Deliverable 6.5

Structural Analysis and SWT Solutions for Typical European Buildings

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Executive Summary

Europe's building stock can be summarised in 10 example buildings which characterise the diversity of structures that could have SWTs installed on them in peri-urban areas across the continent. The example buildings were generated from a study of Europe's range of climates and construction approaches cross referenced typical uses and contexts. The buildings are located in 5 cities from Goteborg to Zaragoza and represent housing, educational, commercial and recreational usages.

By examining the buildings and the variety of their constructional properties and structural conditions, and by looking at the work developed in other SWIP task(s), it has been possible to develop a suite of standardised structural approaches to integrating SWTs on such buildings.

The exact selection of SWT support depends on an evaluation of the condition of, and interrelationship between, roof type, structural span, whether the structures members have any inbuilt and unused structural capacity as well as SWT type desired.

Three broad approaches have been extrapolated; SWTs supported on new Floating bases (concrete or steel) that sit on the roof but do not penetrate through it, SWTs supported on transfer frames that span between underlying structural walls or columns (and may penetrate the buildings lining) and ground mounted support arrangements where the building provides only a stabilising restraint to the SWT loads.

In this way a comprehensive atlas of typical buildings and model SWT integration solutions suitable for them has been proposed.

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Abbreviation list

	Description
SWT	Small Wind Turbine
PUA	Peri Urban Area (suburbs)
msq	Metres squared

1 Introduction

The task at hand is to develop and catalogue a series of structural solutions for the deployment of small wind turbines (SWT) on and around typical European Buildings based on a structural analysis of said typical buildings.

The present report begins by elaborating a methodology for elucidating what constitutes a suite of typical buildings in Europe and continues on to source representative samples of said buildings: These samples are then analysed for their construction and structure and summarised as a set of question which a suitable SWT integration solution would have to address.

The second part of the report examines these structural conditions and reviews possible structural methods for supporting SWTs of built structures in the Europe context (drawing on the experience f deigning SWTs at the 3 SWIP pilots) proposes a number of engineering approaches to installing SWTs on such buildings.

In this way a range of potential SWTs integration approaches, suitable for typical European buildings are presented.

2 Sampling European Buildings

2.1 The Distribution of European Buildings

The most surprising thing about this task has been the discovery that there is no immediately accessible atlas or catalogue of European buildings. This of course means by implication that no catalogue or profile of *typical* European buildings is available either. Thus a significant body of the work has been the development of a methodological approach to determining, from first principles, what constitutes typical European buildings.

2.1.1 Typology- Definition

The first question that needed to be addressed is what are the accepted classifications or types of buildings in society ? Such classification of buildings is routinely done by the type of use to which the building will be put such as school, office, sports etc. Another way to do it is to use a more complex or academic taxonomy known as typology; a classification of (usually physical) characteristics commonly found in buildings and urban places, according to their association with different categories, such as intensity of development, degrees of formality[1], or conceptual framework for instance the small cottage is a typological example of the use type single-family (detached) home.

Perhaps the most advanced recent study of European buildings (albeit domestic) is to be found in the Episcope[2] project of the FP7 programme. Episcope researchers developed a methodology to identify which terminology of type could be accepted as comprehensively classifying European buildings.

[B] Common Definition

In order to exchange information between countries uniform definitions are necessary. Therefore the TABULA consortium has agreed on a number of settings concerning the classification systematics, the data structure and the energy balance calculation to be applied to all National Building Typologies.

Both definitions of a National Building Typology are describing the same physical properties. They are only two sides of the same coin. All TABULA partners are responsible for the consistent transformation between their national and the common definition.

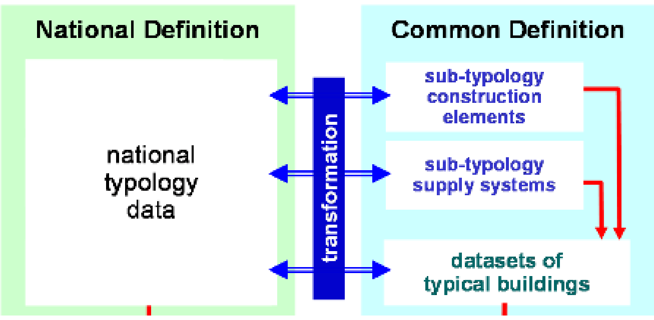

Figure 1. Elaboration of Buildings Typology, Episcope.

[1] https://en.wikipedia.org/wiki/Typology_%28urban_planning_and_architecture%29
[2] http://episcope.eu/building-typology/tabula-structure/concept/

The research considered country, age, construction type and use.

The TABULA partners agreed on the following definitions for a common data structure:

1 Parameters for Classification		
	1 Country	country identification
	2 Region	> national > { region of the country, if necessary }
	3 Construction Year Class	for each country definition of periods: from { year }... to ... { year }
	4 Building Size Class	categories: > single family house > terraced house (single family) > multi-family house > apartment block
	5 Additional Parameter	optional / for example: > semi detached / end-terrace house > mid-terrace house > tower building > half timbered building > panel building > etc.
2 Reference area		floor area based on internal dimensions (see DATAMINE evaluation)

Figure 2.Parameters for Cassification of buildings, Episcope

The outcome of the Episcope efforts and indeed of other similar initiatives, we have come across suggests that the following types can be relied upon to adequately classify European buildings;

- Residential Single dwellings
- Residential multi family (apartment buildings etc)
- Office buildings
- Educational/School buildings
- Buildings with other functions (Hotels/ restaurants, Sports. Retail/Wholesale/Trade)
- Industrial buildings
- Other (none of the above)

2.1.2 Statistical Distribution- Types

Statistics on the European building stock are notoriously underdeveloped. Most analyses that are available have emerged from energy efficiency initiatives and focus on the characteristics of domestic buildings to the exclusion of non-domestic buildings. While residential building inventories are profiled to a high level of detail; analysis of their distribution, spread/location, construction type, standard and energy performance, as well as extensive evaluations of the opportunity to improve their energy ratings, non-domestic building tend to be profiled only according to use.

What we expected to find was a comprehensive atlas or dataset of European buildings that would illustrate for us what proportion of the building stock were respectively; of a certain age range, of different constructional types, of different structural spans (short, medium, long), heights, standing alone or attached (on their sites), flat roofed or having other roof types etc.

The Tabula database does carry extensive information about residential buildings in Europe and as mentioned has generated distributions for us that have informed the selection and characterisation

of type and typologies of European buildings used below. Both the Inspire project[3] created under the FP7 programme and Episcope under Intelligent Energy Europe developed building datasets (Tabula[4] being the latter) focusing on the energy status and improvement opportunities of buildings across Europe but focused almost entirely on residential buildings (Inspire does have a component that includes office buildings). BPIE[5] The European Hub for Building Data promises to function as the first knowledge repository for statistics and policy information on Europe's building stock and to offer data search across countries to make comparisons possible, through its BuildingsData[6] portal

According to Inspire, the total residential floor area in the EU 27 is approximately 17.6 billion msq. Of this 15.1 billion msq is estimated to be heated. Almost three quarters of this (72%) lies in the 'big six' countries; Spain, Italy, France, Germany, UK and Poland. The total office floor area in the EU 27 is approximately 1.25 billion msq. Of this 1126 million msq is estimated to be heated and 846M msq cooled. Almost three quarters of the total floor area (71%), lies in the same six countries that dominate the residential stock; Spain, Italy, France, Germany, UK and Poland.

About 68% of residential, and 58% of office stock, was constructed before 1980[7].

Eurostat[8] focuses on involvement of people with buildings (numbers housed, employment in construction etc) without much regard for type, age or construction class and is more interested in year to year trends than establishing a historic baseline of any kind.

The BuildingData tool offers some intra category search potential;

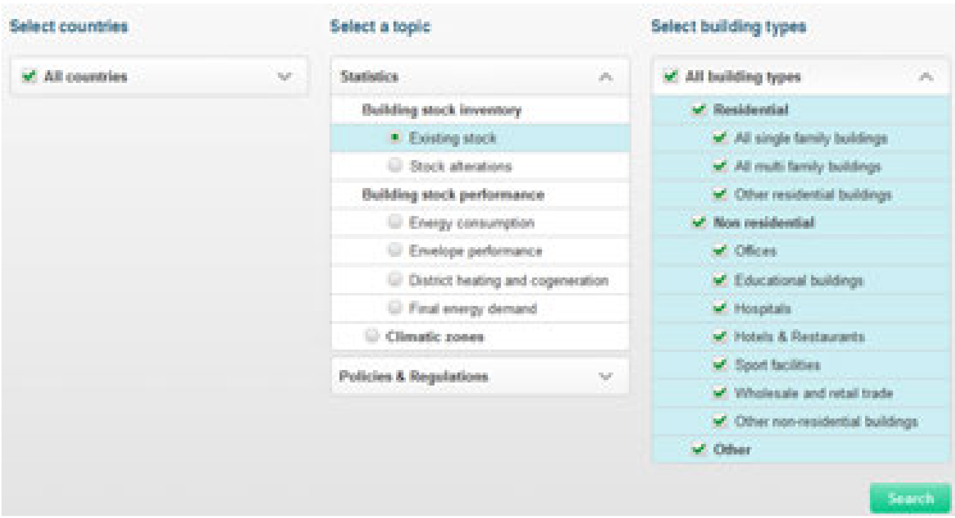

Figure 3. Search Window Buildingdata.eu

The following Building data charts illustrate European building stock by type and for both gross floor area and building numbers across all states (see below).

