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Building Integrated Wind Technologies: from Technical Assessment to Suitable Integration Methods

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ABSTRACT:

The efficient integration of wind technology into a building - which called building integrated wind technology (BIWT) - will be necessary for substantial reduction of CO_2. However, the spread of this integration faces a major problem which is the absence of a framework that helps the architects to determine the suitable integration methods for their buildings. Therefore; an overview of some existing wind power technology for integrating WTs to the building is presented. The approaches are further discussed and evaluated in order to recognize the most suitable integrations for future WTs, and, finally, a conclusion is given as an essential step towards the scientific framework.

Key words: **Building integrated wind technology; Framework; Integration method; Wind technology**.

1. INTRODUCTION

Buildings are responsible for one-third of global energy related CO_2 because of their dependency on fossil fuels and transmission losses [1]. Therefore; building designers are showing an increasing interest in reducing the environmental impact of their buildings. Hence, the first step is to reduce energy demands and the second is to cover most of the remaining needs of building by renewable energies. One of the useful approaches being used is the integration of wind technologies (WTs) into the primary building design to produce energy where it is consumed [2].

BIWT is a building that is designed and shaped with WT in mind [2]. Furthermore, WTs, which have many types, can be integrated into buildings in many forms

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Therefore, a systematic framework is needed to achieve efficient BIWTs. This framework should include four stages: 1) determine site suitability; 2) determine suitable integration methods; 3) determine suitable WTs; and 4) comparison of energy production and consumption. In this regard, the paper aims to introduce the varied methods of WTs integration into the buildings, in addition to the framework for the determination of suitable integration methods as a stage towards the efficient integration of wind technologies into buildings.

2. INTEGRATION METHODS OF WIND TECHNOLOGY

The trend towards BIWT is increasing because the building can support the WTs, harness wind to be driven towards the WTs, and capture higher wind speeds because of the height. Further, this integration can reduce energy transmission losses; reduce fossil fuel resources consumption; increase CO_2 savings; and make a visible "green" image [2; 3; 4; 5]. Therefore, the fundamental considerations and types of integration methods are illustrated in Sections 2.1 and 2.2.

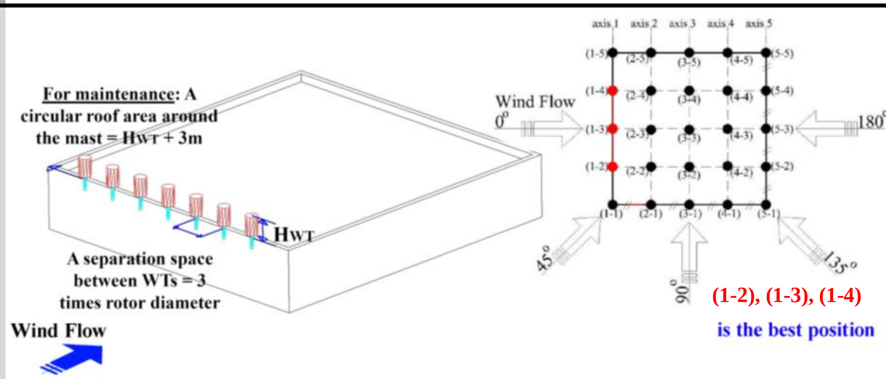
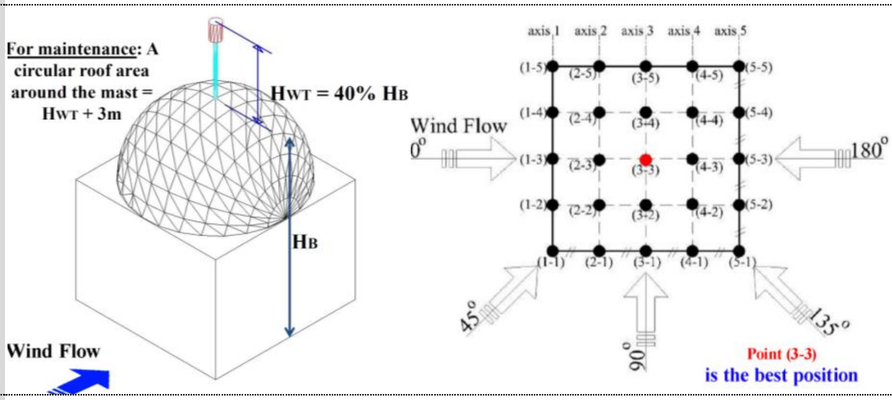
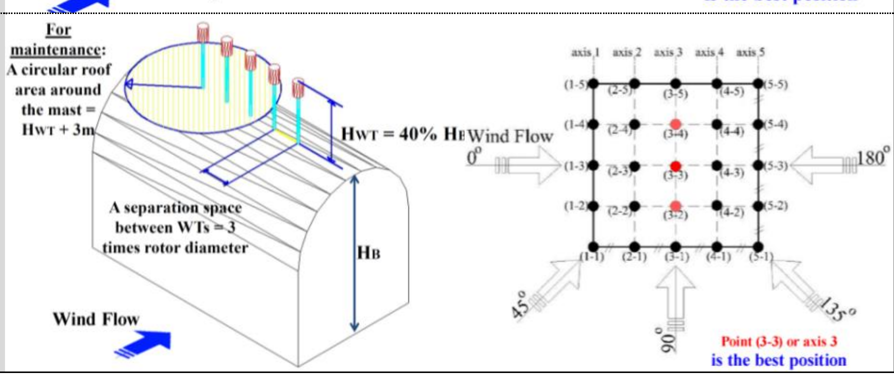
2.1. Fundamental Considerations for Integration Methods

