

1 **Review on the dispersion of traffic-related air pollutants in urban**
2 **areas: Local mitigation strategies, optimization framework, and**
3 **evaluation theory**

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23 **Abstract:**

24 Outdoor air pollution is a significant global issue because it poses a major long-term
25 health risk. A growing number of studies are conducted to develop local mitigation
26 strategies for improving air quality. This review paper critically evaluates the available
27 literature to provide a better understanding of potential local mitigation strategies and
28 ascertain the methods for reducing local air pollution exposure. For these purposes, the
29 first part of the review is categorized into three groups:

30 (i) improving urban ventilation and turbulence level for pollutant dispersion,

31 (ii) controlling source-receptor pathways by constructing barriers,

32 (iii) capturing and mitigating air pollution by introducing pollutant sinks.

33 Subsequently, a series of studies on optimization frameworks are summarized. It is
34 found that surrogate model-based optimization frameworks efficiently handle multi-

1 objective optimizations at a low computational cost. Finally, this review examines
2 publications on the evaluation theory for pollutant dispersion to determine feasible
3 methods for the removal of pollutants from urban areas. This study is useful for urban
4 planners and architects responsible for decision-making.

5 **Keywords:** Pollutant dispersion; Local mitigation strategy; Optimization framework;
6 Evaluation theory; Urban design.

7

8 **1. Introduction**

9 Outdoor air pollution is a significant global issue because it poses a major long-
10 term health risk to children [1], the elderly [2], and people suffering from respiratory
11 diseases [3]. Outdoor air pollution, a substantial hazard to human health, is responsible
12 for approximately one in every nine deaths each year [4]. In Europe, 0.4 million
13 premature deaths per year are caused by air pollution despite reduced concentrations
14 over the last decades [5]. Thus, outdoor air pollution is of particular concern in the built-
15 up urban environment, where elevated pollutant concentrations and potential sufferers
16 converge [6]; the problem is intensified by rapid global population growth, especially
17 in urban areas [7]. The reason is that air quality will continue to deteriorate as long as
18 energy consumption and traffic emissions are increasing as a result of population
19 growth [8]. In addition to advancements in policy and technology, which are required
20 for curtailing emissions at the source, it is also essential to develop novel solutions and
21 adopt appropriate strategies to manage and reduce outdoor air pollution to minimize the
22 negative impact on public health [9], especially in developed cities. Developed cities
23 have made it a priority to coordinate urban construction with air pollutant dispersion
24 and have attempted to reduce air pollution for several decades with significant progress
25 [10]. Nevertheless, the urban outdoor environment is facing significant challenges due
26 to poor outdoor air quality [11]. It has been reported that the pollutant concentrations
27 still markedly exceed public health standards in many cities [12]. Besides, there is
28 convincing evidence that there is no safe threshold for exposure to air pollution [13,14].

1 Thus, it is crucial to reduce pollutant concentration continuously.

2 In some developed cities, the large-scale redevelopment of urban morphology is
3 very costly due to extremely high land prices [15] and historical and cultural values
4 [16]. Therefore, without sacrificing a substantial amount of usable floor area,
5 alternative solutions, such as implementing local mitigation for reducing air pollution,
6 must be considered by cities facing irreversible urbanization [17–19]. In effect, local
7 mitigation strategies are broadly recognized as one of several promising methods for
8 air pollution reduction. However, to date, no publication has reviewed and described
9 these local mitigation strategies and their implementation for air pollution abatement.
10 To the best of the authors' knowledge, several state-of-the-art reviews have been
11 published in related areas (mitigation of air pollution) in the past decade, focusing on
12 the influence of green infrastructure [20–22], solid and porous barriers [23], urban
13 planning strategies [24–26], reactive pollutants [27], ventilation indices [28],
14 isothermal and non-isothermal flow in street canyons [29], and summaries of
15 computational fluid dynamics (CFD) studies [30–32]. Moreover, Li et al. [33] only
16 reviewed pollutant dispersion in urban areas, with a specific focus on the effects of
17 mechanical factors and urban morphology. Thus, it is difficult for urban designers or
18 practitioners to determine how and where local mitigation strategies can improve air
19 quality with maximum efficiency. Accordingly, this paper provides a review of studies
20 that proposed and applied local mitigation strategies to improve outdoor air quality,
21 filling the research gap. The review focuses on the advantages and limitations of the
22 mitigation strategies, as well as on future perspectives.

23 Improving pollutant dispersion in urban areas is relatively complicated since the
24 pollutant dispersion highly depends on different parameters, including mechanical
25 factors (inflow condition, thermal effects, and vehicular motion) and urban morphology
26 (effects of urban density, heterogeneity, and enclosure degree). These aspects were
27 addressed in our previous review paper [33]. Thus, performing extensive parametric
28 analyses to enhance pollutant dispersion is very difficult. However, most architects or

1 urban designers tend to use passive design methods in urban design based on “trial-
2 and-error” [34], which is very time-consuming and may neglect some important
3 parameters. On the other hand, although many studies have shed light on the critical
4 urban geometry or the governing design parameters for local mitigation strategies for
5 air pollution, they have not guided designers to select the best design parameters,
6 considering local and environmental conditions [35]. Due to the lack of systematized
7 knowledge, it is essential to understand existing approaches that support the design of
8 local mitigation strategies considering the dispersion of traffic-related air pollutants.
9 Moreover, urban design always involves more than one objective, requiring multi-
10 objective optimization for air pollution since all influences and constraints should be
11 considered [34]. Accordingly, there is a strong need for a review of optimization
12 frameworks that are suitable for a broad range of design parameters to determine the
13 optimum parameter for different urban geometry or local mitigation strategies and that
14 are widely applicable for multi-design objectives. Subsequently, it is necessary to
15 review methods for evaluating the improvement in pollutant dispersion. In the past
16 several decades, there has been a growing body of literature evaluating the processes
17 governing pollutant dispersion using urban ventilation indices. This topic was reviewed
18 by Peng et al. [28]. The evaluation indices allow for relating the efficiency of pollutant
19 dispersion to urban morphology, incoming flow conditions, and various mitigation
20 strategies. However, most of the evaluation indices are suitable only for the assessment
21 of the existing situation of pollutant dispersion conditions and cannot be used for
22 creating potential optimization pathways. For instance, the age of air can well reflect
23 existing ventilation conditions [36]. A large age of air indicates a poorly ventilated
24 region; thus, it is easy to detect regions with low air quality using this index. However,
25 this index does not guide urban planners to reduce the pollutant concentration in this
26 region. Thus, it is vital to consolidate our understanding of potential optimization
27 pathways for pollutant dispersion before urban designers and planners alter the urban
28 morphology or implement local mitigation strategies. An improved understanding

1 greatly reduces the cost of “trial and error”. Some evaluation theories were developed
2 to guide the optimization by evaluating urban geometry or local mitigation strategies.
3 Consequently, there is a clear need for a review of these evaluation theories to enable
4 appropriate decision-making.

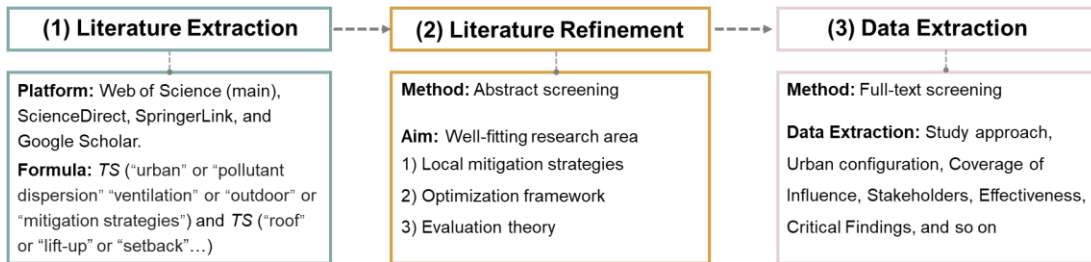
5 Generally, beyond the scope of existing reviews, it is imperative to conduct an
6 exhaustive summary of local mitigation strategies, optimization frameworks, and
7 evaluation theories for pollutant dispersion. First, this article provides information on
8 local mitigation strategies for reducing pollutant concentration in urban areas to answer
9 the following questions. How do the mitigation strategies improve the air quality? What
10 is the potential reduction in pollutant concentration of the mitigation strategies? How
11 can we parameterize the mitigation strategies? Who are the final stakeholders (e.g.,
12 pedestrians walking on the pathways or residents of the surrounding high-rise
13 buildings)? By enumerating these potential mitigation measures and related design
14 parameters or application scenes, urban planners can obtain in-depth knowledge and
15 strong support for future urban designs to implement local mitigation strategies. Second,
16 several optimization frameworks are analyzed to determine the optimum approach to
17 implement and optimize mitigation strategies to reduce outdoor pollutants. With the
18 help of these optimization frameworks, urban planners can significantly improve the
19 efficiency of urban design and reduce the costs of “trial and error”. In addition, the third
20 objective is to review the evaluation theories of pollutant dispersion in an urban
21 environment to ascertain the optimum pathway to improve pollutant dispersion for
22 future urban design.

23 **2. Scope, methods, and outline**

24 This review investigates the local mitigation strategies, optimization framework,
25 and evaluation theories for pollutant dispersion in urban areas. It should be mentioned
26 that this review focuses specifically on the public health benefit of reducing exposure
27 to air pollution produced by vehicles since traffic emissions are the dominant source of
28 urban air pollution [37]. The review does not consider the background concentration

1 due to other sources in the city, such as tall stacks from industrial plants.

2 Moreover, a literature search was conducted on articles published to date in the
3 following internet databases: ScienceDirect, SpringerLink, Web of Science, and Google
4 Scholar. The literature search was performed in early 2021, and articles published until
5 late 2020 were included. The keywords included “urban”, “pollutant dispersion”,
6 “ventilation”, “outdoor”, “mitigation strategies” and all factors mentioned in Sections
7 3- 5. As seen in Fig. 1, we combined all five keywords and each factor one by one for
8 each search of the database (i.e., literature extraction) so that the search covered the
9 following topics: “local mitigation strategies”, “optimization framework”, and
10 “evaluation theory” (i.e., literature refinement). Subsequently, the articles suitable for
11 the review were read thoroughly for data extraction. Only publications in English
12 language journals were included.



13
14 Fig. 1 The flow diagram of this systematic review

15 The review is divided into six sections, including the introduction (Section 1) and
16 the present section. The remainder of this paper is organized as follows, according to
17 the structure of this review in Fig. 2. Section 3 explores local mitigation strategies that
18 have been used as potential solutions for managing and reducing outdoor air pollution
19 in urban areas, including three aspects, i.e., improving ventilation, creating a barrier
20 between traffic emission sources and receptors, and creating a pollutant sink. Section 4
21 presents the various optimization frameworks for improving pollutant dispersion in
22 urban areas, including the general and advanced frameworks. Section 5 gives an
23 overview of the evaluation theory of pollutant dispersion in urban areas, especially for
24 the field synergy theory. Finally, Section 6 summarizes the findings from the review
25 and draws the conclusions.

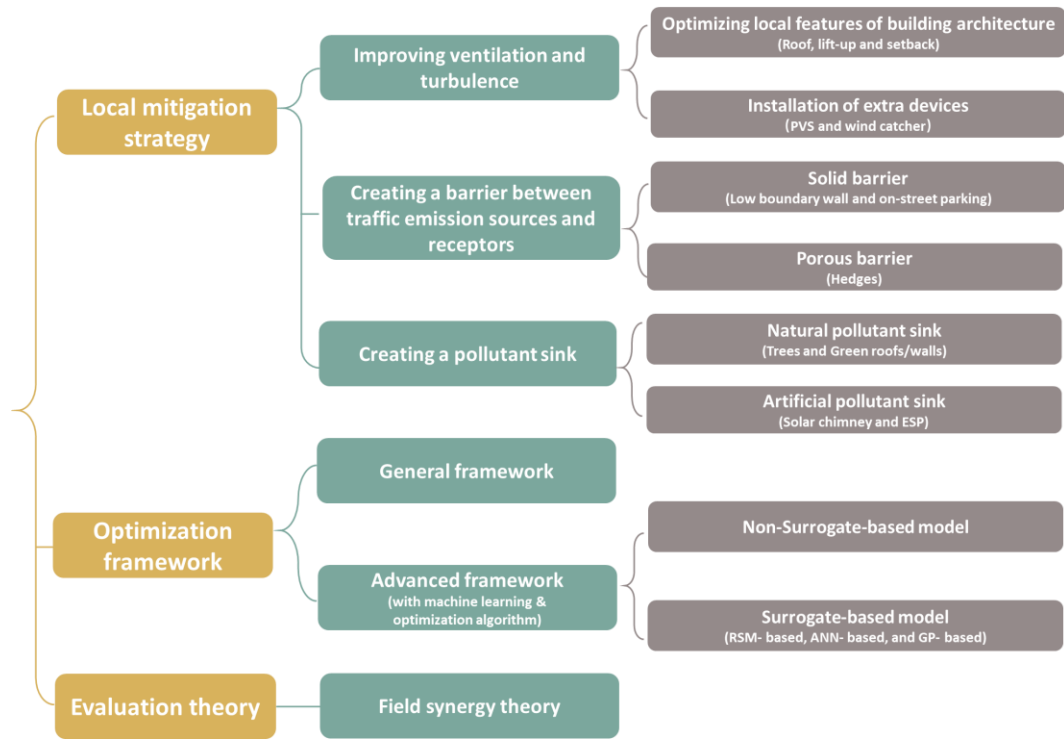


Fig. 2. The structure of this review.