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[3] http://www.inspirefp7.eu/

[4] http://episcope.eu/welcome/

[5] http://www.buildingsdata.eu/

[6] www.buildinsgdata.eu/

[7] http://www.inspirefp7.eu/wp-content/uploads/2014/08/WP2_D2.1a_20140523_P18_Survey-on-the-energy-needs-and-architectural-features.pdf/

[8] http://ec.europa.eu/eurostat/web/main/home/

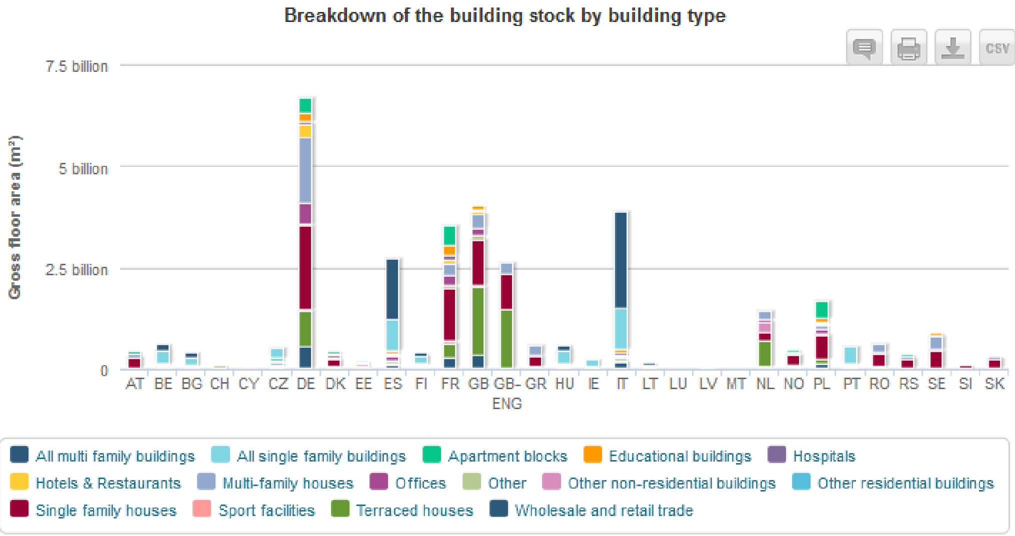

Figure 4. European Building Data by Type and Area (across 27 countries- www.buildgdata.eu)

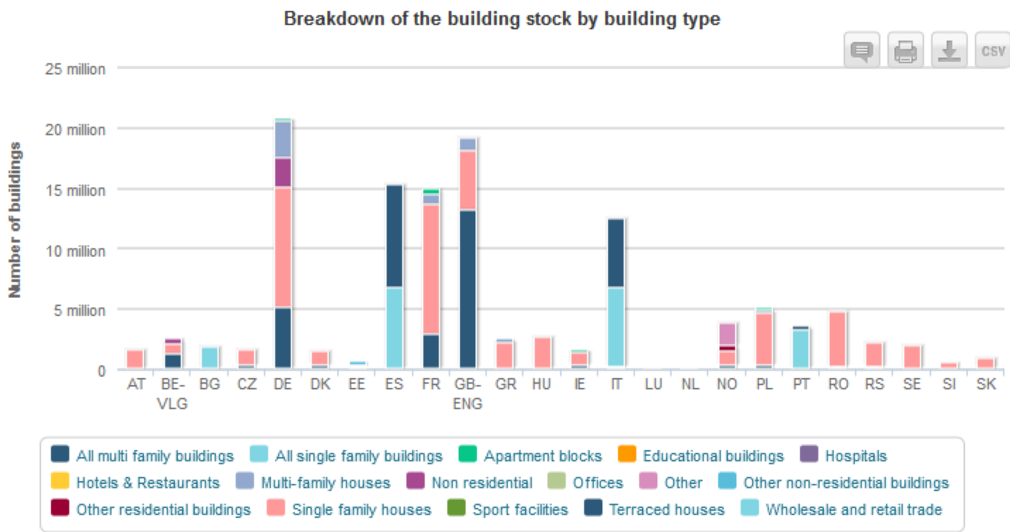

Figure 5. European Building Data by Type and Number (across 27 countries- www.buildgdata.eu)

What this data (and other data not illustrated herein) tells us is that the European built landscape is comprised in broad terms of a rich mix of many building use types with further variation in size, height, age and quality. We can extrapolate that there is a variety in terms of construction and structural approaches also.

What became necessary then is to speculate as to how many of these building types were likely to be found in the peri-urban areas that are subject to wind patterns and have surface roughness most suitable to the deployment of SWTs on buildings (the premise of the entire SWIP project).

Table 1. Type V Height of Europe Buildings

Typology	Industrial	Office	Educational	Residential	Other
Height	1= likely, 0 = unlikely to predominate in peri urban (SWT suitable) areas				
1-2 storey	1	1	1	1	1
2-3 storey	0	1	0	1	1
4-6 storey	0	0	0	0	0
Detached/semi	1	1	1	1	1
≤ 15m high	0	0	0	0	1

This was then corroborated when representative cities were selected (see below) and statistical analysis (of sample views from Google street view) of randomly chosen map grids of these cities peri-urban areas were carried out.

2.1.3 Geographic Distribution-Location

Having determined, or at least suggested, which types of building are most likely to proliferate in Europe's typical peri-urban areas, we now set out to determine what specific structures could be said to represent the typical buildings of Europe.

In theories of architectural history it is axiomatic that climate and material resource availability have influenced the evolution of construction. Over centuries people of a certain climatic-ecological region (a biome) develop building techniques that adapt to the weather/climate of the region and use the materials that are close by. In time, these typical buildings become codified and eventually become the de-facto norm or standard typology (for each use type) of a given region. As society develops, the buildings that follow either cohere to or contrast with them but in all cases they respond.

Our proposition then is that climate can serve as a proxy for construction and thus climate zones can indicate regions of likely constructional homogeneity. Furthermore, we suggest that buildings sampled from these zones can serve as being representative of typical buildings of the zones and, ultimately when taken together, can serve as a catalogue, or at least representative samples, of typical European buildings per se.

Climate zones / Culture Zones

The following chart depicts the typical climate zones in Europe.

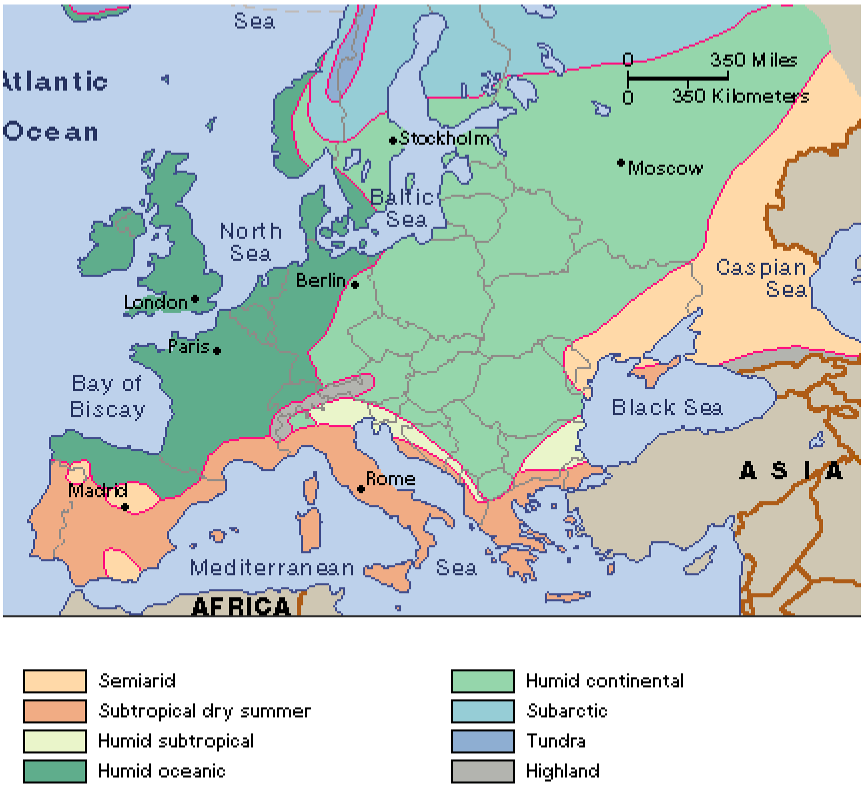

Figure 6. Typical Climatological Zones of Europe

2.1.4 Determining Typical Cities and Buildings

On the basis of the climate zones, which we are proposing serve as an indicator of building cultures, we would present the following 5 cities as representing climate zones the building of which should comprise a representative sample of the European building stock.

Figure 7. Cities that are Representative 'Hosts' for Typical European Buildings (Goteborg, Hamburg, Bratislava, Genève, Zaragoza).

2.1.5 Appropriate Locations in Selected Cities

It is the premise of SWIP that urban SWTs will most likely be applied to buildings in the suburban and peri- urban contexts. This task (T6.1) takes this assumption as the starting point for identification of sample building locations and conditions.

2.2 The Construction of European Buildings

A critical aspect of defining solutions for the structural integration of SWTs into (or onto) a building is the construction properties (stability, rigidity, integrity, span dimension and load paths) of the host building. Building that are framed but flexible create different challenges than those that are rigid, than those that are solid (heavy) but non-monolithic for instance. It becomes important then to survey the range of construction approaches in Europe even if only in outline so as to ensure that the sample buildings we have arrived at are truly representative of Europe's buildings.

2.2.1 Construction Systems Typical to European Buildings

Construction Methods

European buildings typically comprise only a few building methods. The vast majority of suburban buildings are made of masonry or timber or a combination of these with a small proportion using either more indigenous (primitive/alternative) or more modern materials.

It is possible and useful to generalise the architectural characteristics of sub-urban buildings in Europe to state that for instance;

- Most are built in the 20th century by their own (at least originally) users.
- Most are less than 3 storeys tall and have flat roofs or tiled (sloped) roofs.
- Most have one use.
- Most do not sit independently on their own site but adjoin other buildings.

It is further possible to generalise that Europes peri urban buildings can be categorised by the have the following construction parameters and properties:

- Form; rectilinear (rectangular) with sloped roofs, circular/curved etc
- Scale; large volume, many volumes connected, small volume etc
- Height; number of storeys or absolute height
- Cladding/Skin; finished in what material ?
- Age; of construction (can be indicative of construction method)
- Construction method; material of the framing, walls, intermediate elements etc

In attempting to generalise the family of SWT solutions suitable for typical European buildings, we have used these characteristics as analysis points for our sample buildings.

Structural Properties

For the purposes of structural integration of SWTs into (or onto) European buildings, the principle avenues of evaluation would focus on overall loading aspects such as span distance, global stability and the question of whether a buildings structure has any residual (load carrying) capacity in it (after normal calculated loads are accounted for).