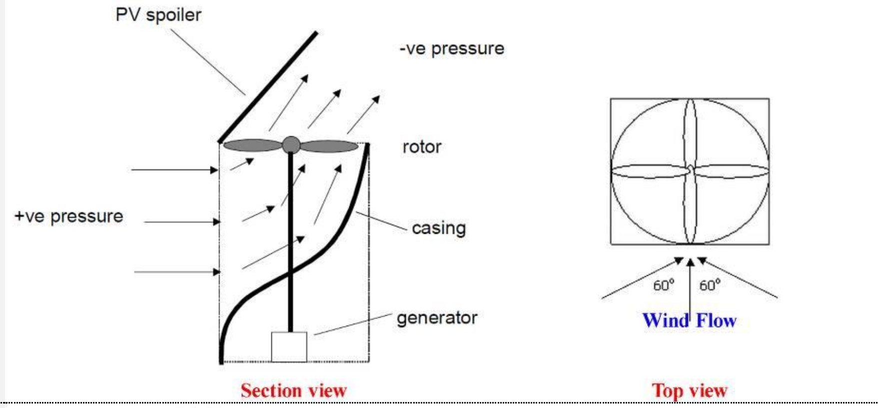
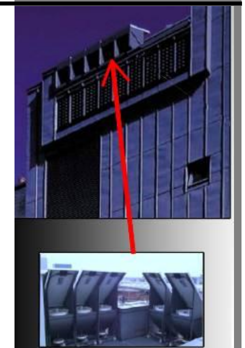
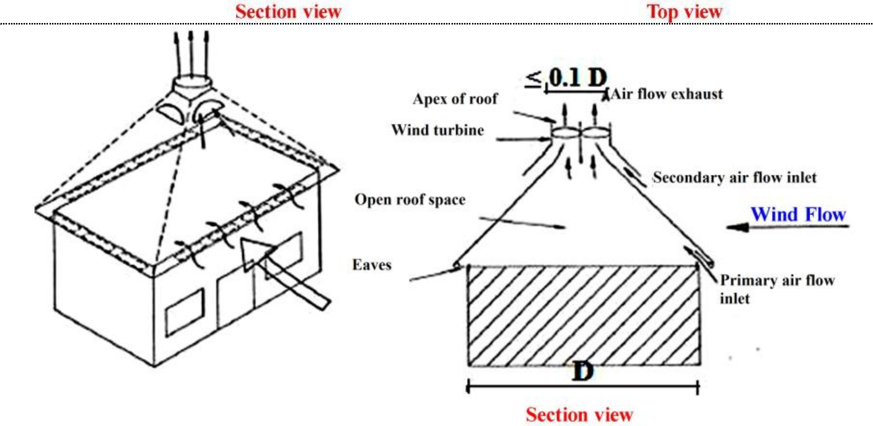
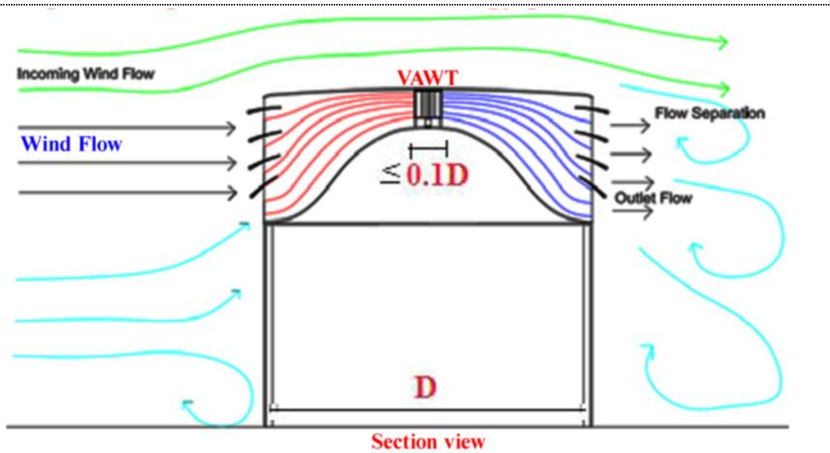
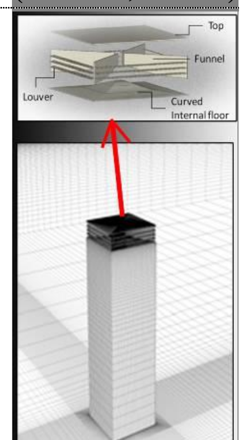
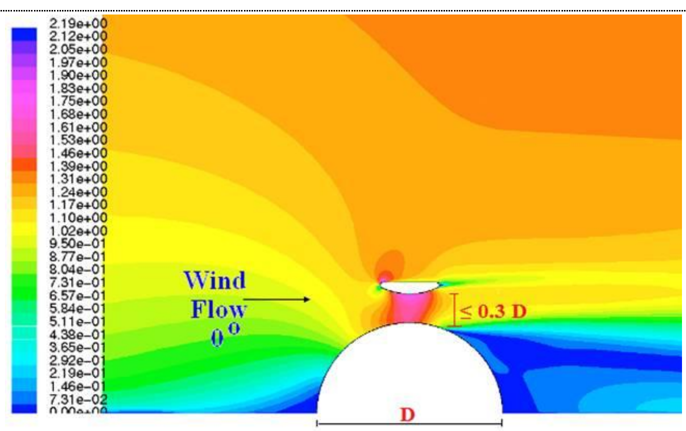
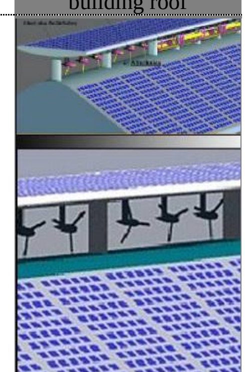
The efficient integration of WTs into buildings must overcome the following fundamental considerations. First: treating vibration from WTs by vibration dampening at the base and head of WT [6]. In addition, acoustic treatment should be done by isolating WTs from occupants in the building with technical or service spaces. Second: designing the external envelope of building to accelerate and not disturb the wind flow towards the WT [2]. Third: considering safety requirements in supporting the WTs. Furthermore, maintenance requirements should be considered by a straightforward and a safe access to WTs components [7]. Moreover, a space within the building for WT system and a passage for cables between WT and main switchboard is required [5; 8]. Finally: Energy yield enlargement by the integration of multiple WTs on the same building is favorable [5].