3. Local mitigation strategies to improve air quality

In this section, three approaches of local mitigation strategies are introduced: (i) improving urban ventilation and turbulence level for pollutant dispersion, (ii) controlling source-receptor pathways by constructing barriers, and (iii) capturing and mitigating air pollution by introducing pollutant sink. It should be emphasized that in this section, only the mitigation strategies for reducing air pollution directly at local scales relevant to direct human exposure are summarized and reviewed. The focus is mainly on local-scale improvement of air quality, including the street scale (less than 100–200 m) and the neighborhood scale (up to 1 or 2 km) according to the classification proposed by Britter and Hanna [38].

3.1 Improving ventilation and turbulence

It is well known that poor ventilation and low turbulence levels result in high in-canyon pollutant concentrations [39]. Thus, it is believed that optimizing building geometry (roofs, lift-up design, and arcade design) plays an essential role in improving ventilation and enhancing turbulent flow, decreasing the accumulation of pollutants

1 inside street canyons. Additionally, adding devices (such as pedestrian ventilation
2 systems (PVSs) or wind catchers) to existing buildings can also increase in-canyon air
3 movement.

4 **3.1.1 Optimizing local features of building architecture (Roof, lift-up, and setback)**

5 **Roof design**

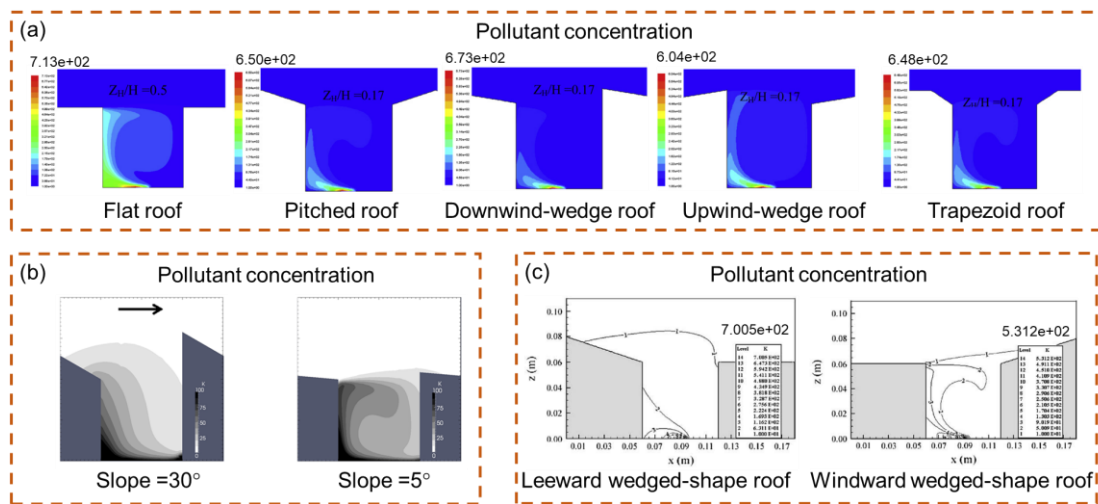
6 Roofs are designed to prevent excessive rain and snow accumulation [40]. Besides,
7 an appropriate roof design is broadly recognized as one of several promising passive
8 control strategies for air pollution. Numerous studies have described the positive effects
9 of an optimized roof design on air quality. For instance, Rafailidis [41] reported that
10 sloped roofs improved the in-canyon natural ventilation and produced more turbulence
11 at the roof level than flat roofs. Subsequently, this phenomenon was confirmed by the
12 wind tunnel experiments of Kellnerova et al. [42]. The possible explanations are related
13 to sloped roofs. First, sloped roofs produce a significant perturbation of the mean flow
14 field behind the roof, enhancing the air exchange [43]. Second, Llaguno-Munitxa et al.
15 [44] found that the larger gradient of wind velocity behind sloped roofs led to a higher
16 potential for turbulence generation compared with flat roofs. Kastner-Klein et al. [45]
17 reported that, in addition to improving streamwise ventilation, pitched roofs also
18 increased the along-canyon velocity components in the entire span of the canyon.
19 Accordingly, Rafailidis [41] concluded that altering the roof geometry might have a
20 larger influence on urban air quality than modifying the canyon aspect ratios.

21 It is worth noting that the influence of roofs is directly related to the roof shape,
22 roof slope (or roof height), and roof configuration (morphological arrangement).
23 Kastner-Klein and Plate [46] compared the influence of a wedge-shaped, pitched, and
24 flat roof in a wind tunnel experiment and observed that the roof shape played a
25 significant role in determining the in-canyon vorticity dynamics and corresponding
26 pollutant transport. Subsequently, Yassin [47] reported that a pitched or trapezoid-
27 shaped roof resulted in significantly higher wind velocity and turbulence levels in the
28 street canyon than a flat roof. Thus, as seen in Fig. 3(a), all four kinds of roofs reduce

1 the pollutant concentration in street canyons compared to a flat roof, especially at the
2 pedestrian level. Furthermore, Llaguno-Munitxa et al. [44] found that round roofs
3 further improved the in-canyon ventilation more than pitched roofs. Interestingly,
4 Huang et al. [48] argued that a change in the roof shape was not directly related to a
5 reduction in pollutant concentration. The concentration reduction was also affected by
6 the roof height of different roof shapes. For instance, at $H_{roof}/H=1/6$, the pollution levels
7 were similar for all roofs; at $H_{roof}/H=1/2$, the round roof had the lowest pollution level,
8 whereas the upwind-wedged roof had the highest pollution level. H_{roof} and H denote the
9 roof height and building height, respectively. Similarly, Takano and Moonen [49]
10 examined the influence of the slope of wedge roofs on pollutant dispersion in a canyon
11 with $H/W = 1$. H is the building height, and W is the street width. The results showed
12 that an increase in the slope of the downwind wedge-shaped roof (up to 30°) improved
13 the ventilation and increased the turbulence level, lowering the pedestrian-level
14 pollutant concentration by up to 34% (Fig. 3(b)). However, an increase in the slope of
15 the upwind wedge roofs improved the in-canyon air quality only when the slope was
16 lower than 18° . At slopes exceeding 18° , the single-vortex flow regime was transformed
17 into a double-vortex regime, resulting in a higher near-ground pollutant concentration.
18 Badas et al. [43] investigated the slope of pitched roofs (ranging from 0 to 40°). The
19 results revealed that increasing the slope of pitched roofs played a key role in enhancing
20 turbulence and ventilation. Thus, the steepest roofs (40°) increased the air change per
21 hour (ACH) at the roof level by almost 200% compared with flat roofs. Huang et al.
22 [50] analyzed the morphology of wedged-shape roofs and pointed out that a wedged-
23 shape roof on the leeward building had much stronger aerodynamic impacts than the
24 same roof geometry on the windward building (Fig. 3(c)). Similarly, Xie et al. [51]
25 studied a combination of pitched and flat roofs. The results showed that most
26 configurations reduced the pedestrian-level pollutant concentrations by approximately
27 38%, and the effect was more pronounced on the leeward side (up to 67%).

28 More information on these studies on roof design, including the study approach

1 (e.g., CFD simulations, field measurement, wind tunnel experiment), urban
 2 configuration (e.g., ideal or realistic street canyon), focus (e.g., the sensitivity parameter
 3 for each local mitigation strategy), the coverage of influence (e.g., only within the street
 4 canyon), and some critical findings, are summarized in Table A.1. In general, the
 5 reviewed studies demonstrate the positive effect of roof design on ventilation and
 6 turbulence within street canyons. Thus, an appropriate roof design enhances the
 7 potential dilution of pollutants, which is beneficial for pedestrians and residents.
 8 However, the scope of influence of roof design is only limited to a small extent (within
 9 the street canyon), as shown in Table A.1. Besides, the roof shapes, roof slope, and roof
 10 configurations should be chosen carefully. The degree of reduction in pollutant
 11 concentration attributed to roof design is greater in a deeper street canyon [52].



12 Fig. 3. (a) Relationship between roof shape and in-canyon pollutant concentration [47];
 13 (b) relationship between roof slope and in-canyon pollutant concentration [49]; (c)
 14 relationship between the morphology of wedged-shape roofs and in-canyon pollutant
 15 concentration [50].

17 Lift-up design

18 The lift-up design of buildings (also known as elevated design or void decks) at
 19 the ground level is frequently used to enhance shading [53]. It creates a semi-open space
 20 underneath high-rise residential buildings as a public space for social activities (leisure
 21 and recreational activities or access routes) [54,55]. The space created by the lift-up

1 design can act as a wind corridor to increase urban wind circulation and mitigate
2 negative health impacts [56,57]. Therefore, the wind speed nearby elevated buildings
3 (removing low-floor building layers) is enhanced [11,58].

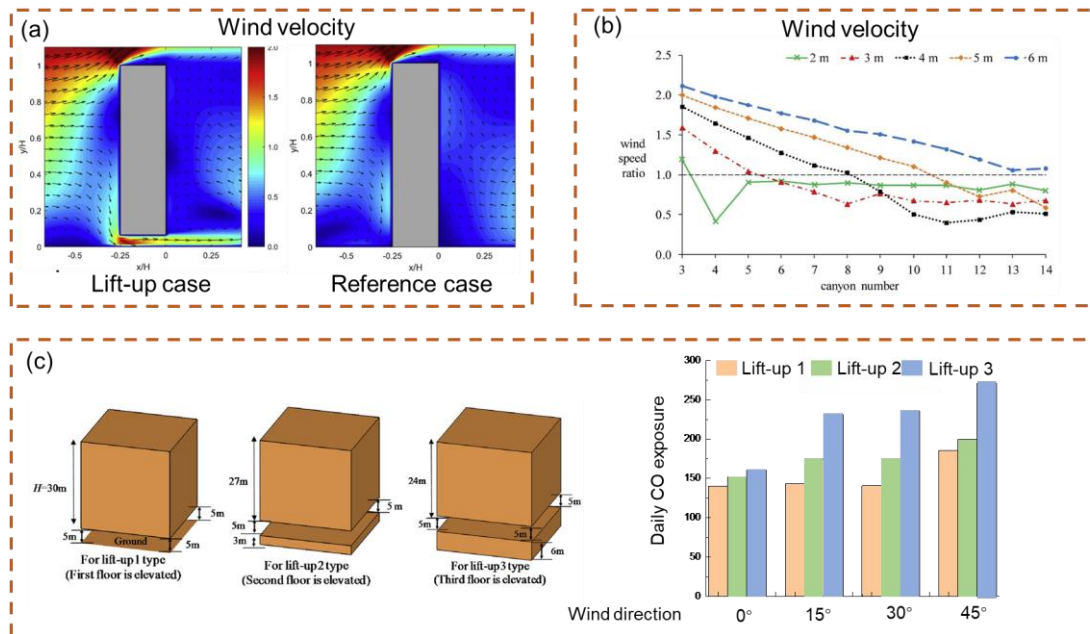
4 The benefits of integrating the lift-up design into existing buildings for improving
5 ventilation conditions have been demonstrated by several studies using a wind tunnel
6 and CFD simulations. For instance, the wind tunnel experiments conducted by Xia et
7 al. [59] demonstrated that the pedestrian-level wind (PLW) ventilation was better for a
8 row of lift-up buildings and the PLW speed was almost 11% higher than that of the non-
9 lift-up buildings. Druenen et al. [60] used CFD simulations and found that the average
10 PLW speed increased (up to 21%), and the lower-speed wake region behind the building
11 was reduced in size (Fig. 4(a)). Du and Mak [15], Due et al. [51], and Huang et al. [62]
12 combined data from a wind tunnel and field measurements from a university campus
13 in Hong Kong and reported that lift-up designs were effective in increasing the wind
14 speed inside and near lift-up areas. These results were supported by prediction data
15 based on lift-up building models with 22 unconventional configurations [63].
16 Furthermore, in different geometries of surrounding buildings and ambient wind speeds,
17 the PLW speed increased by more than two-fold [64] and even five-fold [65].

18 To create a void space (lift-up design), the main building is elevated off the ground
19 by columns, shear walls, center core(s), or a combination of these [35]. The
20 optimization of the dimension or geometry of the lift-up design can significantly
21 increase the PLW speed [55]. Generally, studies have shown a considerable influence
22 of the height, width, locations, and configurations of these columns on ground-level
23 ventilation. Tse et al. [66] concluded that the height and width of columns significantly
24 affected the wind environment at the pedestrian level. Moreover, the column height had
25 a more significant effect than the column width. Also, Du et al. [67] investigated the
26 influence of the width and height of lift-up columns using multi-stage analysis. The
27 results revealed that increasing the column width adversely affected the ventilation at
28 the pedestrian level, whereas the effect of increasing the column height was positive.

1 Under an identical building configuration, the wind speed decreased by 38% as the
2 column width increased from 1 to 4 m. In contrast, increasing the column height column
3 from 4 to 8 m only resulted in a nearly 13% increase in wind speed. Similarly, Chew
4 and Norford [54,68] examined the influence of elevated height in a building array with
5 6-15 streets. The results confirmed that the wind speed increased with an increase in
6 the elevated height. A 2 m height was insufficient to sustain relatively high channeling
7 wind in the approaching wind direction. Increasing the height to 3 m increased the PLW
8 speed by about 25%. However, the improvement was negligible when the elevated
9 height exceeded 4 m (Fig. 4(b)). The influence of the position of the lift-up design was
10 studied by Sha et al. [69]. The results indicated that the first-floor lift-up design was
11 more effective than the second- or third-floor lift-up design. The first-floor lift-up
12 design resulted in a 34–50% reduction in the building intake fraction and daily pollutant
13 exposure, whereas the third-floor lift-up design only yielded a 6%– 25% reduction (Fig.
14 4(c)).