As will be seen below the range of European buildings we propose below as being representative have been evaluated against the following typical structural systems;

- Masonry loadbearing walls
- Concrete construction or steel frame (both with masonry or timber infill panels).
- Timber frame construction

The relationship between the types and the construction properties can be summarized as follows;

Table 2. Relationship between building type and construction properties

Type	Industrial	Office	Educational	Residential	Other
Construction	Y= likely, O = unlikely, to predominate in peri urban (SWT suitable) areas				
Span; long	Y	O	O	O	Y
Span; medium	Y	Y	Y	Y	Y
Span; short	O	Y	Y	Y	O
Framed; flexi	Y	O	O	O	Y
Framed; rigid	Y	Y	Y	Y	Y
Solid (heavy)	O	Y	Y	Y	O

A subsidiary analysis might examine openings and fenestration (which has a relationship to acoustics).

3 A Catalogue of European Buildings

3.1 A Profile of Typical European Buildings for SWT

It was decided to cross reference the various climate zones (defined by their representative cities) and the various possible use types and structural properties /construction methods described above, to generate a profile of conditions of that could be said to be what representative of typical European buildings.

Table 3. Likely hieght of European buildings by use and representativ location

	Type	Industrial	Office	Educational	Residential	Other
	PUA Qualifiers	=1 storey	≤ 3 storey	≤2 storey	Single family Or Small Mutifamily	≤ 12m high
Climate Zone	**Representative City**					
Nordic	Goteburg	X		X		
Oceanic	Hamburg		X			X
Continental	Bratislava		X		X	
Alpine	Geneva	X				X
Southern	Zaragoza			X	X	

We then set out to identify a number of specific buildings that could serve as case studies of each of these conditions.

3.2 Goteburg

Two buildings were identified as answering the conditions generated for Goteburg

Figure 8. Location of Goteborg example buildings vis a vis the urban area.

3.2.1 Light Industrial

The first is a detached light industrial building in Lilhagen.

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Figure 9. Light Industrial Building in Lihagen Goteborg.

It is typical of many factory and industrial building found in European peri urban areas. It would typically stand alone on its own site and have space on all sides.

Table 4.Architectural characteristics, Light Industrial Building, Lilhagen, Goteborg.

Form	Scale/Site	Height	Roof	Construction
Rectangular simple shape volume	Small. Stand alone	< 2 storey	Metal Sheeting	Steel Panel

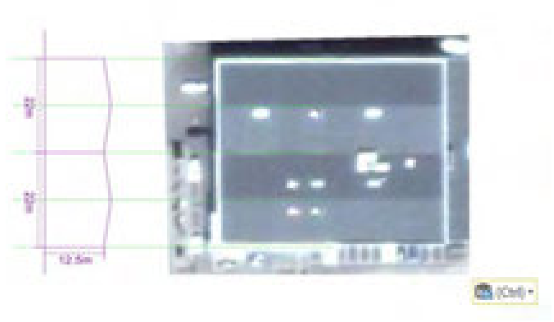


Figure 10. Light Industrial Building, Goteborg

Construction System

The building would often be made of prefabricated steel portal frames infilled with steel panels (with our without insulation) with integrated doors and windows. Roofs would usually be metal also and have geometries that are low sloped with drainage at eaves and valleys.

Smaller pods would be inserted or constructed inside to provide office, staff facilities etc.

Structural Analysis

Such structures are inherently light and often consist of pin jointed as well as rigid jointed frames. These are often repeated (laid out side by side) to increase floor area and to some extent global stability.

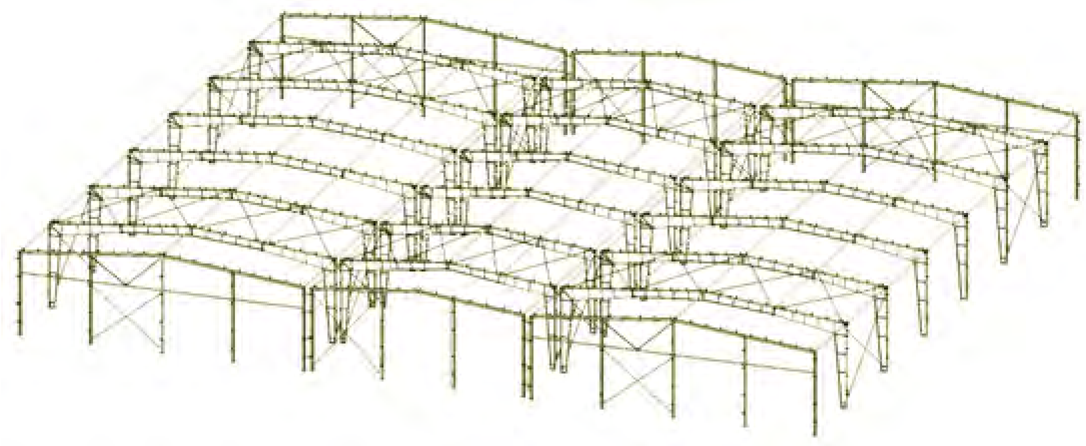


Figure 11. Likley Structural Diagram, Light Industrial Building, Lilhagen, Goteborg

The members are generally engineered to meet the minimum legal loadings and would rarely have much residual strength.

SWT Question

The integration of SWTs on such a building is quite challenging due to the lightweight nature of the condition. In order to arrive at which of the possible structural integration solutions below might suit, we can generalise the SWT support constraints and properties of this building as follows;

Table 5. SWT Conditions, Light Industrial Building, Lilhagen, Goteborg.

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?	●			
Long Span and Has Residential Capacity?	●			

Is Modifiable?	•

3.2.2 Kindergarten

The second building in Goteburg is a kindergarten in Gamlestaden.

Figure 12. Gamlestaden Kindergarten, Goteborg.

It is a two storey brick building set on its own grounds in the context of a housing enclave.

Construction System

It is constructed of masonry and timber with frequent internal walls. Cladding would be of fired brick and roof finish is of fired earth tiles.

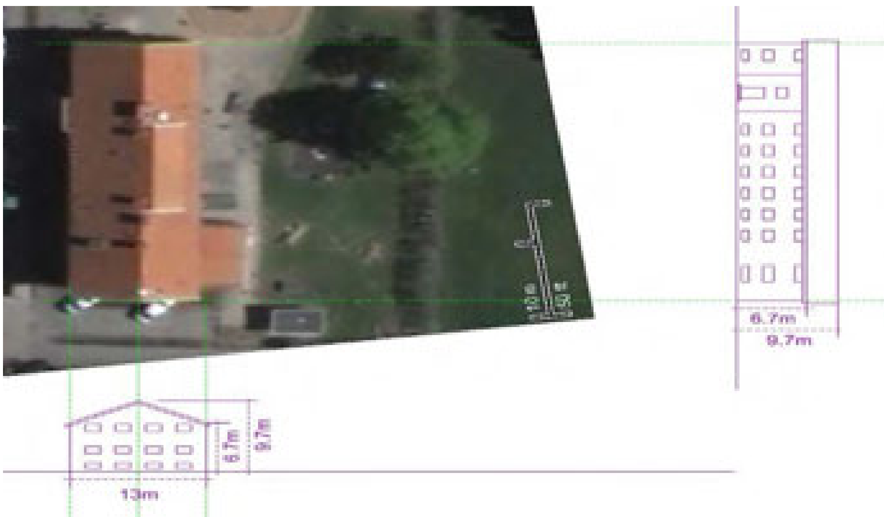


Table 6. Architectural Characteristics, Gamlestaden Kindergarten, Goteborg

Form	Scale/Site	Height	Roof	Construction
Rectangular single simple volume	Small Stand alone	< 3 storeys (+ basement)	Tile	Masonry and timber Load bearing brick walls

Structural Analysis

Such a building will be a solid structure of loadbearing masonry walls and interconnected floors (that, though wooden will be built to serve as structural ties) preventing spread of the walls. There would be frequent internal walls which, if all are loadbearing up as far as the roof, would mean it is essentially a short span structure.

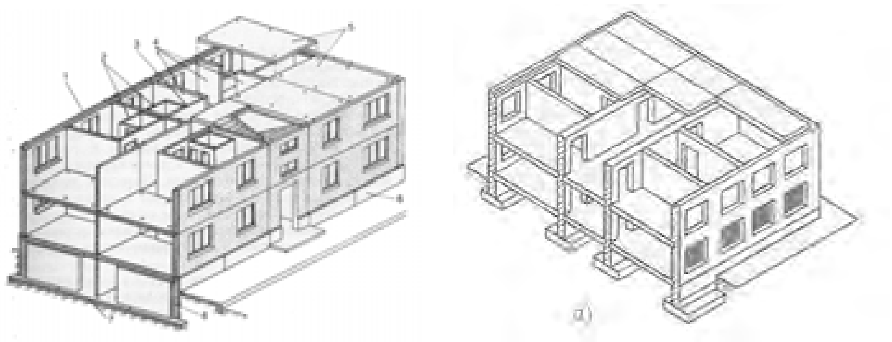


Figure 14. Likely Structural Diagram, Gamlestaden Kindergarten

The sloped roof will probably be formed from structural timber with trusses that use tie members to minimise the tendency for the walls to be spread by roof loads. Typically such buildings will have residual capacity to at least in the walls and foundations.

SWT Question

In a situation like this, support in terms of carrying the loads to ground or indeed spreading of loads, is not generally a problem. The key question becomes what detail mounting will work to secure the SWTs to the roof while preserving weatherproofing.

Table 7. SWT Conditions, Gamlestaden Kindergarten, Goteborg

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?		●	●	
Long Span and Has Residential Capacity?				
Is Modifiable?				

3.3 Hamburg

Two buildings were identified as representing the Hamburg condition.