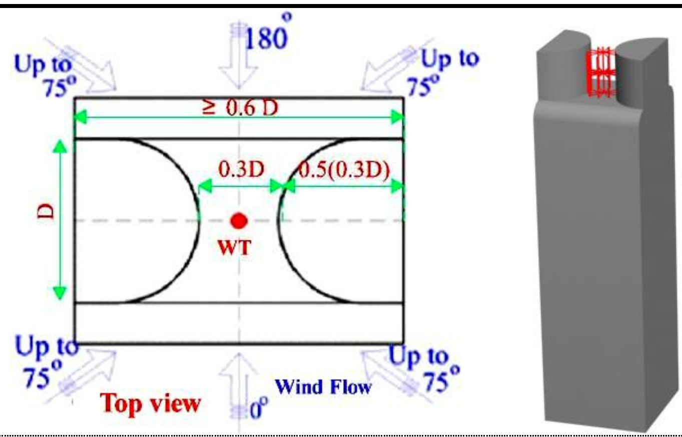
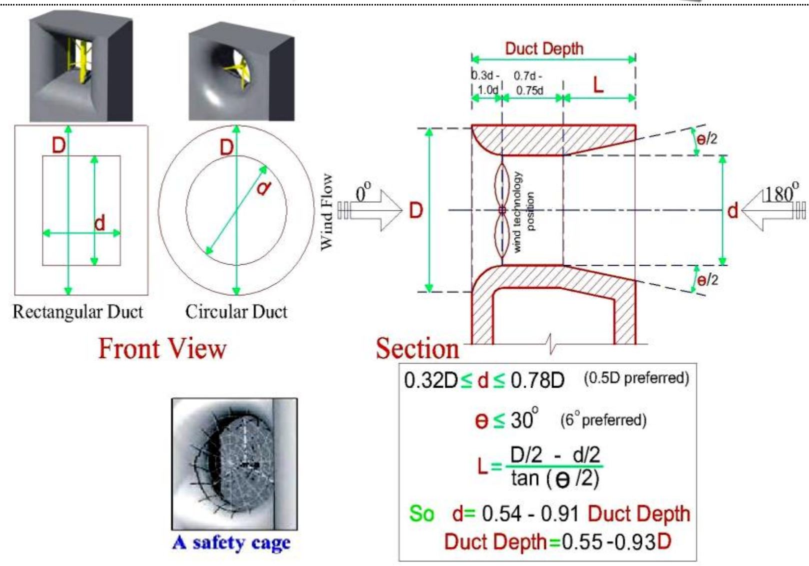
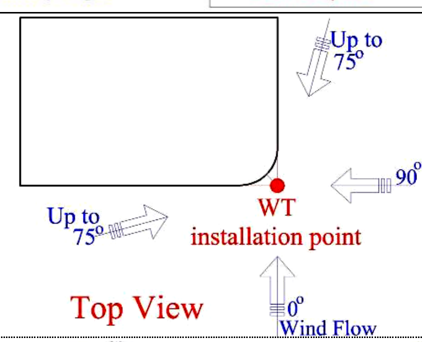
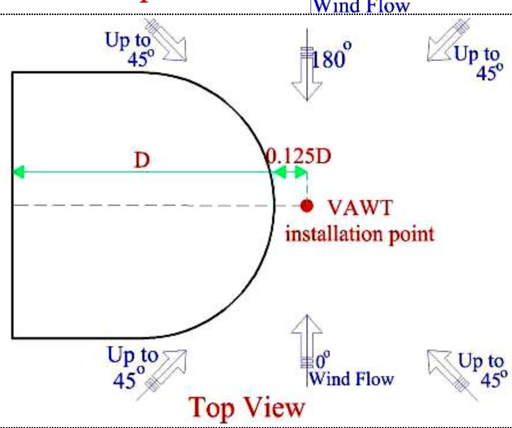
2.2. Integration methods types