15 More information on these studies on the lift-up design is provided in Table A.2.
16 Although the lift-up design can enhance the wind speed in the upstream area of the
17 target building [70], Liu et al. [58] pointed out that the effect of wind enhancement
18 might be limited to a finite area around the target building with the lift-up design.
19 Similarly, Chen and Mak [63] reported that the lift-up design significantly improved
20 PLW ventilation in the near field of a building. However, the improvement weakened
21 with the width of the research region. Besides, most previous studies mainly focused
22 on improving pedestrian-level ventilation using the lift-up design. It might be deduced
23 that the main stakeholders should be the pedestrians near the building with a lift-up
24 design. However, if the lift-up design is used in a group of buildings, the pollutant
25 concentration near the building walls can be reduced, which is beneficial to the
26 residents of the surrounding buildings and not only the pedestrians near the road [69].
27 Furthermore, the lift-up design might be a more effective optimization design strategy
28 for very deep canyons or very tall high-rise buildings. As reported by Zhang et al. [71],

1 in an extremely deep canyon ($H/W = 5$), the pedestrian-level pollutant concentrations
 2 decreased by nearly two orders due to the lift-up design.



3
 4 Fig. 4. (a) Contours of the dimensionless velocity magnitude in the vertical cross-
 5 section for the reference case and the lift-up case [60]. (b) The wind speed ratio in
 6 canyons 3–14. The legend indicates the void deck height (H_{vd}). For example, “2 m”
 7 represents the case with $H_{vd} = 2$ m [54,68]. (c) Daily CO exposure for different lift-up
 8 positions and different ambient wind directions [69].

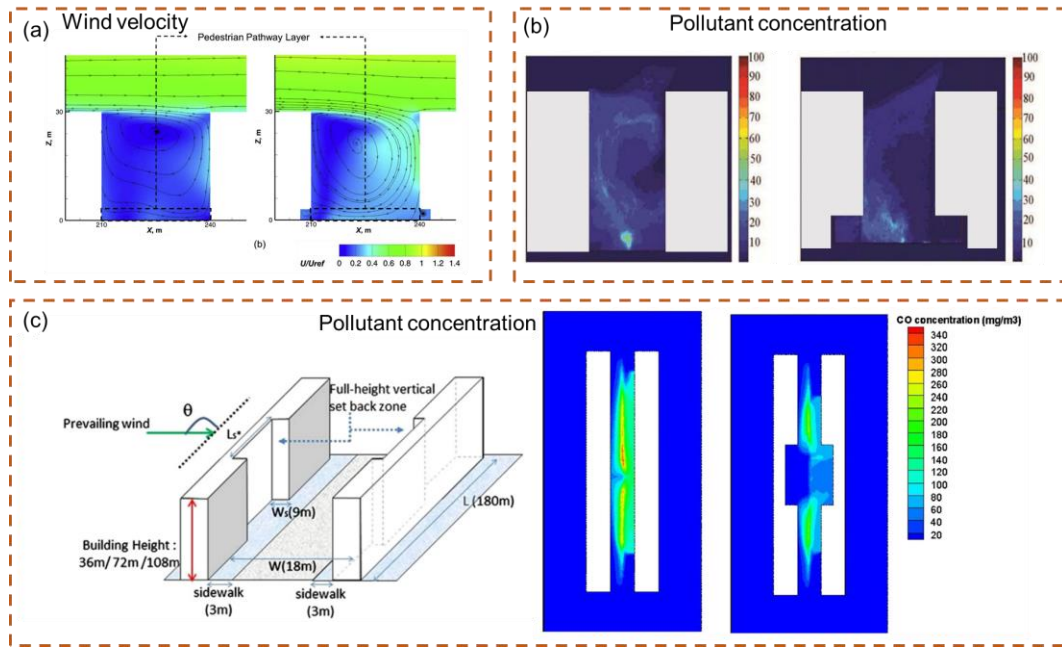
9 Building setback

10 The arcade is a type of building setback that provides a comfortable passage space
 11 for pedestrians, as well as improved ventilation [72]. This design is primarily
 12 implemented as a half-open space by creating an outside corridor on the side of the
 13 main building [35]. Hang et al. [73] demonstrated a direct relationship between the
 14 arcade design and the in-canyon ventilation. Wen et al. [74] found that incorporating an
 15 arcade design into the ideal street canyon arrangements resulted in a 60% increase in
 16 the ACH in the pedestrian pathway layer (PPL) for perpendicular wind since the arcade
 17 design increases the total volumetric airflow rate into the PPL through the windward
 18 and arcade openings (Fig. 5(a)). Interestingly, the ACH in the urban canopy layer (UCL)
 19 was minimally affected by the presence of the arcade because the extent of the UCL

1 was much larger than the arcade space. This finding is consistent with the results of
2 Juan et al. [75], who investigated realistic building models. Accordingly, Huang et al.
3 [76] reported a lower pedestrian-level pollutant concentration when compared with the
4 reference case; the result was attributed to the presence of the arcade (Fig. 5(b)). Lau et
5 al. [77] observed that the building setback ensured sufficient ventilation in the area by
6 creating effective air paths and breezeways in a nearly parallel wind.

7 It is worth noting that the dimensions (height and width) and configurations of the
8 arcade significantly affect the ventilation performance. Wen et al. [74] revealed that
9 increasing the height of the arcade (from 3 to 6 m) led to a nearly 25% reduction in the
10 ACH, whereas increasing the width of the arcade (from 1.5 to 9 m) caused an almost
11 76% increase in the ACH. Ng and Chau [78] reported that, in addition to the typical
12 horizontal building setback (arcade design), the vertical setback also improved the in-
13 canyon air quality by enhancing the vertical dispersion of pollutants in the vertical
14 setback area under a perpendicular wind (Fig. 5(c)). Further, they found that the
15 effectiveness of the vertical or horizontal setback substantially depended on the street
16 canyon height aspect ratio (H/W). The vertical setback was more suitable for canyons
17 with $H/W = 2$ (6% reduction), whereas the horizontal setback was recommended for
18 canyons with $H/W = 4$ (6.5% reduction) and 6 (13% reduction). These values provided
19 the lowest reductions in the personal exposures in the total developed floor area (the
20 total floor area that can be developed at a particular site).

21 More information on these investigations on the building setback design is listed
22 in Table A.3. Generally, building setbacks can be implemented by increasing the
23 distance between the building and the street to increase the airflow at the pedestrian
24 level. Both the horizontal and vertical setbacks improve the air quality of the entire
25 street canyon, thus reducing the pedestrians' and residents' pollutant exposure. Also,
26 the height and width of the arcade should be carefully selected to improve the air quality.
27 Besides, it should be noted that the influence of the building setbacks is limited to a
28 small extent (within the street canyon).



1
 2 Fig. 5. (a) Contours of the dimensionless velocity magnitude in the vertical cross-
 3 section for the reference case and the arcade design [74]. (b) Contours of the pollutant
 4 concentration in the vertical cross-section for the reference case and arcade design [76].
 5 (c) Contours of the pollutant concentration at the pedestrian level for the reference case
 6 and the vertical setback [78].

7 3.1.2 Installation of additional devices (PVS and wind catcher)

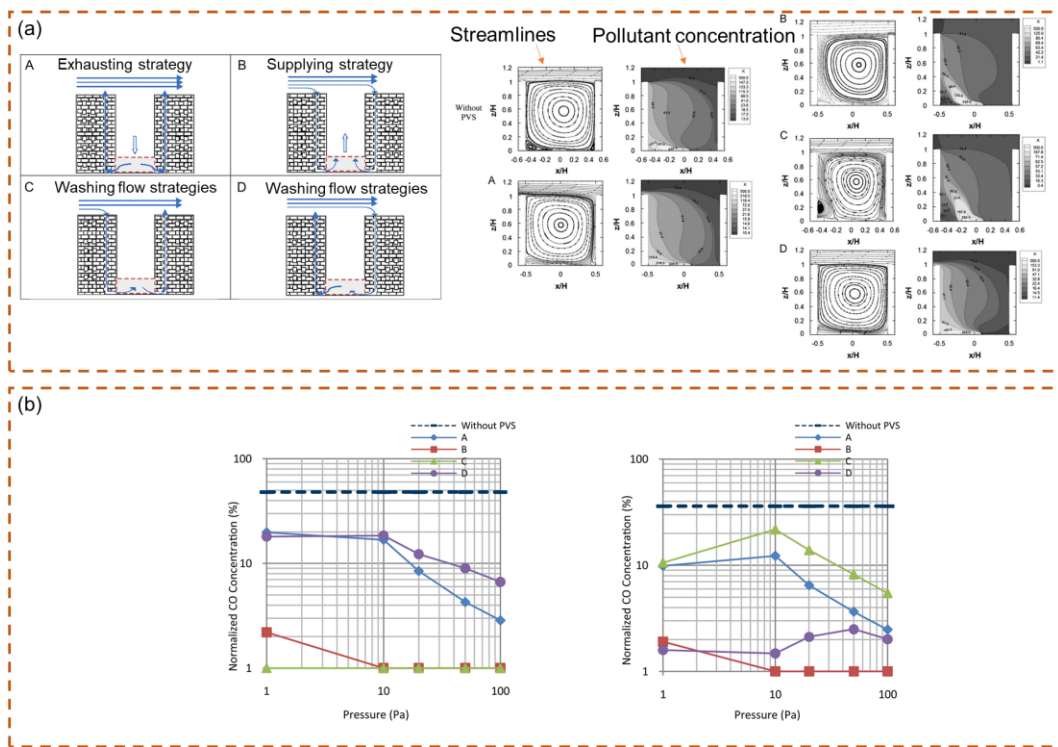
8 Pedestrian Ventilation System (PVS)

9 A PVS was proposed to control the ventilation at the pedestrian level and improve
 10 the air quality in the pedestrian ventilation zone [79]. A vertical duct system was used
 11 to move air from the building roof to the street level [80]. Heating the duct (by solar
 12 radiation) or using an electrical fan represents options to provide the required air
 13 movement.

14 Mirzaei and Haghghat [80,81] tested the effectiveness of several PVSs powered
 15 by an electrical fan, including exhaust strategies, a supply strategy, and washing flow
 16 strategies. The results showed that the pedestrian-level ventilation was improved using
 17 these proposed PVS strategies. Particularly, the supply strategy and exhaust strategy
 18 decreased the pedestrian-level pollutant concentration by up to 75% and 90%,
 19 respectively (Fig. 6(a)). Moreover, the performance of the proposed PVS depended on

1 the fan pressure and ventilation strategy [79]. An increase in fan pressure produced high
 2 air velocity, significantly decreasing the air quality index (AQI) on the sidewalks (Fig.
 3 6(b)).

4 More information on these investigations of PVSs is provided in Table A.4.
 5 Generally, PVSs can be flexibly controlled for removing pollution from pedestrian
 6 sidewalks by controlling the PVS configuration and the fan pressure. In addition to
 7 improving the pedestrian-level air quality, the air quality of the entire street canyon is
 8 also significantly enhanced; thus, pedestrians and residents benefit from PVSs. Besides,
 9 this local mitigation strategy is also limited to the area close to the PVS.



10
 11 Fig. 6. (a) Streamline and normalized concentration contours for different
 12 configurations of pedestrian ventilation systems (PVSs) [80,81]. (b) Normalized CO
 13 concentration at the pedestrian level for various PVS combinations on the left
 14 sidewalk(left plot) and right sidewalk (right plot) for different fan pressures [79].

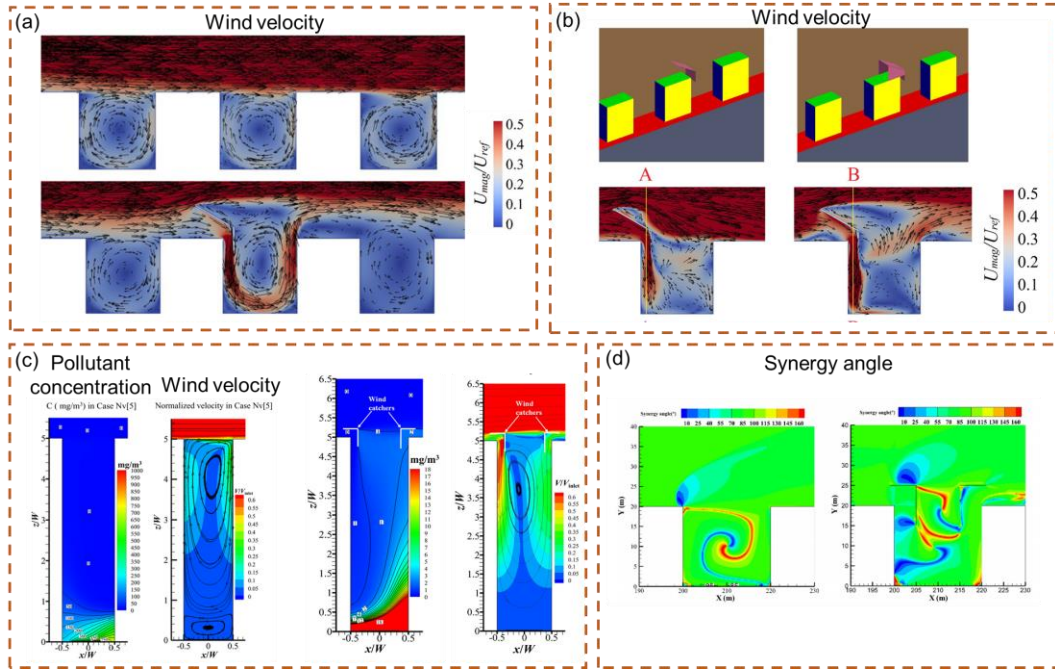
15 Wind catcher

16 Wind catchers are typically used at the indoor/outdoor interface for indoor passive
 17 cooling and natural ventilation; they are prevalent in the Middle East and North Africa.
 18 Chew et al. [82] extended the potential of wind catchers for outdoor ventilation by

1 installing a wind catcher prototype in a water channel experiment. This wind catcher
2 consisted of two rectangular plates. It was installed near the upstream building wall and
3 above the roof over the street. The results showed that the wind catcher enhanced the
4 PLW speed of the target canyon by 2.5 times (Fig. 7(a)). The ambient wind captured by
5 the wind catcher moves through the narrow channel between the top plate and the
6 building roof. The high-speed jet of airflow is directed in a 90-degree turn to the outlet
7 of the wind catcher and flows downwards, boosting the pedestrian-level ventilation.