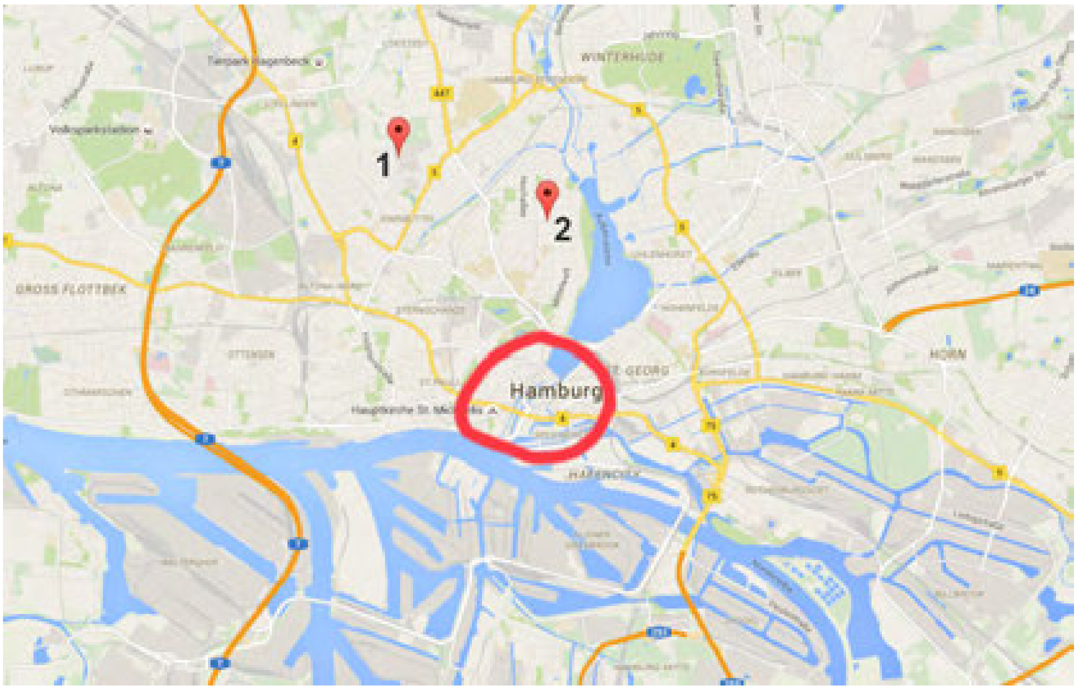


Figure 15. Location of Hamburg example buildings vis a vis the urban area

3.3.1 Large Office Building

The first, in Eimsbuttel, is a large office building set in the midst of a varied suburban block.

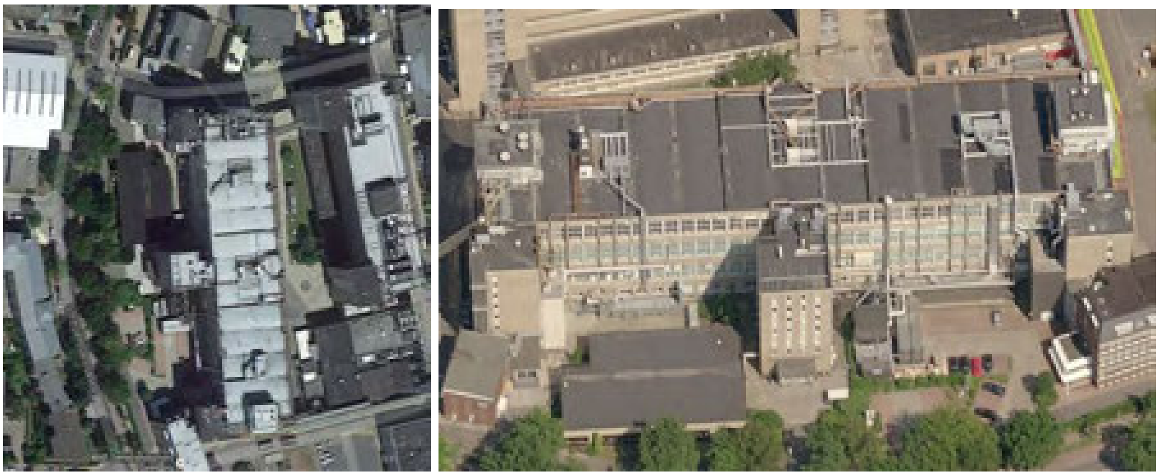


Figure 16. Eimsbuttel Office Building, Hamburg.

It is 4 to 5 storey stall and quite deep in plan. Such a building would one of the more common commercial (office) structure in the inner suburbs of larger European cities.

Construction System

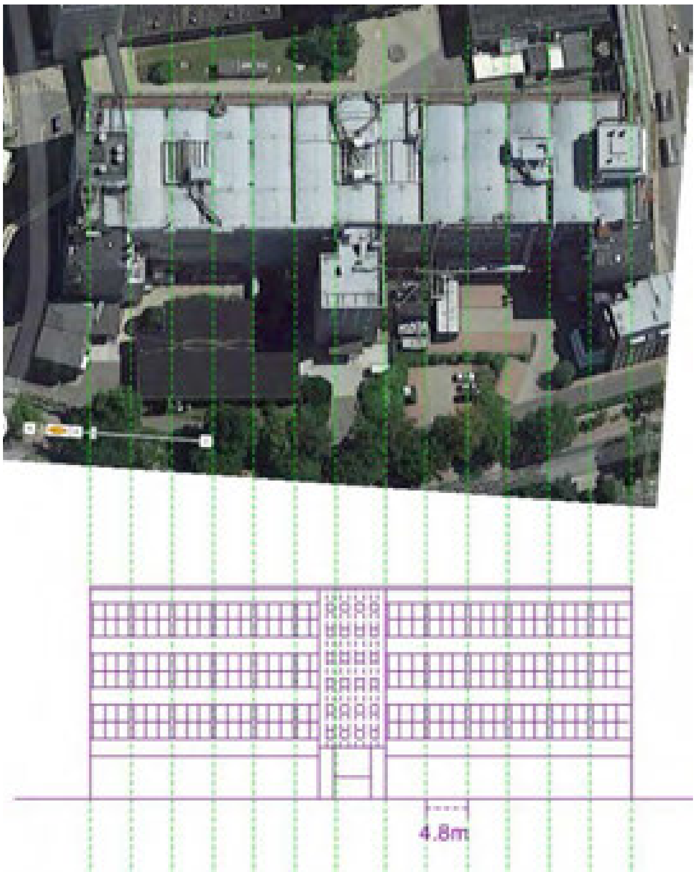


Figure 17. Likley Contruction system. Eimsbuttel Building, Hamburg

These buildings are typically constructed of concrete frames and have an infill of masonry and window panels walls as well as concrete floor and roof slabs. Weatherproofing is by an applied membrane on the roof or possibly by use of an inherently waterproof concrete slab or topping to the roof slab.

Table 8. Architectural Characteristics Eimsbuttel Building, Hamburg

Form	Scale/Site	Height	Roof	Construction
Rectangular single simple volume	Large	4 to 5	Masonry slab	Concrete frame construction and masonry walls

Structural Analysis

The structure of these building is rigid frame comprising of the large concrete columns and beams. The joints of this skeleton are inherently fixed though the occasional solid masonry panels add rigidity to the frame also. The roofs are normally a concrete slab with medium rather than long spans. There would normally be some residual capacity in the structural members.

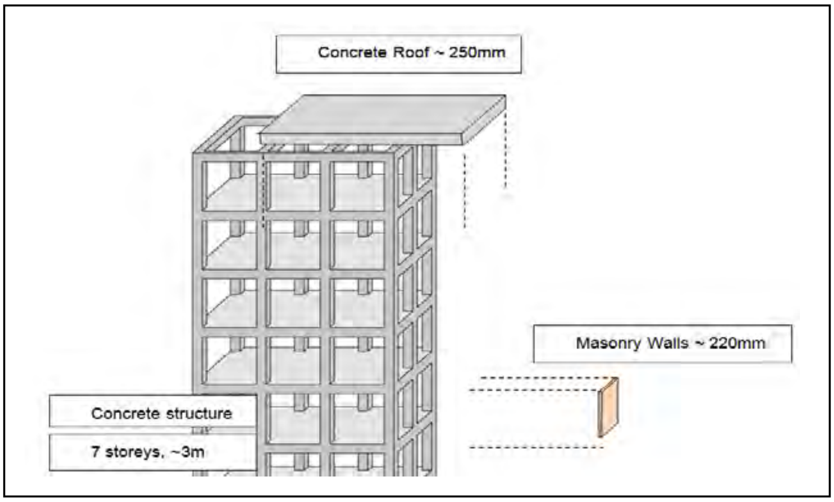


Figure 18. Likely Structural Diagram, Eimsbuttel Building, Hamburg

SWT Question

The principle question for this condition is the connection of an SWT support through the weatherproofing to the structure underneath. The structural parameters that must be considered in selecting a SWT support approach then are;

Table 9. SWT Conditions, Eimsbuttel Building, Hamburg

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?	●			
Long Span and Has Residential Capacity?			●	
Is Modifiable?			●	

3.3.2 Community Sports Hall

The second building is in the Hochallee suburb of Hamburg. It is a large sports hall/amenity building used as a community facility. Depending on the circumstances of the city, most suburbs would have a small number of such buildings.

Figure 19. Sports Hall Hochallee

In this case the building is single storey and stands almost in depended (ie to 3 sides) on a large complex of related buildings and has a vegetation belt to one (long) side.

Construction System

These buildings are similar to light industrial example in Goteburg in that they are made of steel structure (columns beams/trusses) with infill panels of metal cladding. The roof geometry is actually round (arched) and the roof finish is also metal.

Figure 20. Likley Interior and Structural Skeleton, Sports Hall, Hochallee, Hamburg

Table 10. Architectural Characteristics

Form	Scale/Site	Height	Roof	Construction
Rectangular single simple volume	Large Attached	8m ?	Metal panels	Steel frame and stel panl infill

Structural Analysis

This type of building is a pin jointed frame structured using multiple steel column-truss combinations. These would be cross braced using tension elements at least to every second or third bay. Spans would be medium (perhaps 8 to 10 m).