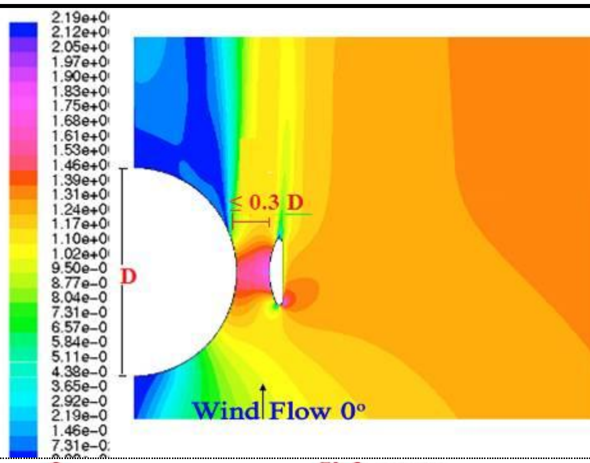
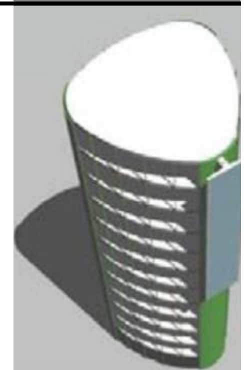
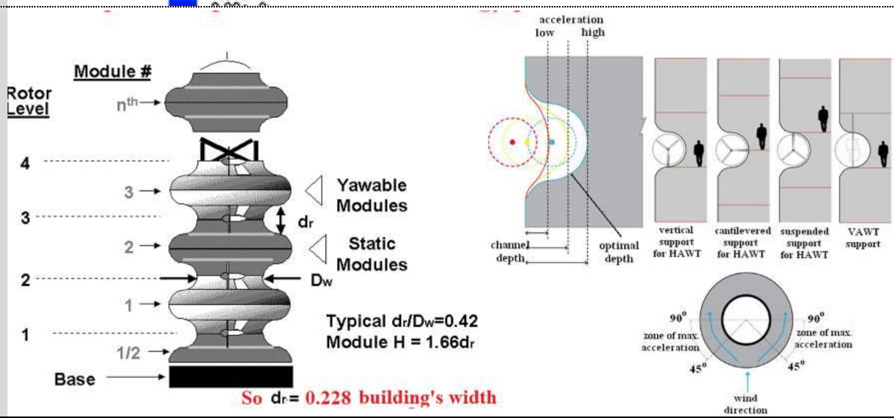
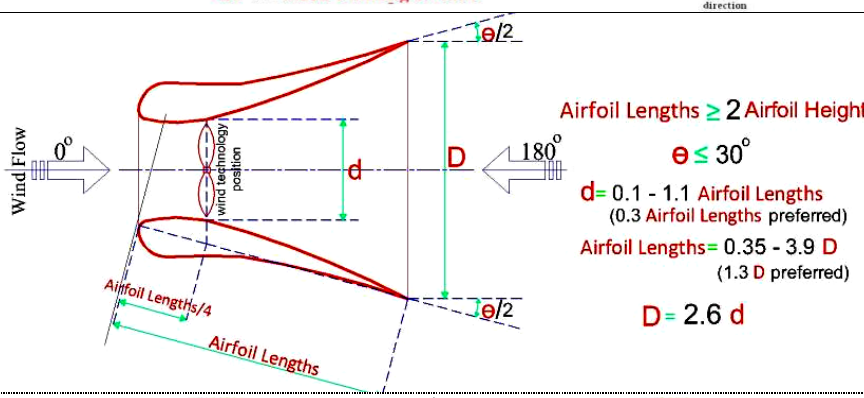
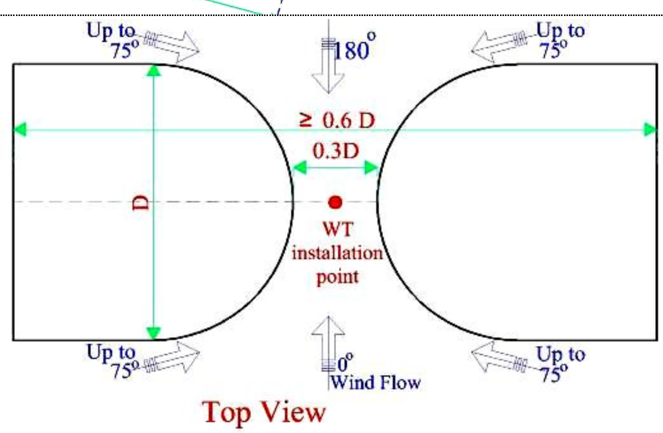
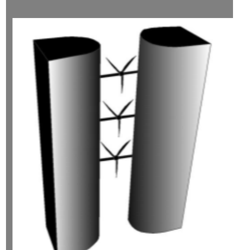
The main methods of WTs integration into buildings vary from integration on roof to integration as an external envelope. In addition, each main integration method has sub-methods which have characteristics and considerations as illustrated in Table 1.