8 Furthermore, since the sidewalls of the wind catcher prevent span-wise leakage,
9 the high-speed jet captured at the inlet of the wind catcher can travel downward with
10 little momentum loss in the span-wise direction until it reaches the ground (Fig. 7(b))
11 [82]. Zhang et al. [71] evaluated the influence of wind catchers on reducing vehicle
12 pollution in a deep canyon. The results showed that the PLW speed increased by one or
13 two orders because of the wind catchers. Hence, wind catchers resulted in one or two
14 orders of magnitude lower pollutant concentrations in the deep street canyon (Fig. 7(c)).
15 A reduction of in-canyon pollutant concentration was also observed by Ming et al. [83].
16 The authors pointed out that the presence of a wind catcher at the roof level significantly
17 enhanced the synergy of pollutant dispersion and airflow within the street canyon area,
18 thus improving the dilution of pollutants (Fig. 7(d)).

19 More information on these studies on wind catchers is listed in Table A.5.
20 Generally, a wind catcher improves the ventilation in the entire street canyon, thus
21 improving the pedestrians' and residents' air quality. The effectiveness of wind catcher
22 can be further improved by altering its position and structure. It is noteworthy that most
23 of these studies used only 2D or quasi-3D simulations. Hence, an engineering analysis
24 of wind catchers is necessary to design wind catchers that adapt to the wind direction
25 and complex urban structures. Also, as summarized in Table A.5, the influence of wind
26 catchers is limited to the street canyon. It was reported by Chew et al. [82] that a wind
27 catcher caused a slight velocity decrease in the immediate downstream area of the
28 canyon.



1

2 Fig. 7. (a) Comparison of normalized velocity magnitude contours and vectors for the
 3 reference case and the wind catcher case [82]. (b) Comparison of normalized velocity
 4 magnitude contours and vectors for the reference case with a wind catcher and a wind
 5 catcher with sidewalls [82]. (c) Comparison of normalized wind velocity and CO
 6 concentration for the reference case and the wind catcher case [71]. (d) Comparison of
 7 synergy angles for the reference case and the wind catcher case [83]

8 3.2 Creating a barrier between traffic emission sources and receptors

9 Pedestrians are typically most affected by traffic emissions due to the short
 10 distance between the source and receptor and minimal mixing. A passive control
 11 strategy that considers the source-receptor distance has been proposed as a viable option.
 12 In a long pathway, the air pollutants can be significantly diluted by mixing with clean
 13 air. Barriers can serve as potentially low-cost options to improve the roadside air quality,
 14 including solid barriers (low boundary walls (LBWs) and on-street parking) and porous
 15 barriers (hedges).

16 3.2.1 Solid barriers (low boundary walls and on-street parking)

17 Low boundary walls/noise barriers

18 The effectiveness of solid barriers on flow patterns and pollutant dilution has been
 19 widely researched, including the use of noise barriers (over 4–5 m tall) along highways

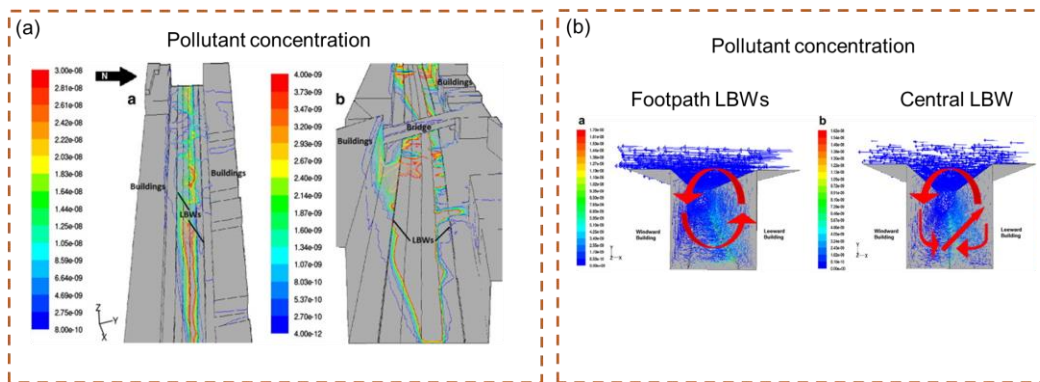
1 [84–86] and LBWs (1–2 m or less in height) [87–89] adjacent to low-speed roadways
2 in urban areas. In general, these studies revealed that solid roadside barriers could act
3 as baffle plates, redirecting the flow and affecting the pollutant dispersion at the street
4 level [90]. Moreover, solid barriers induce significant vertical mixing and shift the
5 plume upward due to an induced updraft motion [91]. Accordingly, traffic emissions
6 must pass over the solid barriers, where the airflow is being directed toward the footpath,
7 substantially increasing pollutant dispersion before the pollutant reaches the footpath
8 [92].

9 McNabola [92] obtained field measurements in a typical street canyon in Ireland
10 and demonstrated the ability of LBWs to influence pollutant dispersion. The presence
11 of LBWs, which were located between the road and footpath, resulted in a 1.7–2.0 times
12 reduction in the volatile organic compound (VOC) concentrations on the footpath
13 behind the LBWs. On-site monitoring and numerical modeling indicated that the LBWs
14 reduced the pollutant exposure of pedestrians walking on sidewalks by up to 40% and
15 75% under perpendicular and parallel wind conditions, respectively, by a combined
16 study of the on-site monitoring and numerical modeling [93–95]. Gallagher et al. [96]
17 provided an understanding of the impacts of LBWs in real-world settings. Their results
18 showed a 1%–35% pollutant reduction resulting from LBWs under varying ambient
19 wind directions and traffic conditions (Fig. 8(a)).

20 It is worth noting that the height and location of LBWs and the street canyon
21 geometry significantly influenced the air quality. King et al. [93] observed that an
22 increase in the height of the LBWs (1 to 2 m) caused a significant concentration
23 reduction (by almost 50%). On the other hand, McNabola et al. [95] revealed that central
24 LBWs were more suitable for wind perpendicular to the street, whereas footpath LBWs
25 provided better air quality for a parallel wind. Also, Gallagher et al. [87] confirmed that
26 central LBWs caused a more significant reduction in the in-canyon pollutant
27 concentration than footpath LBWs (Fig. 8(b)). The authors reported that the street
28 canyon geometry influenced the effectiveness of LBWs on pollutant concentrations.

1 The presence of LBWs resulted in a decrease (up to 30%) or increase (up to 19%) in
2 the leeward pollutant exposure on the footpath for different building height ratios of
3 street canyons.

4 Interestingly, Jeanjean et al. [97] observed that the usage of LBWs caused opposite
5 trends of pollutant concentrations at the pedestrian level on the footpath and in the
6 center zone of traffic lanes. They examined the effectiveness of a solid barrier in Oxford
7 Street, London, considering local wind conditions, and found a 23.8% increase in NO₂
8 concentration in the road zone and a 2.3% reduction in NO₂ concentration on the
9 footpath. Accordingly, it was concluded that the LBWs had a positive effect on the
10 pedestrians but an adverse effect on cyclists or drivers on the roads. Therefore, it should
11 be determined if pedestrians or drivers are the priority before installing LBWs. More
12 information on these studies on LBWs is listed in Table A.6. Although optimizing the
13 height or location of LBWs can improve the air quality at the pedestrian level,
14 especially close to the LBWs, these structures appear not to improve the air quality of
15 residents.



16
17 Fig. 8. (a) Plots of pollutant concentrations in a street canyon with an LBW [96] and
18 (b) plots of pollutant concentrations in street canyons with footpath LBWs and a
19 central LBW [87]

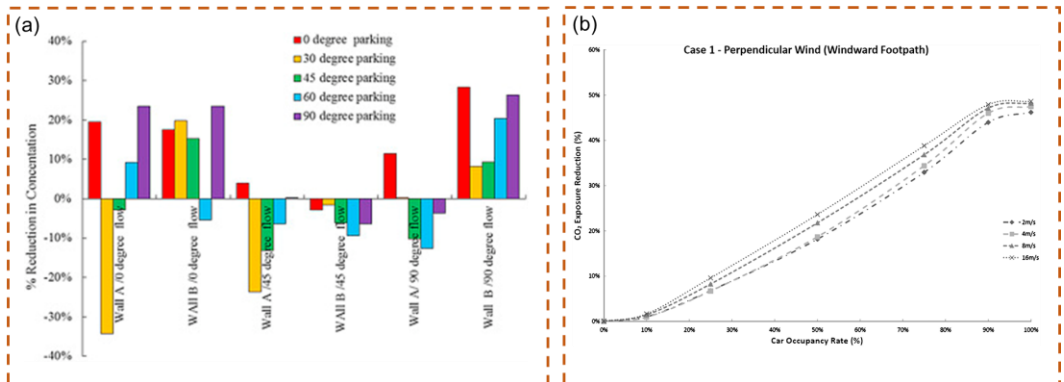
20 Car parking system

21 Parked cars have also been used as obstacles to protect pedestrians from traffic
22 pollutants. Under varying wind conditions and urban geometries, the presence of
23 parked cars led to a nearly 15% to 49% reduction in roadside pollutant concentrations

1 [96,98,99]. The reason is that parked cars extend the pathway of pollutants emitted at
 2 the road level. Thus, the pollutants have to travel a longer distance, around, over, or
 3 under the body of cars, minimizing dispersion [99].

4 The effectiveness of car parking systems depends on the parking configuration and
 5 parking space occupancy. For instance, Gallagher et al. [99] found that parallel parking
 6 (parked cars are parallel to the street) was the most effective method to reduce the
 7 pedestrian-level pollutant concentration. The likely reason is the relatively small space
 8 between the cars. Thus, fewer pollutants can penetrate the footpath through these small
 9 channels and reach the sidewalks. Abhijith and Gokhale [98] found that oblique parking
 10 (30°–60°) resulted in an increase in roadside pollutant exposure of up to 34.3%
 11 compared with parallel parking (Fig. 9(a)). On the other hand, Gallagher et al. [99]
 12 stated that high occupancy rates significantly reduced the pollutant concentration. A
 13 curvilinear pattern of concentration reduction was observed for a parking space
 14 occupancy range of 10% to 90% (Fig. 9(b)).

15 It should be mentioned that on-street car parking systems represent a temporary
 16 barrier to the dispersion of air pollutants, operating in much the same manner as an
 17 LBW. More information on car parking systems has been summarized in Table A.7. Car
 18 parking systems have almost the same scope of influence (pathways of the street canyon)
 19 and final stakeholders (pedestrians) as LBWs. An on-street car parking system at full
 20 capacity can lead to significant reductions in pollutant exposure on the footpath. Its
 21 effectiveness is similar to that of LBWs. However, the effectiveness decreases
 22 substantially with a decrease in the number of parked cars.



23

1 Fig. 9. (a) Percentage reduction in pollutant concentration for various car parking
2 scenarios [98] and (b) plot of the average windward pollutant concentration on the
3 footpath versus the occupancy rate under perpendicular wind conditions [99].

4 **3.2.2 Porous barriers (Hedges)**

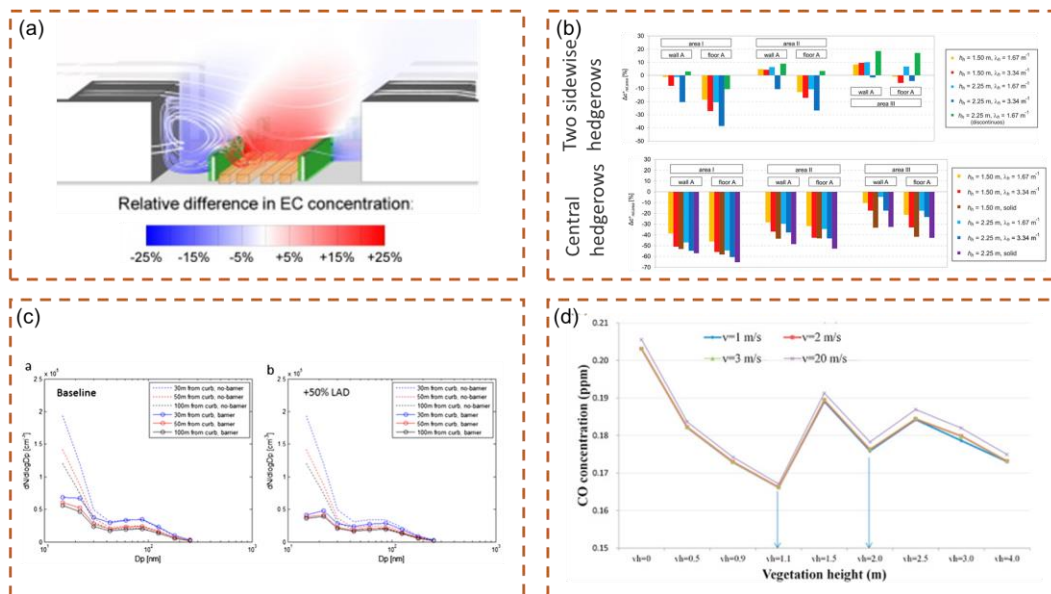
5 **Hedges**

6 The leaf area density (LAD) of hedges (low-level vegetation with a continuous
7 leaf covering from the ground to the top) is relatively high. The hedges can be utilized
8 as a roadside barrier, limiting the exposure of pedestrians to air pollution [100]. The
9 dispersion patterns of pollutants are altered by the hedges similarly to solid barriers.
10 Vos et al. [101] reported that the positive influences of hedges on local air quality could
11 be mainly attributed to the aerodynamic effect rather than the filtering capacity (Fig.
12 10(a)). Hence, hedges create a sheltered area of relatively fresh air just behind the
13 barrier (i.e., within the first few meters, the pavement, sidewalks, and other pedestrian
14 areas adjacent to traffic), where most of the polluted air is found [90]. Although a
15 reduced wind speed was observed in street canyons due to the presence of hedges, the
16 pollutant level was reduced by 24– 61% [13–15].