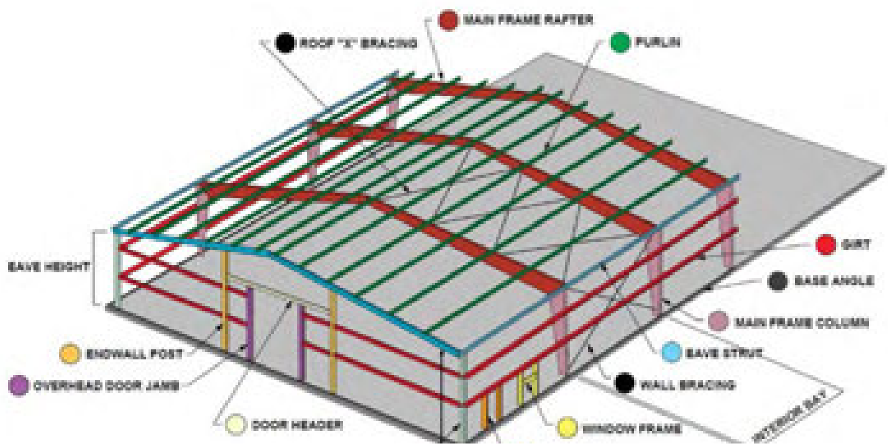


Figure 21. Likely Structural Diagram, Sports Hall, Hochallee, Hamburg

They would not have much residual capacity. There would also by definition be few intermediate walls.

SWT Question

In terms of integrating SWTs the building poses quite a challenge. They have neither residual strength in the structural members nor the potential to be modifiable by introduction of additional internal load paths. These combination of conditions (see table) points to the 3rd possible SWT solution identified below.

Table 11.SWT Condition, Sports Hall, Hochallee, Hamburg

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?				
Long Span and Has Residential Capacity?				●
Is Modifiable?				●

3.4 Bratislava

Two buildings were identified as having the conditions identified in Bratislava

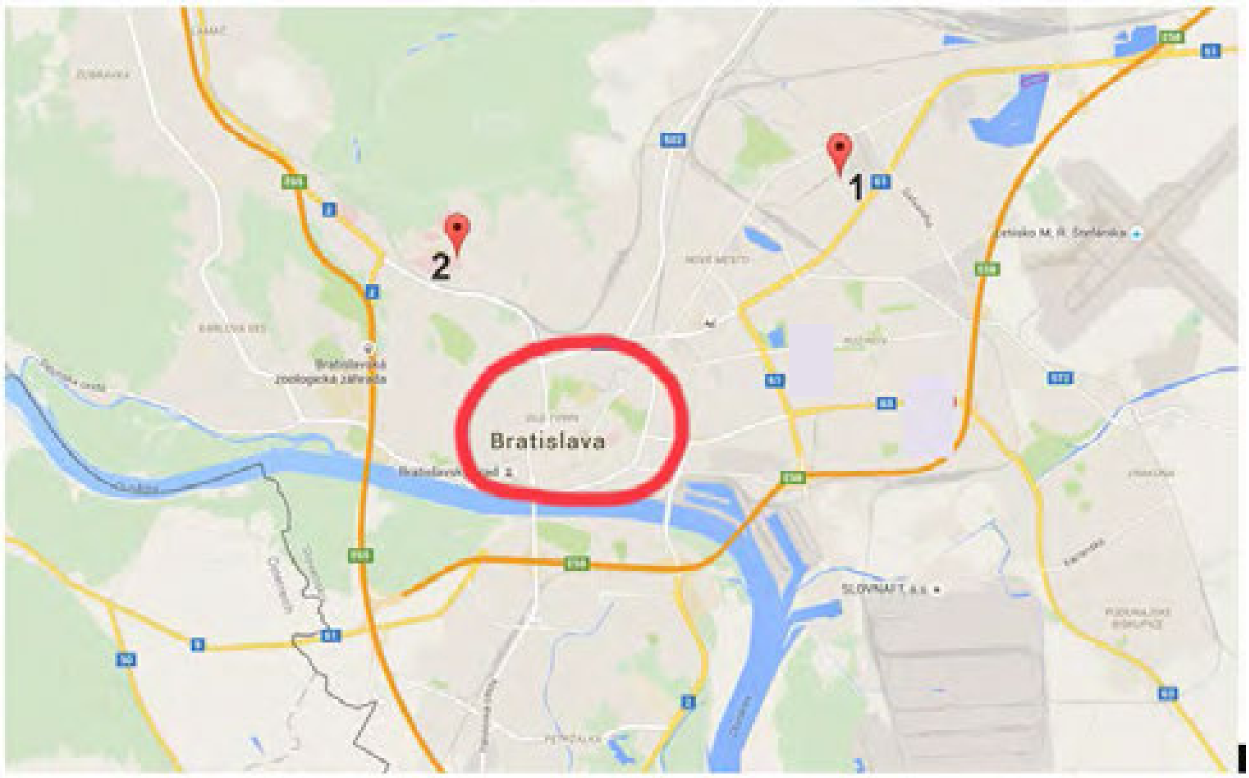


Figure 22. Location of Bratislava example buildings vis a vis the urban area

3.4.1 Suburban Office Building

A suburban office building in the northern suburbs represents a new typology; the suburban (shopping mall) office building. This type of structure is quite common in office parks on the outskirts of regional towns of mid Europe. It is typically two storeys tall and stand on its own ground- that is to say is detached.

Figure 23. Suburban Office Building, Bratislava.

Construction System

Its construction system is assumed to be masonry with steel or timber floors and a skin of brick walls (with windows of course) and a flat roof.

Figure 24. Construction Properties, Suburban Office Building, Bratislava

Table 12. Architectural Properties, Suburban Office Building, Bratislava

Form	Scale/Site	Height	Roof	Construction
Rectangular volume	Small scale	Two storeys + one more at the back	Render	Concrete structure and masonry /brick wall skin

Structural Analysis

Structuraly, it is a rigid building. The rigidity is given by the concrete frame construction and assisted by the tying affect of the roofs (probably concrete slab) and floors (concrete infill or steel) /timber frame flooring. The perimeter walls can be assumed to be strong and in most cases intermediate walls, or the frame elements at bays spacings, could be relied on to carry loads to ground. There should be some residual loadbearing capacity in the structural members.

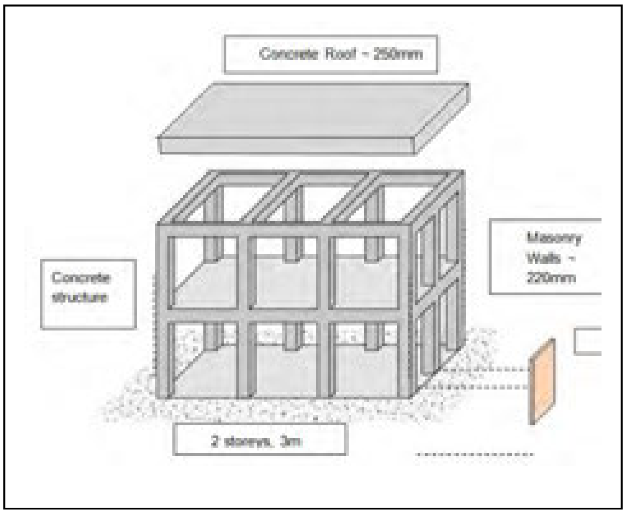


Figure 25. Likely Structure, Suburban Office, Bratislava

SWT Question

In term of installing SWTs to this type of building it is not especially difficult with at least two of our approaches below being applicable. The summary of conditions to be evaluated in considering which to select are summarised as follows;

Table 13 SWT Conditions at Suburban Office, Bratislava

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?	●			
Long Span and Has Residential Capacity?				
Is Modifiable?			●	

3.4.2 Private House (Detached)

A private house was also identified in Bratislava as being typical of the single (ie detached) suburban home typology. There are millions of such homes in suburban areas cities across Europe.

Figure 26. Private House, Bratislava.

Such a condition is to be found on its own site with open space to all four sides and is typically no more than two storeys tall.

Figure 27. Private House, Bratislava.

Construction Type

Their construction varies with region and age but would usually be solid (heavy) in central and southern Europe and lighter –but insulated-in the north.

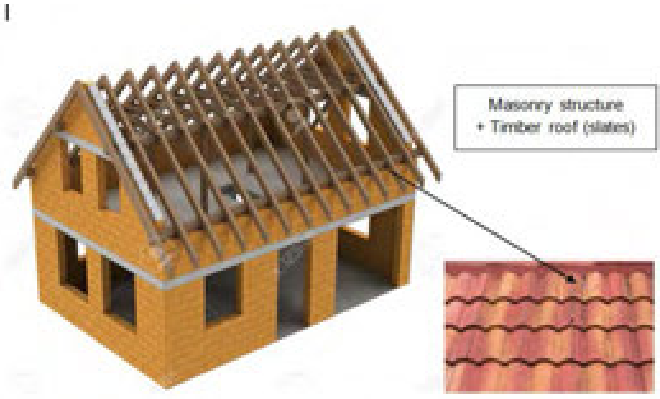


Figure 28. Likely Construction Properties, Private House, Bratislava.

Table 14. Architectural Characteristics, Private House, Bratislava.

Form	Scale/Site	Height	Roof	Construction
Rectangular, simple volumes	Small. Stand alone	< 2 storey	Sloped Tiles	Masonry and wood.

Structural Analysis

In structural terms these examples are simple and strong. Their walls are usually loadbearing and their horizontal planes (floors and roof) tie the structure together. There are usually some, at least, intermediate walls that can transfer loads to grounds and some residual strength can be expected in walls and floors.

SWT Question

The SWT solutions here relies on the short spans and the inherent strength of the external elements. The main challenge is connecting the SWTs to the roof without compromising its weatherproofing as summed up here.

Table 15. SWT Conditions, Private House, Bratislava.

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?		●	●	
Long Span and Has Residential Capacity?				
Is Modifiable?			●	

3.5 Genève

Two Buildings were sampled in Geneva.