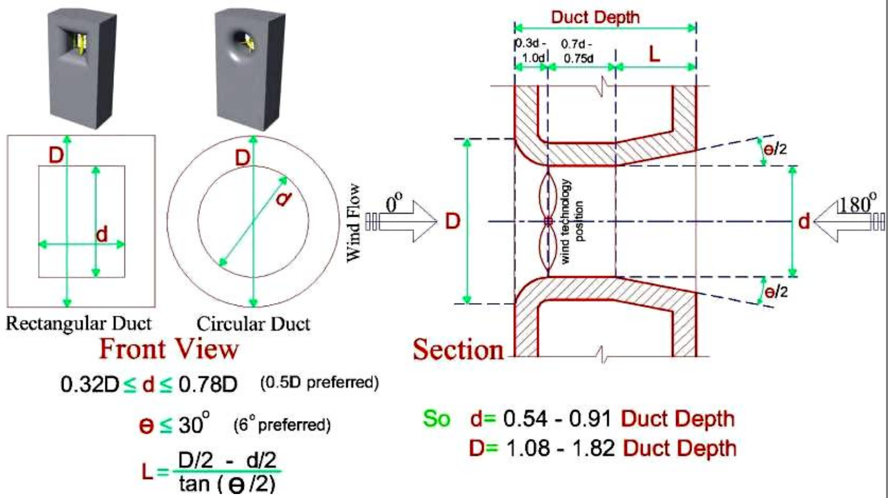
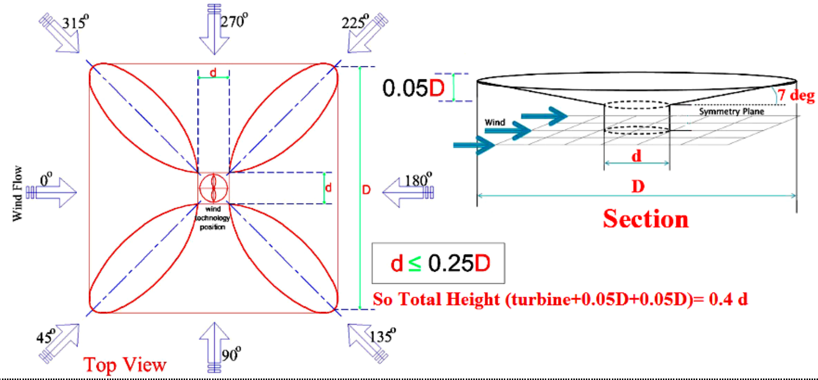
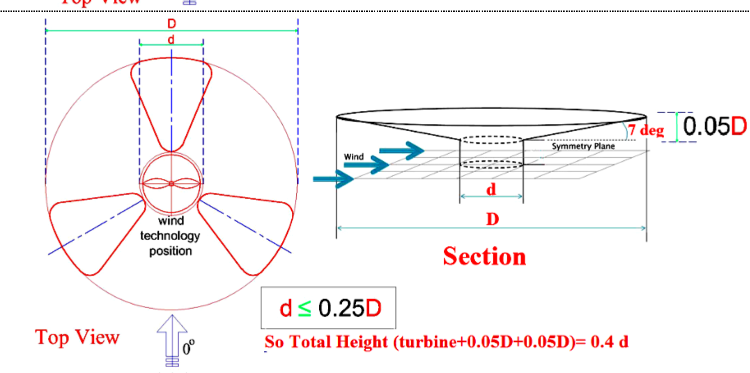
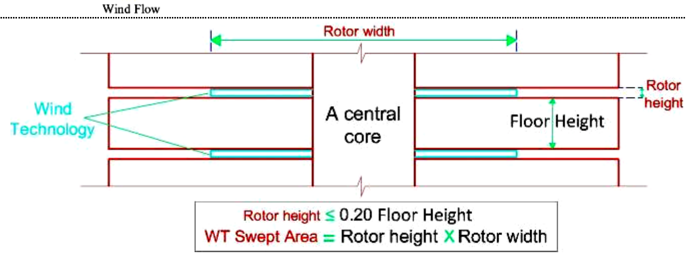
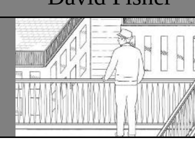
Table 1: The shapes, optimum WT positions and building examples for integration methods types. Source: the authors after [2; 9; 10; 11; 12; 13; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23; 24; 25; 26; 27; 28; 29; 30; 31; 32; 33; 34; 35; 36].