17 Porous barriers can substantially improve pedestrian-side air quality, but the
18 critical parameters of hedges should be considered, i.e., the density (or, inversely, the
19 porosity) and the dimension (height and thickness) [100]. First, Gromke et al. [90]
20 observed higher reductions in pollutant concentrations for one central hedgerow than
21 two parallel hedgerows (Fig. 10(b)). Second, vegetation barriers are not solid but allow
22 some airflow. Accordingly, Kumar et al. [103] recommended that the thickness of
23 hedges should exceed 1.5 m. Besides, according to field measurements obtained by
24 Abhijith and Kumar [104] and CFD simulations reported by Tong et al. [105], pollutant
25 concentrations in the sheltered areas of hedges generally decreased with an increase in
26 LAD (Fig. 10(c)). Research has suggested an optimal LAD range of 1 to 5 m²/m³,
27 depending on the urban geometry and the pollutant type [91,106,107]. Moreover, a
28 larger reduction in the pollutant concentration behind the hedges was generally

1 observed with higher and thicker hedges [90]. However, it should be mentioned that the
 2 effects of highly porous barriers in street canyons are variable and depend on local
 3 conditions, especially for the H/W . In a shallow street canyon ($H/W < 0.5$), it was found
 4 that 2 m was an appropriate height for hedges [103]. However, Li et al. [108] suggested
 5 an optimal height of 1.1 m for a relatively deep canyon ($H/W > 0.5$), as shown in Fig.
 6 10(d). Vegetation barriers are more effective in open-road environments (including
 7 roads with buildings on only one side) than in street canyons due in part to the influence
 8 of complex street canyon geometry on airflows [20]. A relatively tall hedge occupying
 9 a sufficiently large area is required to offer adequate protection, e.g., for children in a
 10 school playground.

11 More information on hedges is listed in Table A.8. Similar to solid barriers, porous
 12 barriers (hedges) only improve pedestrian-level air quality immediately behind the
 13 barrier. Moreover, the parameters of the hedges, including the position and the
 14 geometry (thickness and height), should be carefully chosen.



15
 16 Fig. 10. (a) The relative difference in pollutant concentration for a 4 m high green
 17 barrier compared to the reference case without vegetation [101]; (b) area-averaged
 18 differences in pollutant concentrations for street canyons with two-sided and central
 19 hedgerows [90]; (c) particle size distribution with increasing LAD [105]; (d) the
 20 pollutant concentrations for vegetation barriers with different heights under different

1 wind conditions (v_h denotes the vegetation height) [108].

2 **3.3 Creating a pollutant sink**

3 The above methods can disperse air pollutants and reduce peak concentrations of
4 harmful substances. However, the pollutants are not captured or treated to mitigate air
5 pollution in urban areas. Mitigation can be achieved by creating pollutant sinks,
6 including natural and artificial pollutant sinks.

7 **3.3.1 Natural pollutant sinks (trees and green roofs/walls)**

8 **Trees**

9 It should be noted that trees are generally regarded as the best mitigation method
10 of pollutants regarding health outcomes. Accordingly, the public perception is that trees
11 are effective natural pollutant sinks. However, the mitigation potential of trees is two-
12 sided. Generally, trees interact with air pollutants by deposition (the deposition of
13 gaseous and particulate matters (PMs) onto leaf surfaces) [109] and dispersion (the
14 transport of pollutants by wind from the source and the dilution with cleaner
15 surrounding air) [110]. The large and waxy leaf surface of trees facilitates the deposition,
16 interception, and accumulation of pollutant particles [111], and various gaseous
17 pollutants are absorbed through the stomata [21]. Therefore, trees typically improve air
18 quality [21]. However, trees can also increase the flow resistance in street canyons,
19 slowing down the air circulation and hindering the air exchange [112]. The combined
20 effects of these two processes (deposition and dispersion) are manifold and context-
21 dependent [113,114]. Thus, in-situ field measurements, wind tunnel tests, and CFD
22 simulations have failed to demonstrate conclusively whether trees universally reduce
23 air pollution in all scenarios [20]. Generally, there is no “one size fits all” strategy for
24 planting trees since the effects of trees are highly localized [115]. It is essential to
25 choose suitable tree species adapted to specific conditions.

26 Many cities have city-level plans for increasing the number of urban trees to
27 reduce air pollution [116], a strategy that is supported by field measurements and model
28 studies. Freiman et al. [117] found that ambient PM concentrations were lower in

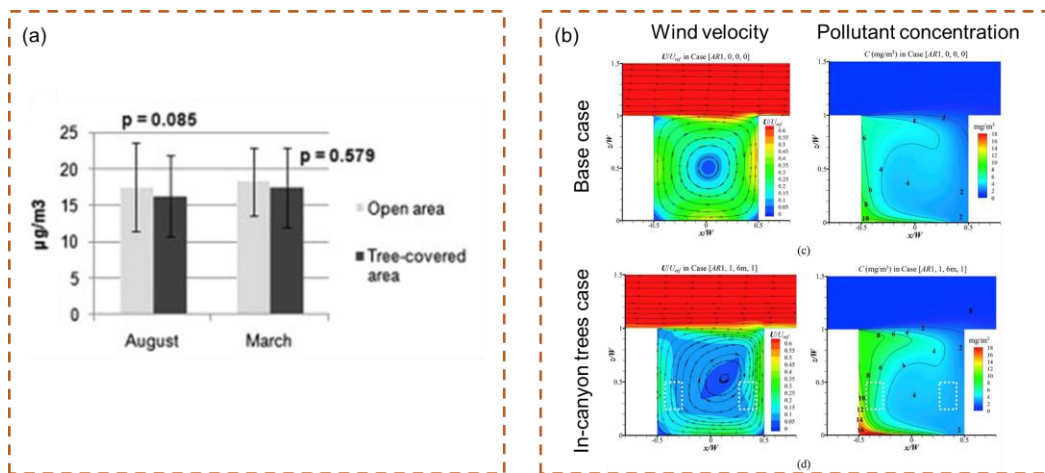
1 neighborhoods with dense urban trees. Similarly, Irga et al. [118] observed that areas
2 with higher urban tree density had lower PM concentrations than other sites. In contrast,
3 some studies demonstrated that urban trees had negligible pollution mitigation benefits.
4 Nowak et al. [119] reported that urban trees generally provided a small contribution to
5 the improvement in air quality of a city via deposition (0.2–1.0% for PM₁₀, 0.1–0.6%
6 for NO₂, and less than 0.005% for CO). Also, a previous review [120] indicated that
7 urban trees only caused a 1% reduction in PM₁₀ concentration in urban areas. Field
8 measurements in Helsinki, Finland, suggested that the air quality in tree-covered areas
9 improved only slightly when compared to treeless areas [121] (Fig. 11(a)). Yli-
10 Pelkonen et al. [122] observed that the NO₂ concentration did not differ substantially
11 between tree-covered and open areas in Baltimore, Maryland. Although urban trees are
12 generally considered beneficial for reducing air pollution, they might not represent a
13 viable solution to mitigating pollution at the city scale [22].

14 At the street canyon scale, improvements in air quality due to the presence of trees
15 have rarely been reported in previous reviews [20,123] and research studies [113,124].
16 Vos et al. [101] and Vranckx et al. [112] investigated the dispersion and deposition
17 effects on air quality and found that ventilation reduction exceeded the positive effect
18 of deposition. The pollutant concentration was higher in street canyons with tree cover
19 than no tree cover, as shown in Fig. 11(b). In-canyon trees resulted in a nearly 20% to
20 58% increase in the average concentration of in-canyon pollutants [97,98,110,125–130],
21 depending on the canyon geometry, wind direction, and pollutant type. Yang et al. [130]
22 reported that a taller tree canopy, a lower tree density, and a smaller LAD increased the
23 personal intake fraction of pollutants.

24 In addition to roadside trees, planting trees in urban parks is an effective strategy
25 for air pollution mitigation in parks [131,132]. Based on a seasonal field monitoring in
26 several parks in Shanghai, China, Yin et al. [133] suggested that trees in parks removed
27 traffic pollutants at the ground-level by 2–35% for total suspended particles (TSP), 2–
28 27% for SO₂, and 1–21% for NO₂ in the park areas. This mitigation effect was more

1 significant at higher NO_x and PM₁₀ levels [131]. In another study, a lower pollutant
 2 concentration was found in parks than in adjacent street canyons [134]. Nonetheless, it
 3 should be mentioned that while trees in urban parks create relatively unpolluted ‘oases’,
 4 their influence on surrounding areas as a pollutant sink is relatively limited.

5 More information on studies of trees as pollutant sinks has been summarized in
 6 Table A.9. Although trees act as pollutant sinks due to the deposition effect, they
 7 provide only a small contribution to the improvement in air quality since their influence
 8 is limited to parks or urban forests. Besides, in-canyon trees may even exacerbate
 9 outdoor air pollution. Thus, only the visitors to parks or urban forests will benefit from
 10 tree planting. Moreover, it should be noted that trees as natural pollutant sinks not
 11 always improve air quality. The release of biogenic VOCs from urban trees can
 12 contribute to the formation of photochemical smog [135–137].



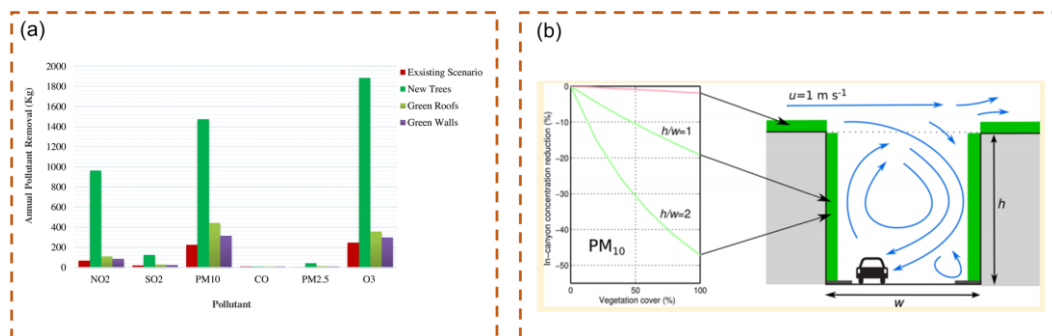
13
 14 Fig. 11. (a) Concentrations of NO₂ in open and tree-covered areas [121]. (b) Plots of
 15 concentrations and wind velocity in canyons with and without trees [130]

16 **Green infrastructure envelope (green roofs/walls)**

17 Green infrastructures mounted on building facades or roofs have significant
 18 potential to reduce public exposure to outdoor air pollution. It has been well
 19 documented that the green infrastructure envelope (green walls or roofs) plays a
 20 significant role in diluting in-canyon airborne pollutants without taking up too much
 21 space [109]. In comparison with in-canyon hedges, the influence of green infrastructure
 22 is dominated by deposition since the green walls or roofs hardly alter the air circulation

1 within street canyons [138]. Yang et al. [139] carried out a modeling study of green
 2 roofs in Chicago. The results indicated that the annual pollutant removal rate of green
 3 roofs was $85 \text{ kg ha}^{-1}\text{yr}^{-1}$. Similarly, Jayasooriya et al. [140] reported that the air quality
 4 at the city scale was enhanced significantly in Melbourne, Australia. It was found that
 5 green roofs were more effective for removing PM10 and O₃ than SO₂, NO₂, CO, and
 6 PM2.5 (Fig. 12(a)). On the other hand, Pugh et al. [10] found that a green wall reduced
 7 the street-level pollutant concentration due to deposition by as much as 60% (Fig.
 8 12(b)). Qin et al. [141] reported that green walls were more effective than green roofs
 9 for improving in-canyon air quality given equal green coverage ratio and street canyon
 10 geometry. Moreover, increasing the LAD and green coverage ratio reduced in-canyon
 11 pollutant concentration.

12 More information on green infrastructure studies is listed in Table A.10. Green
 13 infrastructures reduce the pollutant concentration more efficiently than trees, especially
 14 in street canyons. Thus, the green infrastructure envelope plays a significant role in
 15 improving the air quality for both residents and pedestrians. Also, the LAD, green
 16 coverage ratio, and location of the green infrastructure can be controlled for better air
 17 quality.



18
 19 Fig. 12. (a) Comparison of the annual air pollutant removal amount of tree, green roof,
 20 green wall, and baseline scenarios [140]. (b) In-canyon concentration reduction versus
 21 vegetation cover [10].

