such a comparison will be dominated by the denominator, which is fixed by leaf area, deposition velocity and stomatal conductance, and not by the markets.

This gives rise to a corollary which is overlooked in less formal comparisons. But lowering the price, or even giving it away, does not lower the cost of plant removal for the achieved clean air; if the plant-based removal process is free, then the annual cost per unit clean air is roughly the same as that of filtration, and this is without additional costs of equipment replacement and watering; if the plant is hypothetical and lives forever, then the annual labour cost for watering remains. Doubling the purifier capital cost, on the other hand (mid-cost sensitivity) brings the ratio down to 5,078, while quadrupling the capital cost (high-cost sensitivity) only lowers the ratio to 4,390.

Another cost, which would reinforce the conclusion, is not included in the analysis: the cost of floor area. When plants are used for purification, the opportunity cost of the use of the floor space (108.7 plants/m²) is more important than the cost of the plants.

5.2 Relation to the existing literature

The results agree with the findings of the physical analysis of Cummings and Waring (2020), which demonstrated that the clean air flow offered by potted plants is 2 to 4 orders of magnitude lower than that of standard ventilation systems, and can now also be considered an economic analysis. They also align with more conservative interpretations of the phytoremediation literature, which considers the practical utility of plant-based purification as a matter that has yet to be definitively settled, as well as engineering literature that makes a distinction between passive pots and actively ventilated botanical biofilters.

They are not as at ease with assessments of indoor plants as an affordable method towards cleaner indoor air. This is in part a semantic issue, in that a plant is relatively cheap compared to a mechanical ventilation system, and it does remove. However, cost-effectiveness is a ratio, not a price, and a calculation in common units turns that result on its head. It is also to some extent methodological, as in many chamber studies, percentage removal is reported for a much longer period of time, and is therefore difficult to compare with ventilation or filtration without converting it to volumetric flow.

The field evidence is worthy of a separate comment. Six plants installed in a classroom showed a significant decrease in CO2 and total VOC levels, according to Pegas et al. (2012), and a significant decrease in VOC levels was observed in an office trial by. Such results cannot be easily reconciled with an arithmetic CADR model unless the removal is due to other factors such as the change in the use of the windows, occupancy/instrument siting, or the rooms had very low air exchange rates and high surface-to-volume ratios. The CO2 result is especially troublesome, as the 2,004 to 1,121 reduction in CO2 concentration in an occupied classroom could not have been caused by six plants, as CO2 is a ventilation tracer and so the reduction would more likely indicate an increase in outdoor air supply. This should not be used to discredit field research, but as an incentive to include air exchange rates and occupancy as well as concentrations in field studies.

The health-economic outcomes are largely in line with the literature on filtration. For purifier interventions targeting indoor PM2.5, Fisk and Chan (2017) find benefit–cost ratios of about 4 to 133 for residential and commercial filtration, respectively, and Zhang et al. (2023) (indicate) costs of the order of CNY 38,000–61,000 per DALY (roughly USD 5,400–8,600). The lower cost per DALY here was derived from a higher assumed concentration (indoor concentration) in a smaller room (with three occupants) and using a marginal formulation (rather than the population-average formulation) and should be read more as an order of magnitude than an exact estimate for Dhaka.

5.3 Policy and market implications

Three implications follow. Firstly, green building certification and corporate sustainability reporting must not consider vegetation in the building as a method of controlling air quality. There is a distinction between biophilic design and the use of plants for indoor environmental quality performance; the latter can be defended on wellbeing merits, the former not; and it provides an incentive to replace engineering with decoration. Where schemes are incentivising the planting indoors, they should also have set standards for ventilation performance (and filtration if applicable).

Secondly, marketing statements that potted plants act as air purifiers should be met the same amount of suspicion as any other removal device. Several jurisdictions already have limits on air-cleaner performance using CADR testing as a standard; expanding this expectation to plant-based products – so that any air purification claim is substantiated with a measured CADR – would remove much of the ambiguity at minimal cost.

Third, for high exposure settings like Dhaka, where indoor concentrations are multiple times the guidelines, and outdoor contribution is high, the priority instruments are source control, filtration, and, when outdoor air is cleaner than indoor air, ventilation. None of these are replaced by plants. If they are used as a 'cheap alternative' they risk driving out interventions that have proven to be effective, e.g., among households with limited budgets, which are most vulnerable to inaccurate information about cheap natural solutions.

5.4 Co-benefits and what they can and cannot justify

Amenity provides the best form of defence for indoor plants, not pollution control. Some experimental evidence is non-trivial: effects on perceived restoration, affect and – in some cases – task performance have been found and are contingent upon density, species, visibility and context (Bringslimark *et al.*, 2009). These are valid design goals, and can be used as a justification for interior landscaping in offices, schools and medical environments.

They can't explain the amount they need for the air cleaning. With the usual density of annual plants as decorative plants of one to five plants per room, the amenity cost is likely to be more than the annual cost of USD 33-164, while the air-quality cost is hardly noticeable. The annual cost for a single room at the required density for the air-quality effect to be measurable is USD 42,652, with an amenity value of the 1304th plant being close to zero. Both of the two objectives are different in scale and need to be addressed separately in policy: plants for amenity, engineering for air.