Integration methods types		Integration methods shape and optimum WT positions	Building example
On roof	On parapet		  Museum of Science (Boston, UK)
	Domed		NA
	Vaulted		NA

Integration methods types		Integration methods shape and optimum WT positions	Building example
Concentrator on roof	Ducted Wind Turbine Module		 Lighthouse building (Glasgow, UK)
	Robertson and Leaman's Roof		  Council House 2 (Melbourne, Australia)
	Integrated Roof Wind Energy System (IRWES)		 IRWES integrated on building roof
	Aeolian Roof		 Aeolian Roof building-augmented system

<table>
<tr><th colspan="2">Integration methods types</th><th>Integration methods shape and optimum WT positions</th><th>Building example</th></tr>
<tr><td></td><td>Between two shrouds</td><td>
</td><td>NA</td></tr>
<tr><td></td><td>In a duct on building roof</td><td>
</td><td>
Strata SE 1 building (London, UK)</td></tr>
<tr><td rowspan="2">On building side</td><td>Edge or corner</td><td>
</td><td>
Kinetica building (East London, UK)</td></tr>
<tr><td>Curved side</td><td>
</td><td>
Building with integrated VAWTs on tracks</td></tr>
</table>

Integration methods types		Integration methods shape and optimum WT positions	Building example
	Aeolian Corner		 Aeolian Tower building-augmented system
	Wind Amplified Rotor Platform (WARP) system		NA
Between twin buildings	Between airfoil-shaped buildings		 Bahrain World Trade Centre (Manama, Bahrain)
	Between half sphere-shaped buildings		 Three HAWTs integrated between half sphere-shaped buildings

<table>
<tr><th colspan="2">Integration methods types</th><th>Integration methods shape and optimum WT positions</th><th>Building example</th></tr>
<tr><td colspan="2">Concentrator within a building façade</td><td>
</td><td>
WEB building Project</td></tr>
<tr><td rowspan="3">Combined concentrator within a building façade</td><td>Flower concept with four petals</td><td>
</td><td>
SkyZED building Project</td></tr>
<tr><td>Flower concept with three petals</td><td>
</td><td>
Paul Michael Pelken building project</td></tr>
<tr><td>Between building floors</td><td>
</td><td>
The rotating tower by David Fisher</td></tr>
<tr><td colspan="2">As an external envelope of building</td><td>It is preferable to install WTs at the windward of building envelope (front and sides) and avoid the leeward (rear).
Windbelt technology integrated with the building parapet (by Humdinger company) →</td><td></td></tr>
</table>

3. VARIABLES FOR DETERMINING SUITABLE INTEGRATION METHODS

For determining suitable integration methods of WTs into a building in an exact site; a framework is created based on two main points: (1) Site variables and (2)

Integration methods variables, as shown in Fig. 1. These two points are illustrated in Sections 3.1 and 3.2.

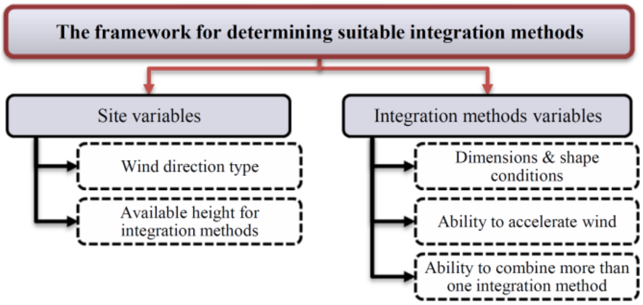


Figure 1: Variables for the determination of suitable integration methods.

3.1. Site Variables

Site variables that affect the selection of suitable integration methods are both wind direction type and available height for integration methods which are illustrated in Section 3.1.1 and 3.1.2.

3.1.1. Wind Direction Type

Wind directions type in the site can be uniform, weakly unidirectional, strongly unidirectional and bi-directional as studied in Table 2. Moreover, each integration method has suitable and non-suitable wind directions types as shown in Table 3. As a result, for any exact site; there are some non-suitable integration methods that should be excluded.

Table 2: Wind directionality classification. Source: the authors after [2]

Classification	Criterion
Uniform	No more than 60 % of the wind comes from one wind direction* or from one wind direction plus 75° range from the prevailing wind direction on both sides.
Weakly unidirectional	More than 60 % of the wind comes from one wind direction* or from one wind direction plus 75° range from the prevailing wind direction on both sides.
Strongly unidirectional	More than 75 % of the wind comes from one wind direction* or from one wind direction* plus 75° range from the prevailing wind direction on both sides.
Bi-directional	More than 95 % of the wind comes from two opposite wind directions or from two opposite wind directions plus 75° range from the two opposite wind direction on both sides.