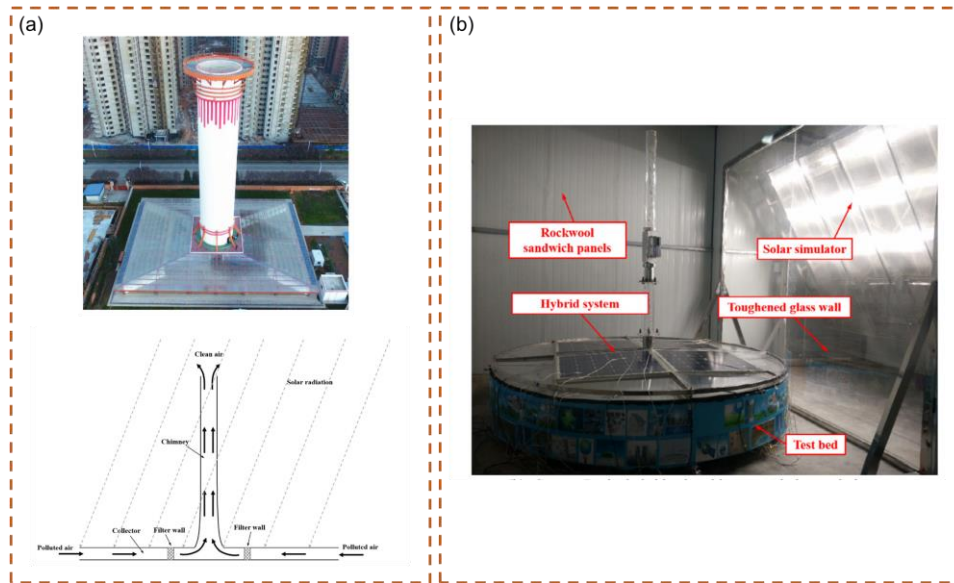
22 3.3.2 Artificial pollutant sinks (solar chimney and electrostatic precipitator)

23 Solar chimney

24 The use of a solar chimney to reduce exposure to air pollutants is a relatively new

1 area of research. Traditionally, solar chimneys were developed to generate electricity
2 by capturing solar energy [142]. Since the air density decreases with the temperature, a
3 solar chimney causes upward air movement due to buoyancy to drive turbines for
4 generating electricity [143]. Zhou et al. [144] proposed a solar-assisted large-scale
5 cleaning system to reduce air pollution during electricity generation. A filter bank was
6 placed near the entrance of the chimney to separate the pollutant particles such as
7 PM_{2.5} from the air. Similarly, Ming et al. [145,146] proposed a method for large-scale
8 removal of non-CO₂ greenhouse gases (GHGS) using a solar chimney device with
9 photocatalytic technology. This solar-driven system filtered out noxious particles and
10 emitted clean air. Gong et al. [147] extended the study and proposed a new type of solar
11 chimney system with an inverted U-shaped cooling tower and water spray system to
12 remove large-scale air pollutants. This system provided 69,984,000 m³ of clean air per
13 day. Furthermore, a solar-assisted large-scale cleaning system (SALSCS) with a 500 m
14 high chimney was proposed by Cao et al. [148]. By generating thermal airflow, the
15 polluted air was moved through filters to separate PM (PM 10 and PM 2.5).
16 Subsequently, a smaller experimental cleaning system with a solar-driven purifier
17 called a smog-free tower (SFT) with a 60 m high chimney was put into operation in
18 Xi'an, China [149–151] (Fig. 13(a)). Experiments showed that the SFT reduced the
19 PM_{2.5} concentration by 11%-19% within a 10 km area around the solar chimney.
20 Huang et al. [152] proposed a hybrid solar chimney and photovoltaic (PV) system with
21 a small footprint (Fig. 13(b)). Suction fans powered by PV panels were used to improve
22 the air quality, further reducing the required land area.

23 More information on studies on solar chimneys is listed in Table A.11. Solar
24 chimneys represent a passive mitigation strategy and have excellent potential to remove
25 pollutants from urban areas. These devices remove pollutants from a relatively large
26 area, improving the pedestrians' and residents' air quality. Nonetheless, it should be
27 mentioned that the land requirement for these devices should be carefully considered
28 in future work.



1

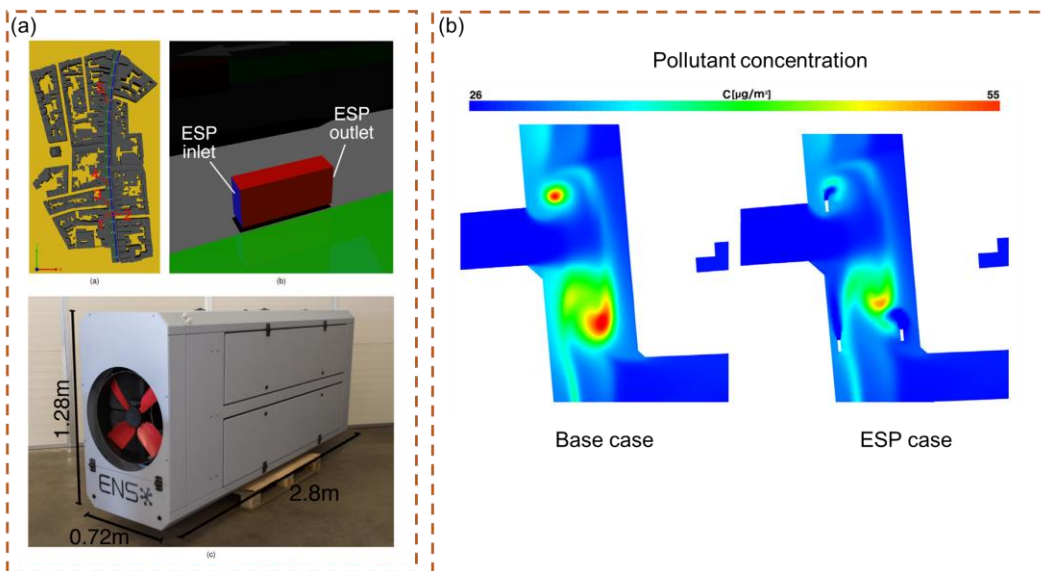
2 Fig. 13. (a) Photo and schematic diagram of SALSCS [149–151] and (b) photos of a
 3 hybrid solar chimney and photovoltaic system [152].

4 **Electrostatic precipitator**

5 In contrast to solar chimneys, an electrostatic precipitator (ESP) is powered by
 6 electricity and improves the local air quality. The potential of ESPs for air pollution
 7 exposure reduction has been demonstrated. For instance, ESPs were installed to ensure
 8 clean air in critical urban areas (such as hospitals or schools) to benefit particularly
 9 vulnerable people (such as patients or students) [153]. The ESPs were also installed
 10 near sources of high pollutant emissions, such as the major arterial roads or parking
 11 garages [154]. Blocken et al. [154] examined the effectiveness of ESPs for local
 12 pollutant removal in semi-enclosed parking garages. Significantly, the local outdoor
 13 PM10 concentration close to the garages was reduced by more than 50%, and the
 14 downstream concentration decreased by up to 10%. Boppana et al. [155] investigated
 15 the influence of an ESP installed in a typical street canyon in Singapore. The results
 16 confirmed that the radius of influence of an individual ESP was almost 5–6 times the
 17 unit’s length. A group of ESPs resulted in a 7.6% reduction in the average PM levels.
 18 Similarly, Lauriks et al. [156] analyzed the pollutant removal by an ESP in an urban
 19 street canyon in Antwerp, Belgium (Fig. 14(a)). In locations with poor ventilation, the
 20 ESP units significantly reduced the concentration level (up to 40%) (Fig. 14(b)).

1 Additionally, Dash and Elsinga [157] demonstrated that installing ESPs on solid
2 barriers was beneficial for local air quality. ESPs can be effective in locations that are
3 problematic in terms of air quality legislation [156].

4 More information on studies on ESPs has been provided in Table A.12. Generally,
5 ESPs placed in strategic locations can significantly improve the local air quality, but
6 the area of influence is limited. The use of ESPs represents an active mitigation strategy,
7 but their cost and placing have to be considered. Besides, it should be stressed that ESPs
8 require anthropogenic-generated energy in their operation, which may, in turn, create
9 air pollution, although not necessarily in the urban areas. In this regard, although ESPs
10 can be installed to reduce pollutant levels at concentration hotspots, they should not be
11 used on a large scale.



12
13 Fig. 14. (a) Schematic diagram of the locations of 5 electrostatic precipitators (ESPs)
14 inside the domain, the magnification and orientation of the 5th unit, and a photo of the
15 ESP unit [156]. (b) Comparison of PM10 concentrations for a case with and without an
16 ESP [156].

17 Moreover, most studies on local mitigation strategies focused on the neutral
18 condition (iso-thermal condition). Chen et al. [158,159] obtained outdoor
19 measurements at different scales and demonstrated that the buoyancy force was the
20 dominant force in urban ventilation, especially in deep street canyons. The synergy

1 effect of mechanical ventilation and the buoyancy force should be considered in future
2 work for optimization design.

3 **4. Optimization framework for improving pollutant dispersion**

4 The optimization frameworks can be classified into general optimization
5 frameworks and advanced optimization frameworks that use machine learning and
6 optimization algorithms, as shown in Fig. 15.

7 **4.1 General optimization framework**

8 Du and Mak [35] proposed a general optimization framework for increasing the
9 wind velocity at the pedestrian level. The flowchart of this framework is presented in
10 Fig. 15(a), showing the four steps. The first step obtains basic information on the target
11 area, including the local wind conditions, the building, and geomorphological
12 information. Different prediction methods are used (i.e., field measurement, wind
13 tunnel experiment, and CFD simulation) to obtain the PLW environment. The next step
14 is to detect the wind velocity by combining the prediction results and the evaluation
15 criteria (e.g., the air ventilation assessment (AVA) scheme in Hong Kong). The
16 following step applies the improvement measures to the target area. The final step is to
17 re-evaluate the PLW environment after adopting the improvement measures. If the
18 optimized results do not meet the evaluation criteria, new improvement measures are
19 adopted. Subsequently, a case study of a university campus was conducted. The results
20 indicated that the general framework substantially and systematically improved the
21 local wind environment. Nonetheless, this general framework is based on a “trial- and-
22 error” passive design method and has a single objective. Thus, an advanced
23 optimization framework that uses machine learning and an optimization algorithm is
24 urgently needed.

25 **4.2 Advanced optimization frameworks**

26 Advanced optimization frameworks can be divided into non-surrogate and
27 surrogate model-based frameworks.

1 **4.2.1 Non-surrogate model-based framework**

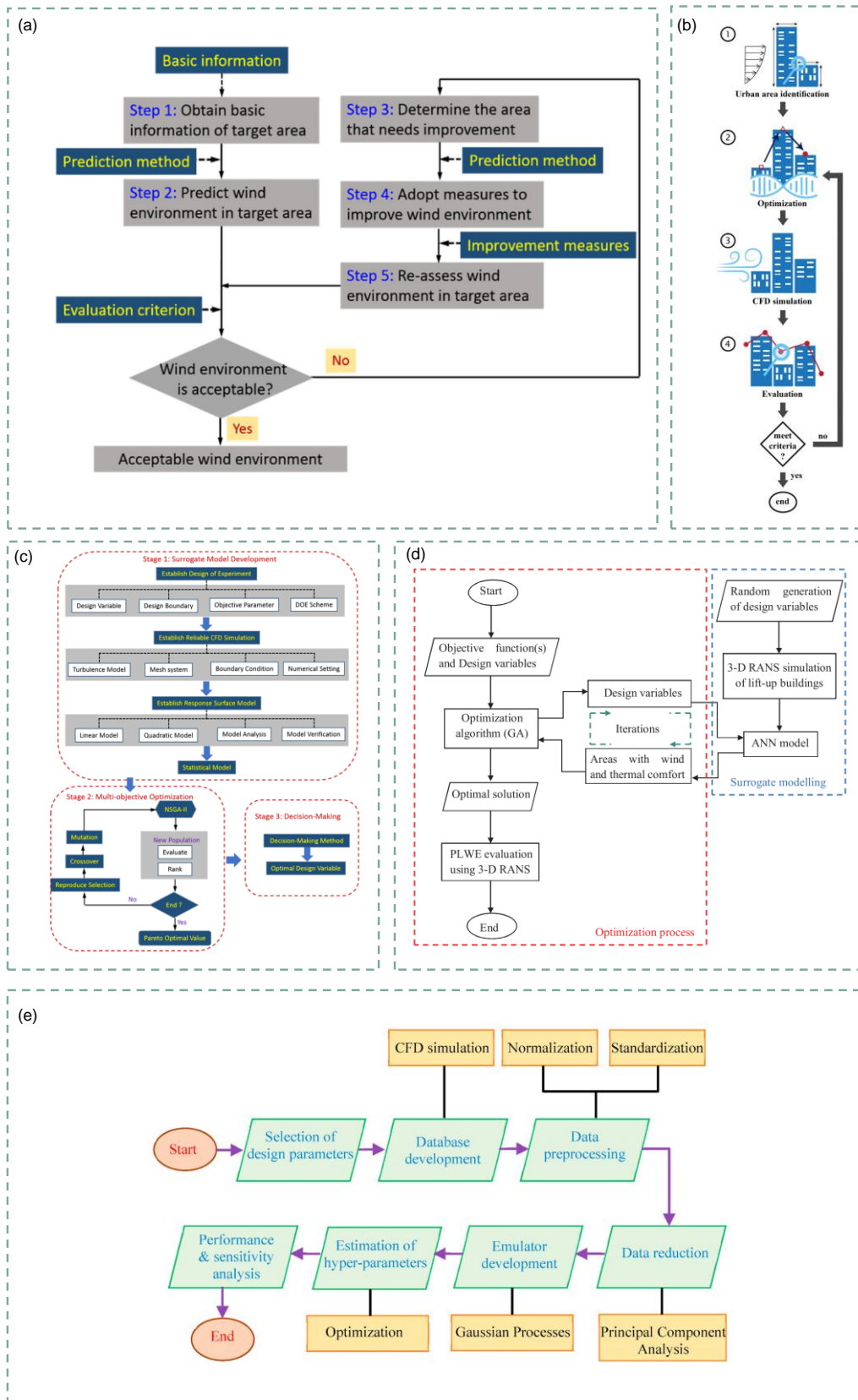
2 Kaseb et al. [160] proposed a non-surrogate model-based framework that
3 combined a CFD simulation with a genetic algorithm (GA), one of the most popular
4 optimization algorithms to improve the local wind environment by optimizing the
5 building heights and plan area density of a realistic urban area. As seen in Fig. 15(b),
6 this optimization framework consists of four steps: urban area identification,
7 optimization algorithms, CFD simulations, and evaluations. The first step is similar to
8 that of the general framework; however, the GA is adopted in the second step. The
9 attributes of the target urban areas (building height and plan area density) are assigned
10 and updated using the GA combined with particle swarm optimization (PSO). The
11 following step consists of the prediction and evaluation of the wind environment by
12 CFD simulations. Steps 2 and 3 are repeated for each evolutionary period, and the
13 evolution is controlled by a series of hyper-parameters, including the population size
14 (the number of generated urban areas), the number of generations, the crossover rate,
15 and the mutation rate. The population is then sorted based on the optimal value of the
16 evaluation criteria up to the current evolutionary period. The process continues until
17 the termination condition has been met. Finally, the optimal case is sent to Step 4 for
18 evaluation. A case study of a real urban area in Tehran, Iran, was conducted using the
19 proposed design framework. The results showed that the wind speed had increased by
20 nearly 19%. Although the computational time and cost were lower than for the “trial-
21 and- error” method, over 900 cases were predicted by the CFD simulation for an urban
22 area with 20 buildings. This outcome was attributed to the limitation of combining the
23 GA with a CFD simulation.