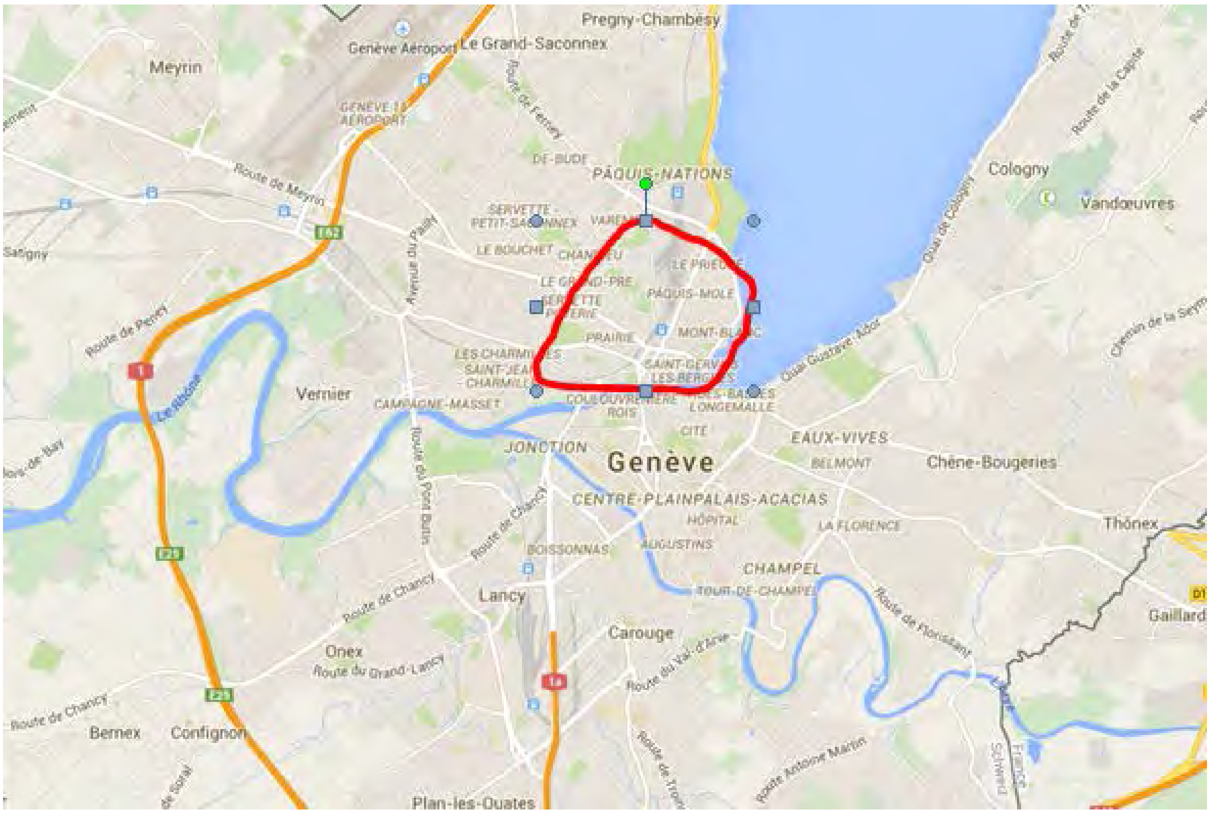


Figure 29. Geneva and city centre

3.5.1 Factory

The first of these is a factory building near the Geneve Universities campus. It represents the suburban factory typology, a bit like the light industrial condition we have seen before but with a more complex functioning and context.

Figure 30. Suburban Factory Complex, Geneve.

Figure 31. Factory Complex, Geneve-Aerial Views

The building is single storey largely free standing adjacent to busy roads and in this case (though obviously not typical) rising ground to one (long) side.

Construction System

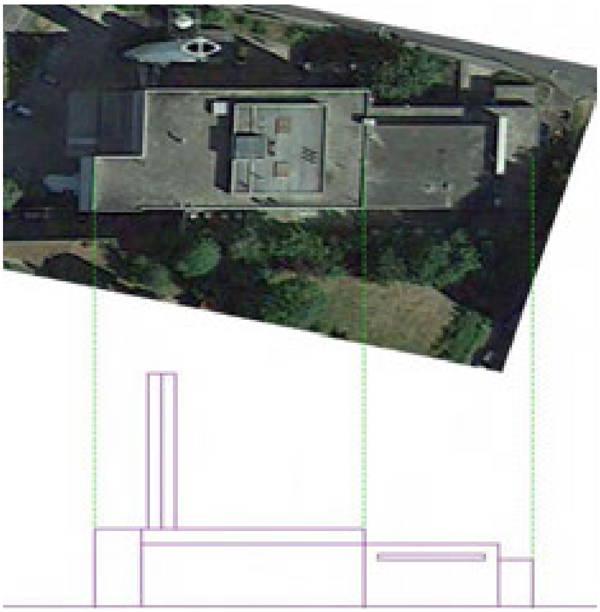


Figure 32. Likely Construction System, Factory, Geneve

Construction of such a building would be of thick masonry walls (with some heavy concrete framing) and roof with few openings. Such a construction would be characterise by an austere finish that expreses itself overtly as being industrial.

Table 16. Architectural Properties, Factory Complex, Geneve

Form	Scale/Site	Height	Roof	Construction
Rectangular large volumes	Large Stand alone	= 15m	Concrete slab	Concrete structure and rendered masonry walls

Structural Analysis

Such large industrial buildings are typically long span with either a solid structural approach or a rigid frame approach with either leading to a very stable and strong building. It can be expected that the

structural elements while sparsely spaced will have significant residual capacity. While inherently strong, a significant question remains over how continuously supported the large flat roof area is.

SWT Question

Thus the roof capacity would need to be verified. If it is supported adequately or if simple modifications can be done to make it so, the first SWT solution would be likely to work. The properties to be considered in confirming which approach to select on such a building is as follows;

Table 17. SWT Conditions, Factory Complex, Geneve

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?				
Long Span and Has Residential Capacity?	●			
Is Modifiable?				

3.5.2 Suburban Retail Centre

A typical suburban shopping development has been identified as matching the second Geneva condition.

Figure 33. Suburban Retail Centre, Geneva

Set in a low rise are of the Geneva suburbs, this ‘big box’ retail development is common across mid and southern Europe. They are normally single storey and set in their own grounds amidst large areas of parking (front) and service yards (rear).

Construction System

The construction of such a building would be of rigid frame construction achieved with an almost domestic approach and detailing. Masonry walls and steel or timber floors would often be used but would be increased in standard to provide for critical safety functions like fire separation. Light metal roof trusses woul often be used to create the roof. In this case these are done in a saw tooth roof configuration.

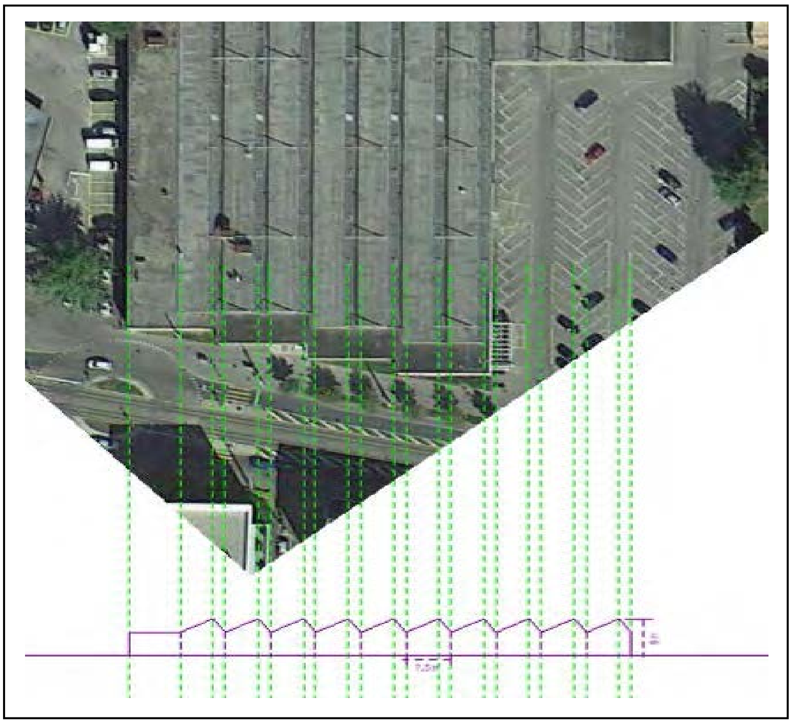


Figure 34. Construction System, Suburban Retail

Table 18. Architectural Properties, Suburban Retail Centre, Geneva

Form	Scale/Site	Height	Roof	Construction
Rectangular, large footprint	Large Free standing	Single storey = 3.5m	Stepped geometry Metal /glazed cladding	Masonry and roof truss

Structural Analysis

Such a condition is characterised by short spans and frequent intermediate walls that probably carry loads from roof to ground.

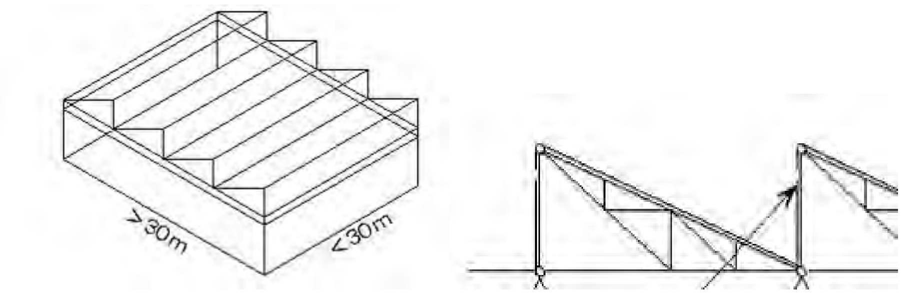


Figure 35. Likely, Structural Diagram, Suburban Retail Centre, Geneva

That said roof members would be expected to be quite weak with little residual capacity.

SWT Question

In this sense the following properties would need to be considered so as to select which SWT solution below is most likely to succeed;

Table 19. SWT Condition, Suburban Retail Centre, Geneva

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?		●	●	
Long Span and Has Residential Capacity?				
Is Modifiable?			●	

3.6 Zaragoza

Two Buildings were chosen in Zaragoza both in the north eastern suburbs of the city.