*One wind direction means the prevailing vertical wind direction on the site.

Table 3: Suitable wind directions types (marked with √) for each integration method (concluded from Table 1).

Integration methods \ Wind directions types		Uniform	Weakly unidirectional	Strongly unidirectional	Bi-directional
On roof	On parapet			√	
	Domed	√	√		
	Vaulted			√	√
Concentr--ator on roof	Ducted Wind Turbine Module			√	
	Robertson and Leaman's Roof	√	√		√
	IRWES	√	√		√
	Aeolian Roof			√	√
	Between two shrouds		√	√	√
	In a duct on building roof		√	√	√
On building side	Edge or corner		√	√	√
	Curved side		√	√	√
	Aeolian Corner		√	√	√
	WARP system	√	√	√	√
Between twin buildings			√	√	√
Concentrator within a building façade			√	√	√
Combined concentrator within a building façade		√	√		
As an external envelope of building		√	√	√	√

3.1.2. Available Height for Integration Methods

Integration on building roof and in a concentrator on building roof methods can only be used above building height, i.e. in the distance between building height and construction permitted height (which determined by height regulations). In addition, other methods can only be used under building height i.e. in the distance between minimum suitable height for WTs and building height. It should be noted that the minimum suitable height for WTs is 1.5 times the surrounding obstacles height [37], particularly that within 500 m or within 4.5 times the surrounding obstacles height whichever is longer upwind for the prevailing or exploited wind directions [38; 39]. Furthermore, each integration method has height conditions. Therefore, by comparing building height with minimum suitable height for exploiting WTs and construction permitted height in the site, some integration methods can't be used as shown in Table 4.

Table 4: The cases of comparison between the building height and construction permitted height or suitable height to exploit WTs, in addition to excluded integration methods (marked with √) for each case. Source: the authors after Table 1and [2; 8; 9; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23; 32; 40; 41].

Cases No. in Fig. 2	Cases explanation*	Excluded integration methods									
		On roof			Concentr--ator on roof						
		On parapet	Vaulted	Domed	Between two shrouds	Others	On building side	Between twin buildings	Concentrator within a building façade	Combined concentrator within a building façade	As an external envelope of building
A	Hb = Hc	√	√	√	√	√					
B	Hb< Hc		√	√	√						
C	Hb = Hm						√	√	√	√	√
D	Hb > Hm							√	√	√	
E	Hb< Hm	√					√	√	√	√	√

* Symbols key: Hc is the construction permitted height; Hm is the minimum suitable height for WTs; and Hb is the building height.

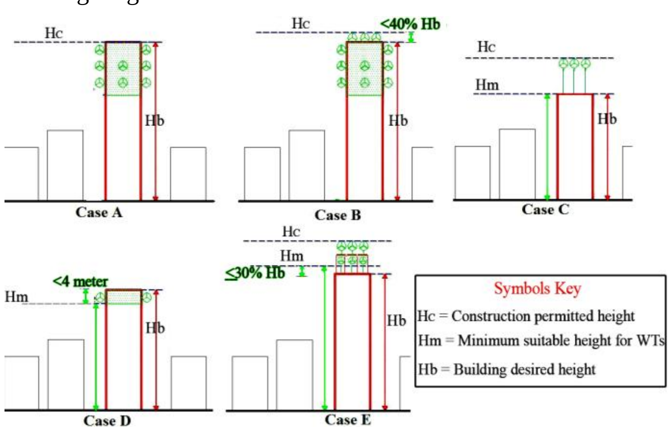


Figure 2: The cases of comparison between building height, construction permitted height and suitable height to exploit HAWTs. Source: the authors after [2; 8; 9; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23; 32; 40; 41].

3.2. Integration Methods Variables

Integration methods variables that affect the selection of suitable integration methods are dimensions & shape conditions, ability to accelerate wind and ability to combine which are illustrated in Sections from 3.2.1 to 3.2.3.

3.2.1. Dimensions & Shape Conditions

The dimensions and shape conditions of integration methods effect on the selection of suitable methods, as shown in Table 5.

Table 5: The dimensions and shape conditions of integration methods which lead to the exclusion of integration methods (marked with √) (concluded from Table 1).

Dimensions and shape conditions *	Excluded integration methods								
	On roof			On building side		Between twin buildings			
	On parapet	Vaulted	Domed	WARP	Others	irfoil-shaped building	half sphere-shaped buildings	Concentrator within a building façade	Combined concentrator within a building façade
D_1 or D_2 < (Hc - Hb)+3m		√	√						
D_2 < 5 Hb	√								
The building design can't be separated into two towers						√	√		
The building attached to another building from both sides				√	√				
The building attached to another building from one side				√					
The building back attached to another building with height equals or higher or slightly lower (with less than 4m) than Hb				√		√	√	√	√
The building can't be shaped near a circular plan				√					√
D_1< 2 Hb						√			
(Hb - Hm) < 0.1 D_1						√			
D_2 < 0.6 D_1							√		
(Hb - Hm) < 1.08 D_1								√	

* Symbols key: Hc is the constructions permitted height; Hm is the minimum suitable height for WTs; Hb is the building height; D_1 is the building dimension which in the same direction with the prevailing wind flow; and D_2 is the building dimension which faces the prevailing wind flow.