24 **4.2.2 Surrogate model-based framework**

25 In contrast, the surrogate model-based optimization framework does not integrate
26 the CFD simulations with the optimization algorithms. Du et al. [161] proposed a
27 response surface methodology (RSM)-based framework for improving the wind
28 environment by optimizing the lift-up design, as illustrated in Fig. 15(c). The first step

1 was to select the design parameters in the design of the experiment (DoE) and generate
2 a design dataset. The second step was the establishment of reliable CFD simulations. A
3 regression model (a type surrogate model) using the RSM approach was established
4 using the dataset generated by the DoE. Subsequently, the surrogate models were
5 coupled with the GA to determine the Pareto optimal design point (optimal result). This
6 optimization framework with the optimum lift-up design parameters was successfully
7 applied to improve the wind environment around an isolated building. Furthermore, Du
8 et al. [67] proposed a more advanced framework to deal with a multi-objective problem.
9 The optimization process was similar to the previous study, except for the final step, as
10 shown in Fig. 15(c). In the final step, the Pareto optimal design points were processed
11 using decision-making techniques, such as the Linear Programming Technique for
12 Multidimensional Analysis of Preference (LINMAP) and Shannon's entropy, to
13 determine the optimum values. Similarly, different approaches can be used to develop
14 the surrogate model, such as an artificial neural network (ANN) [55] and the Gaussian
15 process (GP) [162], as shown in Fig. 15(d) and (e), respectively.

16 Generally, fewer cases are needed to develop a surrogate model than a non-
17 surrogate model-based framework. Thus, these frameworks significantly reduce the
18 overall computational costs and speed up the optimization process. For example, the
19 GP-based framework for optimizing the PLW environment around an isolated building
20 is more than 400 times faster than its CFD counterpart [162].



1

2 Fig. 15. (a) General optimization framework [35]. (b) Advanced optimization

3 framework without a surrogate model [160]. (c) Advanced optimization framework

1 with RMS-based surrogate model [67]. (d) Advanced optimization framework with
2 ANN-based surrogate model [55]. (e) Advanced optimization framework with GP-
3 based surrogate model [162]

4 **5. Evaluation theory for improving pollutant dispersion**

5 Few studies focused on the evaluation theory for pollutant dispersion in urban
6 areas, except for the mass transfer field synergy theory proposed by Ming et al.
7 [83,163,164].

8 The mass transfer field synergy theory for outdoor urban areas originated from the
9 well-established heat transfer field synergy theory. Guo et al. [165] regarded convective
10 heat transfer as a heat conduction problem with an internal heat source. The authors
11 proposed the field synergy principle of heat transfer enhancement by integrating the
12 boundary layer energy equation. Subsequently, this field synergy principle of heat
13 transfer was successfully applied to turbulent flow by Zeng and Tao [166]. Then, Liu
14 et al. [167] established a synergy equation of energy and momentum for turbulent heat
15 transfer, revealing the synergy between heat flow, mass flow, and fluid flow as a driving
16 force during turbulent heat transfer. Subsequently, motivated by the analogy between
17 heat transfer and mass transfer, Chen et al. [168] extended the field synergy theory to
18 the analysis of convection mass transfer in an indoor space (confined space), revealing
19 the impact of the synergy between the velocity vector and the pollutant concentration
20 gradient on the decontamination rate of indoor ventilation. Based on the mass and heat
21 transfer field synergy theory in confined spaces (e.g., the wavy channels, corrugate
22 ducts, circular tube, and indoor space), Ming et al. [164] proved the applicability of the
23 field synergy theory to the study of pollutant transmission in open spaces using model
24 similarity, as seen in Fig. 16(a). The flow in a confined space (e.g., between two parallel
25 plates) is symmetric about the centerline. There is an observable velocity gradient
26 inside the boundary layer, whereas the velocity in the core flow region is constant. The
27 half-domain of this confined space is analogous to a semi-confined structure, e.g., the
28 fluid flow through a plate. Moreover, the mass transfer field synergy theory in open

1 spaces has been successfully used to guide the optimization of urban geometry factors,
2 such as in a viaduct, the roof shape [164], and the design of wind catchers [83].

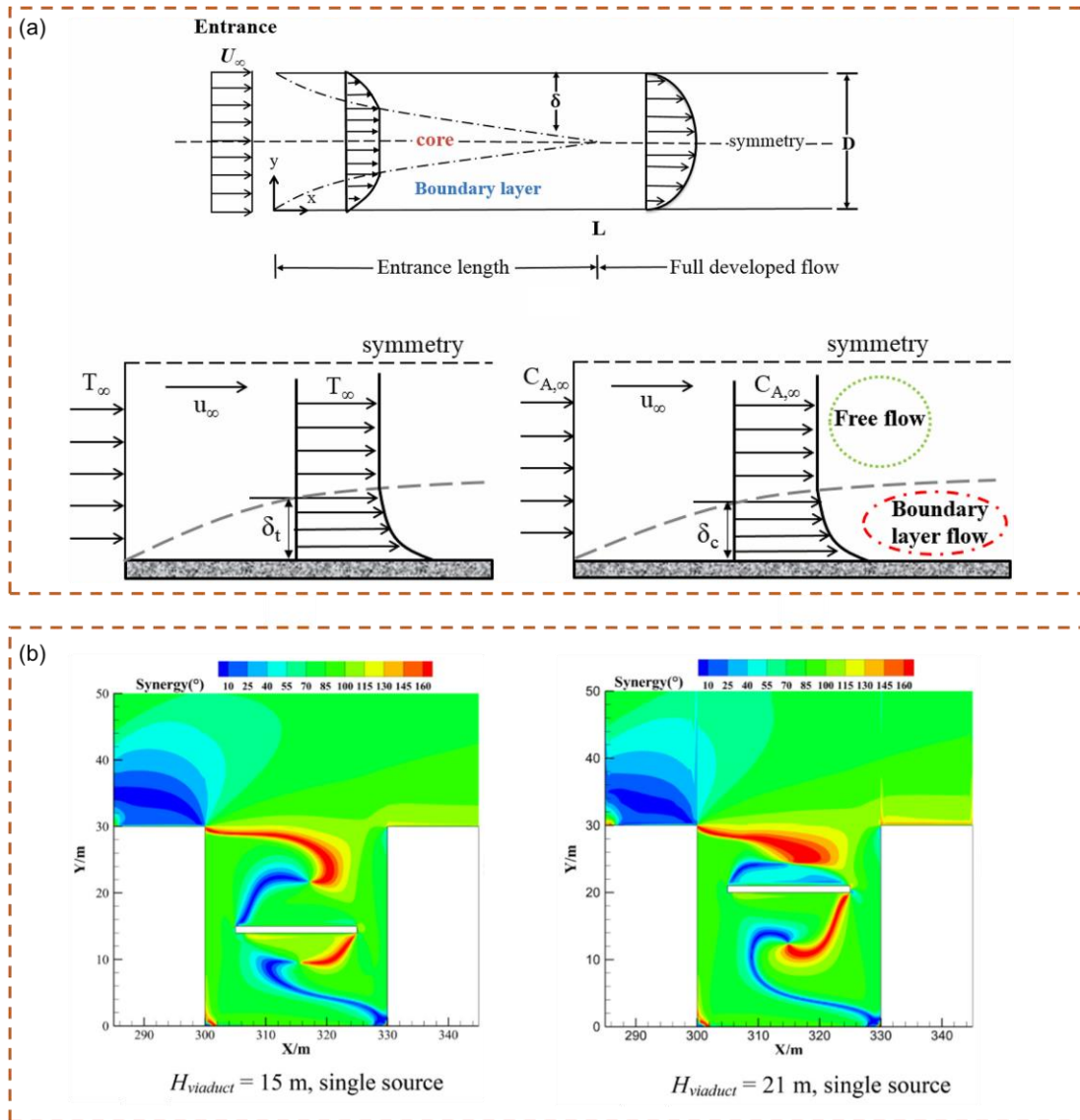
3 Ming et al. [164] suggested, based on the field synergy theory, that it is possible
4 to increase convective mass transfer, i.e., increasing the value of the dimensionless
5 integral number of the field synergy, F_{cm} . This proposed optimization pathway is related
6 to the dimensionless number, i.e., the Sherwood number Sh , which can be derived from
7 the concentration conservation equation of the steady-state mass diffusion. This Sh
8 number characterizes the relative size of the convective mass transfer and diffusion
9 mass transfer as follows:

$$10 \quad Sh = Re Sc \int_{\Omega} \overline{U} \cdot \overline{\nabla C} dV / V = Re Sc F_{cm} \quad (1)$$

11 where U is the flow speed, ∇C is the component concentration gradient, Re is the
12 Reynolds number, Sc is the Schmidt number, and F_{cm} is the mass transfer field synergy
13 number. Accordingly, the Sherwood number is not only related to the Re and Sc but also
14 depends on the coordinate angle between the velocity vector and the concentration
15 gradient vector, i.e., the integration value of the dot product of the two vectors in the
16 target area (F_{cm}). Generally, the larger the dot product of the two vectors, the larger the
17 F_{cm} is, the larger the Sherwood number is, and the better the convective mass transfer
18 effect is [164]. We use the field synergy analysis on the influence of the viaduct height
19 on pollutant concentration as an example. As the height of the viaduct increased, the
20 area with a large synergy angle in the street canyon increased, and the average synergy
21 angle increased; thus, the more unfavorable the diffusion of pollutants in the street
22 canyon was (Fig. 16(b)).

23 We provide a brief discussion on local mitigation strategies using this optimization
24 pathway and the lift-up design as an example. This design significantly improves the
25 pedestrian-level ventilation but has a negligible influence on vertical ventilation, which
26 is in line with the pollutant concentration gradient. Thus, the lift-up design has a poor
27 mass transfer synergy in the vertical direction and mainly improves the air quality at
28 the pedestrian level. In contrast, the installation of wind catchers improves the air

1 quality of the entire street canyon due to a better synergy of the velocity vector and the
2 concentration gradient vector. Hence, these pollutants can be significantly diluted by
3 incoming fresh air and can be removed from the street canyon. However, the control of
4 the source-receptor pathways by constructing barriers does not seem to change the mass
5 transfer synergy of the entire street canyon; thus, the in-canyon pollutant concentration
6 hardly changes. Interestingly, creating an artificial pollutant sink can substantially
7 improve the air quality since the flow direction toward the sink is consistent with the
8 concentration gradient from the pollutant source (traffic lines) to the pollutant sink
9 (solar chimney or ESP). However, a natural sink, such as street trees, does not provide
10 a mass transfer synergy; thus, the influence of trees as a pollutant sink remains limited.
11 Generally, the optimization pathway of enhancing the synergy of the velocity vector
12 and the concentration gradient vector is quite effective. New local mitigation strategies
13 can be developed using this pathway.



1
 2 Fig. 16 (a) Illustration of the model similarity from a confined space to an open space
 3 and (b) Contours of synergy angle of viaducts with different heights [164]

4 **6. Conclusion**

5 Outdoor air pollution is a significant global issue due to the major long-term health
 6 risk. We reviewed studies on the optimization of pollutant dispersion, with a focus on
 7 traffic pollutants in urban environments. The main objective of the review was to
 8 investigate local mitigation strategies, with a particular concentration on the mechanism,
 9 the potential reduction in pollutant concentrations, and the parameterization of those
 10 strategies and the final stakeholders. Generally, local mitigation strategies can be
 11 divided into three categories: (i) improving urban ventilation and turbulence level for

1 pollutant dispersion, (ii) controlling source-receptor pathways by constructing barriers,
2 and (iii) capturing and mitigating air pollution by introducing pollutant sinks.
3 Subsequently, we reviewed the optimization frameworks that consider a broad range of
4 design parameters, including the design of local mitigation strategies, parameter
5 optimization for different urban geometries or local mitigation strategies, and
6 applicability for multi-design objectives. Evaluation theories were reviewed to
7 consolidate the understanding of the potential optimization pathway for developing
8 new local mitigation strategies and urban morphology. The following conclusions can
9 be drawn from the literature review:

10 (1) The optimization of the building architecture (e.g., roof design, lift-up design, and
11 setback design) and the addition of devices (e.g., pedestrian-level ventilation systems
12 and wind catchers) provide significant potential to improving ventilation and the
13 turbulence level. Both pedestrians and surrounding residents will benefit from a
14 reduction in pollutant concentrations in urban areas resulting from these strategies.
15 Nonetheless, it should be noted that most strategies are only effective in a small area
16 (within the street canyon).