5.5 Limitations

The model is steady-state and single-zone, thus models do not consider spatial variation, intermittent operation and interactions between plants and local airflow. The assumed 3% reduction in indoor PM2.5 due to plants is a central value around a genuinely uncertain value, for which the sensitivity analysis ranges between 1 and 10%, and at the upper end, the cost per DALY is only USD 2.82 million. Plant performance is assumed to be constant, but it can change with light, temperature, humidity, condition of the substrate and plant health, and it may diminish as sorption sites are filled. The health translation is based on a linear approximation of a non-linear exposure–response function, adult all-cause mortality, and a health valued in DALYs instead of a value of statistical life. A VSL-based approach would increase the monetary gains of both interventions and change the absolute cost-effectiveness of filtration, but not the ratio between the technologies, the key result. Morbidity, productivity and cognitive benefits are not included, which understates filtration benefits relative to the benefits of a plant, as filtration deals with the particle exposures most associated with these benefits. Cost data are indicative market prices, not audited prices, and vary from country to country. The ventilation comparator is climate specific, meaning that the energy penalty would be less in temperate climates and more in very hot climates. Lastly, the technologies are considered separate when in fact a building may have only a small incremental cost of having plants for amenity and filtration for air quality, as the results suggest.

5.6 Research agenda

Three priorities follow. Additionally, results of phytoremediation studies should be reported per plant, per square metre of leaf area, air exchange rate and chamber volume to enable aggregation and comparison to engineered alternatives. Field trials should measure particles, include ventilation and occupancy controls adequate to distinguish plant effects from air exchange effects, and should be designed so as to avoid those effects. One of the only open techno-economic options for a plant-based biofilter is active botanical biofilters, and this should be assessed on a per-unit-of-CADR basis including fan energy, water and media replacement.

6. CONCLUSIONS

This paper examined the ability of indoor plants to cost effectively mitigate air pollution. It uses a clean-air-delivery-rate framework to calculate clean air delivered by the potted plants based on 196 published chamber measurements and finds that the median clean air delivery rate of one potted plant is 0.023 m3 h−1, meaning that more than a thousand potted plants are required to match the ventilation of a small room, or 109 per m2. Given indicative South Asian costs, that stock of supplies is valued at USD 42,652/year for its annual buying, watering and replacement costs, equating to a levelised cost of USD 0.162 per cubic metre of clean air, which is about 2,357 times the cost of the HEPA filters and 312 times the cost of mechanical ventilation. In terms of health, the cost of plant based PM2.5 abatement is approximately USD 9.4 Million per DALY avoided, while portable filtration is approximately USD 1,662 per DALY avoided, below 1 times GDP per capita. Approximately 2,357 times the measured performance would be required to break even with filtration using a potted plant. Even with the best set of assumptions explored, plant-based abatement is still USD 165,344 per DALY, 64 times GDP per capita. The policy conclusion is clear. While the use of plants inside buildings can be a legitimate and useful part of biophilic design and can have modest and context-dependent impacts on perceived wellbeing, it is not a technology for controlling air pollution and the numbers of plants needed to serve that function are physically implausible and economically unsound. Amenity should be separated from engineering and any clean air claims made in green building schemes, corporate sustainability claims and public health messaging should quantitate the clean air delivery rate for any clean air claim and focus on source control, ventilation and filtration – which provide much more clean air per dollar and per unit of floor area.

8. DECLARATIONS

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability

All parameters used in the model are reported in Table 1; the analysis is reproducible from those values and the equations in Section 3. No new empirical data were generated.

Ethics Statement

This study used only aggregated, de-identified publicly available secondary data. No individual-level patient data were accessed. Ethical approval was not required per institutional guidelines for secondary analyses of publicly available aggregate surveillance data.

Author Contributions

Md Oyalid In Sifat: Conceptualisation, Methodology, Formal Analysis, Writing – Original Draft. **Wasif Sadik:** Data Curation, Visualisation, Writing – Review & Editing. **Khadiza Tul Tahira:** Data Curation, Visualisation, Writing – Review & Editing. **Saad Ibna Mannan:** Data Curation, Visualisation, Writing – Review & Editing. **Attick bonik:** Data Curation, Visualisation, Writing – Review & Editing. **Md Abid Ahnaf:** Conceptualisation, Methodology, Formal Analysis, Writing – Original Draft. **Md. Shohag:** Data Curation, Visualisation, Writing – Review & Editing. **Fakhrul Islam:** Data Curation, Visualisation, Writing – Review & Editing. **Md Ariful Islam Sani:** Conceptualization, Data Curation, Methodology, Formal Analysis, Supervision, Writing Original Draft, and Writing - Review & Editing. All authors read and approved the final manuscript. **Ittesum Fardin Sunbeam:** Data Curation, Visualisation, Writing – Review & Editing.

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