3.2.2. Ability to Accelerate Wind

Ability to accelerate wind for integration methods are varied as shown in Table 6. This means that, the priority of selection should belong to integration method with the highest acceleration value.

Table 6: Selection priority order of integration methods depending on the maximum increase in wind speed. Source: the authors after [9; 10; 16; 17; 18; 19; 20; 21; 22; 28; 30; 32; 34; 42; 43; 44].

Integration methods		**Maximum increase in wind speed(V)***	**Order of selection priority**
On roof	On parapet	1.15 V	14
	Domed	1.14 V	15
	Vaulted	1.16 V	13
Concentrator on roof	Ducted Wind Turbine Module	1.35V	8
	Robertson and Leaman's Roof	1.10 V	16
	IRWES	1.23 V	9
	Aeolian Roof	1.60 V	4
	Between two shrouds	1.40V	7
	In a duct on building roof	1.78 V	3
On building side	Edge or corner	1.22V	10
	Curved side	1.46V	5
	Aeolian Corner	1.60 V	4
	WARP system	1.80V	2
Between twin buildings	half sphere-shaped buildings	2.49 V	**1**
	airfoil-shaped buildings	1.21 V	11
Concentrator within a building façade		1.78 V	3
Combined concentrator within a building façade	Flower concept with three petals	1.44 V	6
	Flower concept with four petals	1.20 V	12
	Between building floors	0.78 V	17
As an external envelope of building		0.78 V	17

* It is compared to a free standing wind turbine at the same location. It should be noted that the data of maximum increase in wind speed are presented for indicative purposes only to choose from different integration methods, as it will vary in both the positive and negative direction depending on the particular real-life project being considered. Hence, a CFD or wind tunnel test is used to determine the exact increase in wind speed for a specified building.

3.2.3. Ability to Combine Integration Methods

Ability to combine more than one integration method together on the same building is suitable for some integration methods and not for others. Therefore, using some integration methods leads to the exclusion of other integration methods as shown in the matrix in Table 7. It should be noted that, integration as an external envelope of building isn't excluded by using any integration method.

Table 7: Matrix to determine the excluded integration methods (marked with √) for each integration method.

Integration methods		On roof			Concentrator on building roof						On building side				Between twin buildings		Concentrator within a building façade	Combined concentrator within a building façade		
		On parapet	Domed	Vaulted	Ducted Wind Turbine Module	Robertson and Leaman's Roof	IRWES	Aeolian Roof	Between two shrouds	In a duct on building roof	Edge or corner	Curved side	Aeolian Corner	WARP system	Between airfoil-shape buildings	Between half sphere-shaped buildings		Flower concept with four petals	Flower concept with three petals	Between building floors
On roof	On parapet				√	√	√	√	√	√					√					
	Domed					√	√	√	√	√					√					
	Vaulted					√	√	√	√	√					√					
Concentrator on roof	Ducted Wind Turbine Module	√				√	√	√	√	√					√					
	Robertson and Leaman's Roof	√	√	√	√		√	√	√	√					√					
	IRWES	√	√	√	√	√		√	√	√					√					
	Aeolian Roof	√	√	√	√	√	√		√	√					√					
	Between two shrouds	√	√	√	√	√	√	√		√					√					
	In a duct on building roof	√	√	√	√	√	√	√	√						√					
On building side	Edge or corner											√	√	√						
	Curved side										√		√	√						
	Aeolian Corner										√	√		√						
	WARP system										√	√	√		√	√	√	√	√	√
Between twin buildings	Between airfoil-shaped buildings	√	√	√	√	√	√	√	√	√				√		√	√	√	√	√
	Between half sphere-shaped buildings													√	√			√	√	√
Concentrator within a building façade														√	√			√	√	√
Combined concentrator within a building façade	with four petals													√	√	√	√		√	√
	with three petals													√	√	√	√	√		√
	Between building floors													√	√	√	√	√	√	

4. CONCLUSIONS

This paper presented WTs integration into buildings by illustrating the integration methods from integration on building roof to integration as an external envelope of building. It also defined the set of fundamental considerations that should be considered to achieve successful integration of WTs into buildings which are from vibration treatment to energy yield enlargement. It also illustrated that, every integration method has its acceleration advantage; suitable wind directions; and positioning considerations. Hence, there is no preferable integration method in general. But each specific building in specific site has the most preferable integration methods. As a result, the selection of suitable integration methods is affected by both site and integration methods variables. This preliminary study could be considered as the basis for further research and development of the efficient integration of wind technologies into building and a key aspect to conduct complete systematic framework.

5. REFERENCES

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