17 (2) Both solid barriers, including LBWs, noise barriers, on-street parking systems, and
18 porous barriers (hedges), can create sheltered areas of relatively fresh air immediately
19 behind the barrier at the pedestrian level, where most of the polluted air is found. It is
20 noteworthy that this mitigation type is only beneficial to pedestrians behind the barriers
21 since the pollutants are not removed.

22 (3) As a natural pollutant sink, the green infrastructure envelope, including green walls
23 and green roofs, plays a significant role in improving air quality for residents and
24 pedestrians. In contrast, urban trees provide a negligible contribution to the
25 improvement in air quality, except in parks or urban forests. In addition, in-canyon trees
26 may aggravate outdoor air pollution. Thus, only visitors of parks or urban forests will
27 benefit from tree plantings. On the other hand, solar chimneys have significant potential
28 to remove pollutants from urban areas and are effective in a broad area. Nonetheless, it

1 should be mentioned that the land requirements should be carefully considered in future
2 work. In contrast, the installation of ESPs in strategic locations can significantly
3 improve the local air quality level without occupying a large amount of space.

4 (4) Surrogate model-based optimization frameworks, including RSM-based, ANN-
5 based, and GP-based frameworks, have lower computational costs and perform
6 optimization faster than other types of frameworks. These optimization frameworks are
7 well suited for multi-objective problems.

8 (5) Few studies considered optimization theories for pollutant dispersion in urban areas,
9 with the exception of the mass transfer field synergy theory. This theory was used
10 successfully to increase the synergy of the concentration gradient and wind velocity
11 vector to improve pollutant dispersion in urban areas.

12 In summary, this paper provided a comprehensive and systematic review of the
13 local mitigation strategies, optimization frameworks, and evaluation theories for
14 improving pollutant dispersion in urban areas. Accordingly, this study is beneficial for
15 urban planners and architects responsible for decision-making.

16

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27

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- 18

19 Appendix

20 Table A.1. Overview of studies on roof design

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[43]	CFD (V)	2D-S ($H/W = 0.08-2.5$)	Effects of roof slope (0–40° for pitch roof)	The whole street canyon	Pitched roofs enhanced the TKE at the roof level and provided a significant perturbation of the mean velocity field, increasing the air exchange rate, regardless of the slope and the aspect ratio.
[45]	WT	3D-S ($H/W = 1, L/W = 5-15$)	Effects of roof shape (flat & pitch)	The whole street canyon	Pitched roofs enhanced along-canyon velocity components in the entire length of the canyon
[42]	WT	2D-S ($H/W = 1$)	Effects of roof shape (flat & pitch)	The whole street canyon	Pitched roofs induce violent flow with large vortices penetrating the street, intensifying ventilating in the upper part of the canyon
[46]	WT	2D-S ($H/W = 1$)	Effects of roof shape (flat, pitch, & wedge)	The whole street canyon	Roof shape played a significant role in determining the in-canyon vorticity dynamics and corresponding pollutant transport
[47]	CFD (V)	2D-S ($H/W = 1$)	Effects of roof shape (flat, pitch, downwind/upwind wedge, & trapezoid) & Roof height ($H_{roof}/H = 0.17, 0.33$ and 0.5)	The whole street canyon	Compared with flat roofs, the wind velocity increased for pitched & trapezoid-shaped roof and decreased for wedge-shaped roofs; wind velocity decreased as the H_{roof} increased; TKE increased as the H_{roof} increased; pollutant concentration decreased as the H_{roof} increased At $H_{roof}/H = 1/6$, the pollution levels were similar for different roof types; at $H_{roof}/H = 1/3$, the pollution levels were much higher for the upwind-wedged and slanted roof than for the round, trapezoidal, and downwind wedge-shaped roofs; at $H_{roof}/H = 1/2$, the round roof had the lowest pollution level and the upwind wedge-shaped roof had the highest pollution level
[48]	CFD (V)	2D-S ($H/W = 1$)	Effects of roof shape (flat, pitch, downwind/upwind wedge, trapezoid, & round) & Roof height ($H_{roof}/H = 1/6, 1/3$ and $1/2$)	The whole street canyon	
[49]	CFD (V)	2D-S ($H/W = 1$)	Effects of roof slope (0–30° for a wedged-shape roof)	The whole street canyon	The effect depended on the roof slope. A slope of 18° was the threshold between double and single vortex structures.

[50]	CFD (V)	2D-S ($H/W = 1$)	Effects of roof morphological configuration	The whole street canyon	The leeward wedged-shaped roof had much stronger aerodynamic impacts than the same roof geometry on the windward building
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Study approach: Exp.= Experiment, MS= modeling study, WT = Wind tunnel measurements, WC = Water channel measurements, FM = Field measurements, CFD (V) = CFD with validation, and CFD (NO) = CFD without validation; **Urban configuration:** C = City, S= Street canyon, B = Building, GB = a group of buildings, λ_F = Frontal area density, H/W = Height aspect ratio (building height/street width), L/W = Length aspect ratio (street length/street width).

Table A.2. Overview of studies on lift-up design

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[59]	WT	Ideal GB	None	Pedestrian level behind buildings	Lift-up designs increased the surrounding PLW speed by almost 11%
[61]	CFD (V)	Realistic GB	Effects of building geometry	Pedestrian level inside and near lift-up areas	Lift-up designs increased the wind speed inside and near lift-up areas
[66]	CFD (V)	Ideal B	Effects of lift-up column height & weight	Pedestrian level behind buildings	The height and width of columns significantly affected the ventilation at the pedestrian level; the column height had a more significant effect than the column width
[67]	WT	Realistic GB	Effects of lift-up column height & weight	Pedestrian level behind buildings	Increasing the column width adversely affected the ventilation at the pedestrian level, whereas the effect of increasing the column height was positive
[68]	CFD (V)	Ideal GB	Effects of lift-up height	Pedestrian level throughout all buildings	Improvements in the pedestrian level ventilation were relatively small when the elevated height exceeded 4 m
[69]	CFD (V)	Ideal GB	Effects of lift-up position	The entire space around buildings	The first-floor lift-up design was more effective than the second or third-floor lift-up design

Table A.3. Overview of studies on setback design

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[74]	CFD (V)	Ideal S ($H/W = 0.33$ to 3)	Effects of height and width of arcade	The pedestrian level of the street canyon	Increasing the arcade height (from 3 to 6 m) led to a nearly 25% reduction in ACH, whereas increasing the arcade width (from 1.5 to 9 m) caused an almost 76% increase in ACH.
[76]	WT	Ideal S ($H/W = 2$)	Influence of arcade on pollutant concentrations	The whole street canyon	Arcade design resulted in a reduction in pollutant concentration at the pedestrian level.
[78]	CFD (V)	Ideal S ($H/W = 2, 4, \& 6$)	Effects of horizontal & vertical setback	The whole street canyon	The vertical setback was more suitable for a canyon with $H/W = 2$, whereas the horizontal setback was more suitable for a canyon with $H/W = 4$ and 6

Table A.4. Overview of studies on PVSs

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[81]	CFD (V)	Ideal S ($H/W = 1 \& 2$)	PVS strategies	The whole street canyon	The exhaust strategy reduced concentrations in the street canyon by about 40%. The supply strategy showed similar performance. The washing flow strategy was satisfactory for removing pollutants from the duct system.
[80]	CFD (V)	Ideal S ($H/W = 2$)	PVS strategies	The whole street canyon	PVS improved the ventilation inside the building canopy under stable and unstable weather conditions.
[79]	CFD (V)	Ideal S ($H/W = 1$)	PVS strategies and fan pressure	The whole street canyon	An increase in fan pressure produced higher wind velocities, which significantly decreased the AQI

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Table A.5. Overview of studies on wind catchers

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[82]	WC	Ideal S ($H/W = 1$)	Effects of wind catcher position & structure	The whole street canyon	Wind catchers installed on the upwind building enhanced pedestrian-level wind speed of the target canyon by 2.5 times; sidewalls of wind catcher prevented spanwise leakage
[71]	CFD (V)	Ideal S ($H/W = 5$)	Effects of wind catchers in a deep canyon	The whole street canyon	Wind catchers reduced the pollutant concentrations by one or two orders of magnitude in a deep street canyon
[83]	CFD (V)	Ideal S ($H/W = 1$)	Synergy analysis of wind catchers	The whole street canyon	The wind catcher significantly enhanced the synergy of pollutant dispersion and airflow in the street canyon

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Table A.6. Overview of studies on LBWs

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[93]	FM	Realistic C	Effects of the height of LBW	Behind the LBW at the pedestrian level	An increase in the height of LBWs (1 to 2 m) caused a significant reduction in pollutant concentration (by almost 50%)
[95]	CFD (V)	Ideal S ($H/W = 1$)	Effects of the position of LBW	Pedestrian level	Central LBWs were more suitable for wind perpendicular to the street, whereas footpath LBWs resulted in better air quality for parallel wind
[87]	CFD (V)	Ideal S ($H/W = 1$)	Effects of the position of LBW	Pedestrian level	Central LBWs caused a more significant reduction in the pollutant concentration than the footpath LBWs
[97]	CFD (V)	Realistic C	Potential final stakeholders benefiting from LBWs	Pedestrian level	A solid barrier caused an increase in NO_2 concentration near the road and a reduction in NO_2 concentration on the footpath.

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Table A.7. Overview of studies on on-street parking

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[98]	CFD (V)	Ideal S ($H/W = 0.5$)	Effects of parking density	Behind the cars at the pedestrian level	Oblique parking (30° – 60°) caused an increase in roadside pollutant exposure of up to 34.3%
[99]	CFD (V)	Ideal S ($H/W = 1$)	Effects of occupancy rates	Behind the cars at the pedestrian level	A curvilinear pattern of concentration reduction was observed for a parking occupancy range of 10% to 90%
[16 9]	CFD (V)	Ideal S ($H/W = 1$)	Effects of the shape of parked cars	Behind the cars at the pedestrian level	The shape of parked cars might influence the air quality

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Table A.8. Overview of studies on the hedges

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[90]	CFD (V)	Ideal S ($H/W = 0.5$)	Effects of hedge position	At the pedestrian level of street canyons	One central hedgerow provided higher reductions in pollutant concentrations than two parallel hedgerows
[104]	CFD (V)	Realistic C	Effects of LAD of hedge	Behind the hedges at the pedestrian level	The pollutant concentration in the sheltered areas of hedges generally decreased with an increase in leaf area density (LAD)
[108]	FM & CFD (V)	Ideal S ($H/W = 0.18$ & 0.78)	Effects of the hedge height	Behind the hedges at the pedestrian level	The optimal height of 1.1 m was recommended for a canyon of $H/W = 0.78$

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Table A.9. Overview of studies on trees

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[117]	FM	Realistic C	Effects of trees at the city scale	Around the trees	Ambient PM concentrations were lower in neighborhoods with dense urban trees
[121]	FM	Realistic C	Effects of trees at the city scale	N/A	Air quality in tree-covered areas only slightly improved as compared to treeless areas
[112]	CFD (V)	Ideal S ($H/W = 0.5$ & 1)	Effects of trees at the street canyon scale	The whole canyon	The reduction in ventilation was much stronger than the positive effect of deposition
[130]	CFD (V)	Ideal S ($H/W = 0.5-5$)	Effects of trees at the street canyon scale	The whole canyon	In-canyon trees increased the average concentration of in-canyon pollutants
[133]	FM	Realistic C	Effects of trees in urban parks	The coverage areas of urban parks	Trees removed traffic pollutant at the ground level by 2–35% for TSP, 2–27% for SO ₂ , and 1–21% for NO ₂ in the coverage areas of the park

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Table A.10. Overview of studies on the green infrastructures

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[139]	MS	Realistic C	Effects of green roofs at the city scale	N/A	The annual pollutant removal rate of green roofs was 85 kg ha ⁻¹ yr ⁻¹
[140]	MS	Realistic C	Different pollutants	N/A	Green roofs were most effective for removing PM ₁₀ and O ₃
[10]	CFD (V)	Ideal S ($H/W = 1$ & 2)	Green roofs in different canyons	The whole street canyon	Green walls cause a reduction in the street-level pollutant concentration of 60%
[141]	CFD (V)	Ideal S ($H/W = 0.5-2$)	Comparing green roofs and walls	The whole street canyon	Green walls were more effective than green roofs for improving in-canyon air quality

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Table A.11. Overview of studies on solar chimneys

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[149]	CFD (V)	N/A	Influence of solar chimney on nearby air quality	A 10 km area around the solar chimney	A smog-free tower reduced the PM _{2.5} concentration by 11%-19% within a 10 km area around the solar chimney
[152]	CFD (V) & Exp.	N/A	A hybrid solar chimney and PV system	Around the solar chimney	Suction fans powered by PV panels improved the air quality with a small footprint.

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Table A.12. Overview of studies on ESPs

Ref.	Study approach	Urban configuration	Focus	Coverage of Influence	Critical Findings
[154]	CFD (V)	Realistic C	ESP for parking garages	Around the ESP	Local outdoor PM ₁₀ close to the garages was reduced by more than 50%, and the downstream concentration decreased by up to 10%
[155]	CFD (V)	Realistic C	ESP in realistic street canyon	Almost 5-6 times of the unit length around the ESP	A group of ESPs reduced the average PM levels by approximately 7.6%.
[156]	CFD (V)	Realistic C	ESP in realistic street canyon	Around the ESP	In some locations with poor ventilation, the ESPs significantly reduced (up to 40%) the concentration level

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