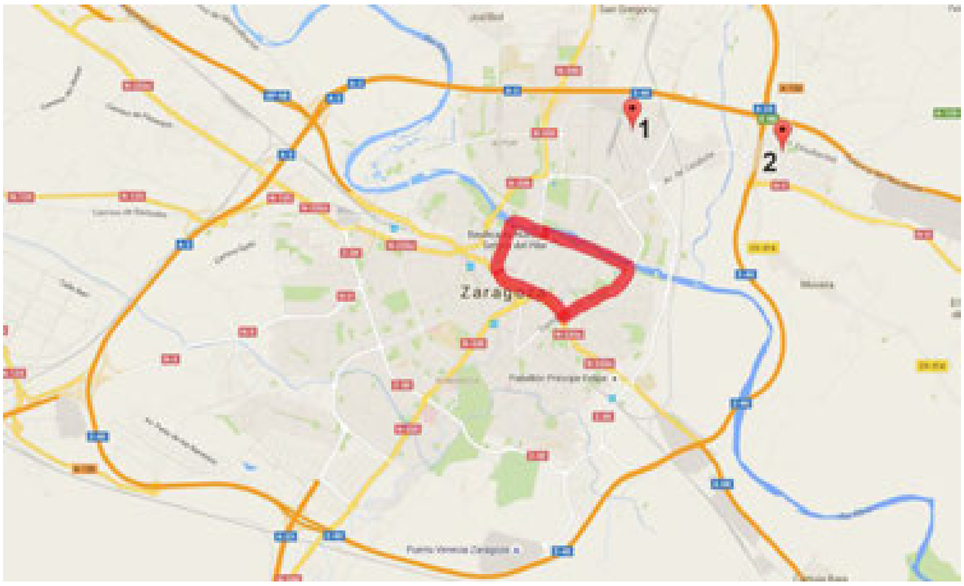


Figure 36. Location of Zaragiza g example buildings vis a vis the urban area

3.6.1 Primary School

The first is a primary school just south of the peripheral highway of Zaragoza.

Figure 37. Primary School, Zaragoza

It is a 2 storey simple building surrounded by the open spaces typical of schools that is ubiquitous in the suburbs of mid and southern European regional cities.

Construction System

School such as this are usually a hybrid of both domestic and industrial construction systems both modified to provide for safety functions (fire, heat loss and acoustics) while remaining economical. In this case it is likely that the building is made of masonry walls (both intermediate and external) and concrete floors and roofs. In some places roofs are sloped and may be finished in waterproofing membranes or (as is the case here) fired tiles.

Table 20. Architectural Properties, Primary School, Zaragoza

Form	Scale/Site	Height	Roof	Construction
Multiple interconnected rectangular volumes	Medium scale	2 storeys (~3m each)	Flat or sloped Tile to concrete	Concrete frame and masonry walls/roof

Figure 38.Likley Construction System, Primary School, Zaragoza

Structural Analysis

Structurally, such a typology is usually structured as a rigid frame (generally with concrete members and masonry infill (walls, floors/ roofs) which serve to increase stability further. The spans are often quite short (<10m) and primary frame elements will often have residual capacity to carry new roof loads to ground.

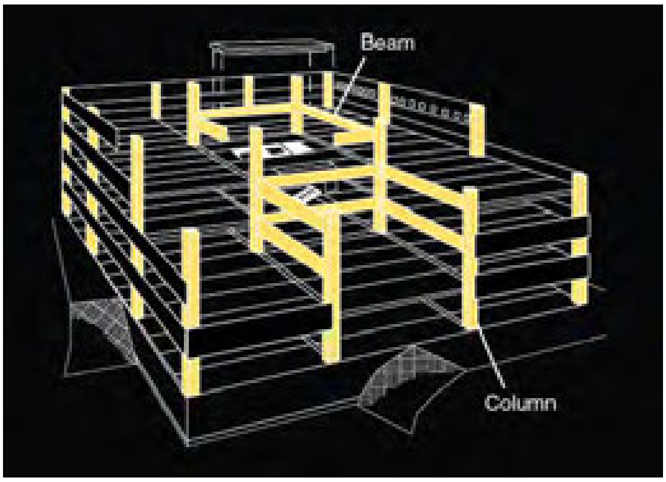


Figure 39. Likely Structural Diagram, Primary School, Zaragoza

SWT Question

In terms of adding SWTs to such a building the flat roofs offer the best opportunity. They must however be checked for capacity to span to intermediate walls. The SWT considerations can be summed up as follows;

Table 21. SWT Condition, Primary School, Zaragoza

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?	●		●	
Long Span and Has Residential Capacity?				
Is Modifiable?	●			

3.6.2 Multi Family Housing

The second Zaragoza building is a multi family housing building on the Avenida Estudiantes area of the city. It is a modest development of perhaps 8 apartments and is three storeys tall. Such a development would be typical of European inner suburbs and the edges of city centres.

Figure 40. Multi Family Apartment Block, Zaragoza.

Construction System

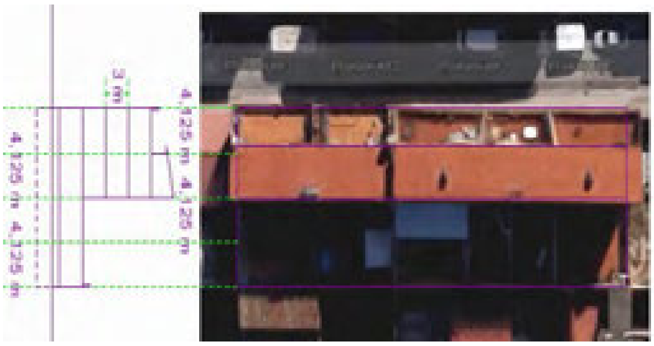
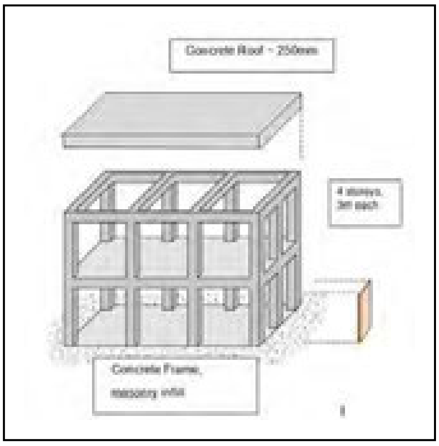


Figure 41. Construction System, Apartment Block, Zaragoza

These types of buildings would generally be solid or rigid frame construction made from a mix of concrete main elements (walls and floors) with masonry infill and envelopes. The roof on this example is almost traditional (sloped with fired clay tiles as finish) but in many cases would be flat.



Structural Analysis

Spans would typically be short with frequent intermediate load bearing walls (or beam column combinations) that run to roof level. Due to the particularities of how such buildings are developed however, it should not be assumed that structural members have any significant residual carrying capacity.

SWT Question

A number of the possible SWT solutions set ot bewp wou apply to this typology. In considering which is most likely to work, the following structural properties would nned to be evaluated.

Table 22. SWT Condition, , Apartment Block, Zaragoza

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span?	●	●	●	
Long Span and Has Residential Capacity?				
Is Modifiable?			●	

4 Structural Solutions for SWTs on Typical Buildings

4.1 SWTs Support Characheristcs of European Buildings

From our above studies of the construction of typical European buildings, we can conclude that they offer the potential to support SWT installations according to conditions that depends on their construction system, structural system, materials, roof geometry and span as well as the residual capacity of structural members. These can best be summarised as follow;

Table 23. Viable condition combination for SWT installations

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None
Short Span ?	●	●		
Long Span and Has Residual Capacity ?	●	●		
Walls Have Residual Capacity ?			●	
Walls /Roof is/are Modifiable ?	●	●	●	

4.2 Categorising SWT Solutions

SWT solutions can, from a structural point of view be categorised according to both roof geometry and the structural support available. These can be cross referenced back to the individual samples of European buildings above and utilized to generate an atlas of structural approaches to installing SWTs on the buildings.

4.2.1 Roofs (Geometry) Types;

It is evident that we can classify the roof type into three classes;

1. Flat roofs
2. Sloped Roofs
3. Stepped/Complex roofs

Each of these offers different support opportunities and also structural particularities that have to be assessed in arriving at a recommendable solution.

4.2.2 Structural Support Types

The supporting structure of European building can be divided in 3 types:

Solid Structures

As we have seen in our European examples above, residential and historic buildings in Europe tend to be built from masonry whether stone, brick or block (and often a combination). Walls would generally have been thick so as to overcome the inherent tendency for the brick and blocks to separate-which is the greatest structural challenge of these construction type. They would often have had intermittent elements of framing between sub elements (eg masonry wall to wood floors) to increase overall stability.

Rigid Frames

In European context these would generally be of concrete construction either concrete beams and columns with masonry (ie rigid) infilled wall and floor panels, or concrete walls and floors forming in themselves a rigid whole.

Pinned Frames

The framed structures often used for warehouses, factories (and later multi storey residential and office buildings) were generally made from steel (though increasingly also nowadays in wood). They employ an economy of material in a very precise structural arrangement (breadth & depth, braced or pinned joint, span distance and spacing) and thus do not carry much 'reserve' structural capacity and, have little potential to accept application of SWTs unless modified or reinforced.

Span and Reserve Structural Capacity

Another important structural question influences the decision as to which approach to providing support for the SWTs may be taken. At the time of the original design the structural characteristics of the beams, slabs and wall will have been specified by an engineer. Depending on the jurisdiction and the age, they will have added a factor of safety, or margin of error to the assumed (calculated) loading on the structural element in question. In some countries they are mandated to assume additional loading of 50% more than they calculated loads, in some places 100%. It is this reserve (or residual) capacity that may in some situation be usable now to take the weight of a SWT.

Modification to the Buildings

A further aspect to be considered is the possibility for localised adjustments to the building. These would be in two classes; structural additions so as to improve the roofs load carrying capacity and weatherproofing adjustments, so as to restore the buildings functionality after, for instance, a SWT has been connected through the weather proofing layer (tiles or final membrane) to the structure underneath. Either or both may be necessary depending on which approach below is chosen.

4.3 Floating Base-Flat Roof SWT Structures

4.3.1 Spreader Plates

Smaller Applications

Where the receiving building combines a flat roof with a rigid (concrete) or solid (masonry) structure, the preferred method of introducing a roof mounted SWT is by creating a floating 'base' that is applied to the existing roof. Depending on the reserve (structural) capacity of the roof and the weight of the turbine, this can be a relatively easy installation for small (max 2 – 3 kW) SWTs.

The base can be a concrete pad of sufficient plan dimensions to spread the loads over a given are of roof and of sufficient depth that it can take the connection from the wind turbine supports (mast or frame). It could also be a frame made from steel members.

The floating 'slab' (or spreader frame behaving similarly to a slab) is laid onto the roof in such a layout (ie relationship to underlying structure, existing spans, etc) that the additional load is spread evenly (not concentrated at points) and weatherproofing is not compromised.

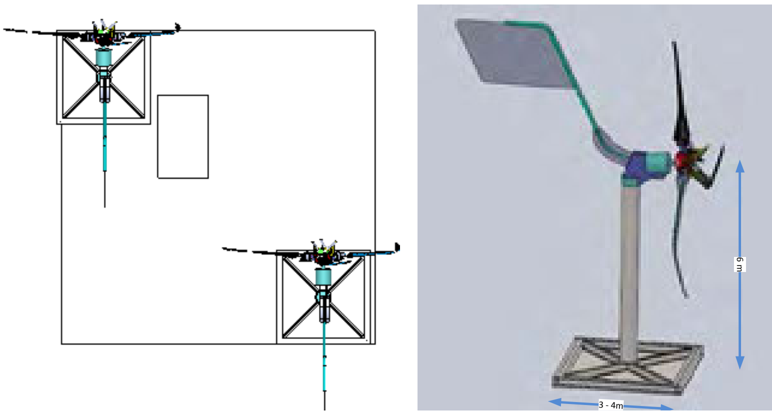


Figure 43. Floating base SWT scheme

Where a spreader frame (made out of steel) is proposed, the introduced weight is significantly reduced concentrating it at the perimeter where it will still provide enough resistance to overturning, and reach the lines of support underneath, while offering structure for the SWT at the point where it is required. This has the additional advantage of possibly being applicable to a low slope roof as well as a completely flat one.

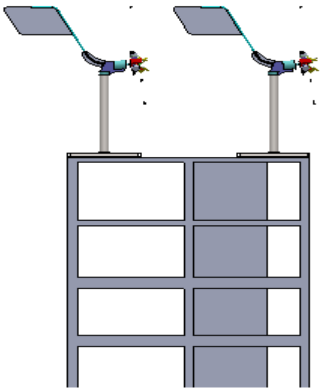


Figure 44. Floating base SWT support approach

Taller Buildings

In the case of taller framed buildings there is often a flat roof over at least the technical room (containg the services equipment). Where such horizontal areas are situated above structural load paths, SWTs designed to array along edge might be utilised as shwn in foloowing example.

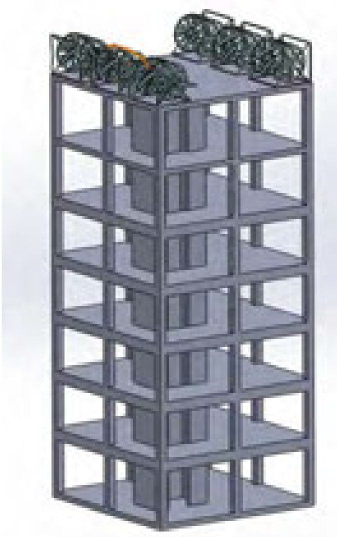


Figure 45. Floating Base for SWTs on Higher Buildings.

Reserve Capacity Limitations

The main problem with the floating slab method, especially on historic buildings, is that such roofs were often originally designed with only a little extra weight capacity (mainly allowing only for snow or rain and some maintenance). If this reserve capacity is now used for the installation of a turbine, it could be dangerous for the building. So, as most buildings will have been designed in such a way that they could take the additional loadings of a wind turbine on the roof, the potential for using this method in old buildings may be limited.

Weatherproofing

In the vast majority of situations where SWTs are being added to buildings, maintaining the weatherproofing (the topmost tile, metal sheeting, membrane or waterproof concrete layer) functioning is essential. Support solutions that can bear onto the building without affecting the

weatherproofing are at all times preferable. The floating base solution above, where loads permit, is the most ideal way to do this.

4.4 Framed Solution

Where loading characteristics or roof geometry (slope) does not suit a floating slab base, the next option to consider is the application of a frame so as to modify the detail of the receiving elements to make them more suitable.

4.4.1 Transfer Frames

If the load bearing capacity of the roof surface itself is not enough but there is sufficient residual strength in nearby walls and their foundations, then it may be possible to transfer the SWT loads directly to the nearest supporting (or supportable) structural element. Structural frames can be applied so as to span from one line of support (an underlying structural wall walls for instance) to another and the frame then become the host of the SWTs supports. A major challenge in practice with this tends to be that The main problem here is the actual access to the structure from the roof top, is not always easy and will of the involve removing some of the weatherproofing layer (and later reinstating it). In terms of location it is usually best to fix to the walls of stair cores or elevator shafts as these combine short spans with, generally, good structural capacity (and sometimes access to the roof). In these cases the interconnecting (transfer) structure would normally be in steel and could be stepped (see below) or flat depending on the configuration of the existing building. Tis arrangement might also suit certain kinds of sloped roofs.

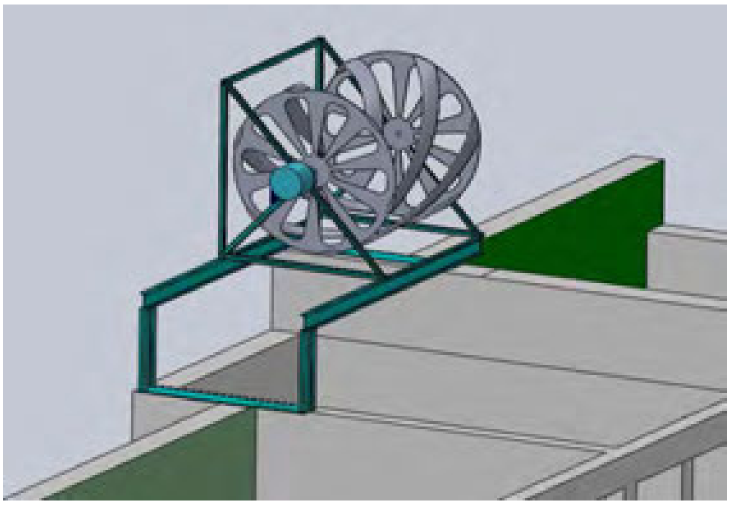


Figure 46. Transfer Frame as SWT Support

The problem with isolation elements is that while the more flexible they are, the more they reduce transmission (of vibration), this is also what undermines the overall dynamic stability of the turbine. Essentially, the elastic element is the minimum performance filter, so the more rigid the support pads , the less vibration it attenuates.

4.4.2 Framing to Sloped Roofs

Sloped (pitched) roofs whether single pitch, double pitch or even saw tooth present the same basic problems as flat roofs but additionally are effected by the sloping itself. The fact that these type of roof have a slope will complicate not only the attachment of the support structure to the building but also the selection of the type of SWTs installation placed due to airflow complications.

Figure 47. SWT Frame supports on sloped roofs

Small Scale Slope Roofs

The most likely solution is to commission a bespoke frame that can be engineered to not only support the SWT but can be inserted under the roof covering (top), or/and have water proofing aprons fabricated into them, so as to sit over any penetrations to weatherproofing layer (bottom)'

Industrial

In many cases where pitched roof occur and where SWTs are sought, the building will be an industrial type of structure (long span, large footprint). Some of the industrial buildings will have strong vertical structures like the one use for overhead cranes or other heavy duty services, these might also be used to offer support to small wind turbine (max 2 – 3 kW). It will strongly depend on the required height of the turbine and the angle of roof inclination.

4.5 Ground Mounted Approaches

When none of the possibilities explained above applies another possible solution is to bear the support directly onto the ground and use the buildings structure only to restrain lateral loads.

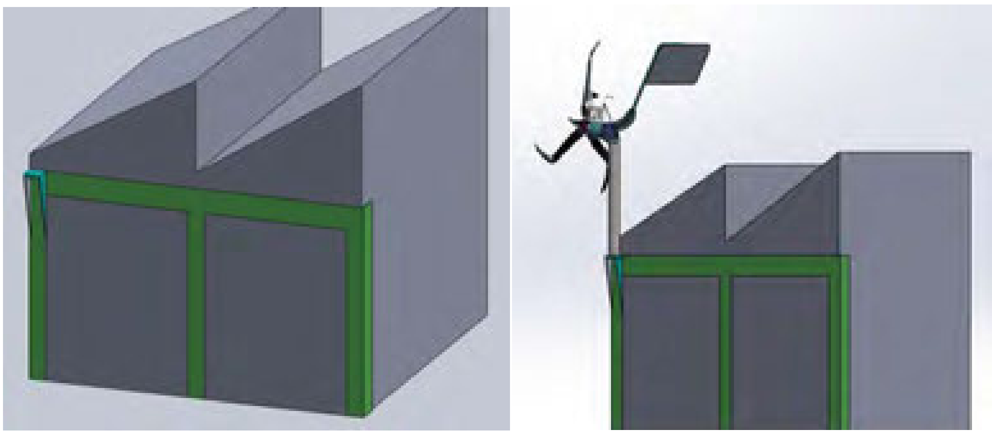


Figure 48. Ground Bearing, Building Restrained SWTs

4.6 Internal Reinforcement Modification

Adding Support to Internal Walls or Beams

Where a building's roof geometry (dimension, orientation, slope) does suit the application of any of the above SWT solutions but the residual load carrying capacity is weak (or where the building has more complex internal layouts), a solution may be found in the cross walls (on plan) or intermediate framing (on section). In these cases the potential to add internal reinforcement to these intermediate structural elements so as to increase the capacity of the roof to carry SWTs is often present.

Also in these cases, especially where the internal wall and beam arrangements give rise to stepped roof profiles, more creative SWTs solution such as crossflow horizontal turbines (which spread their load fairly evenly) can be employed.

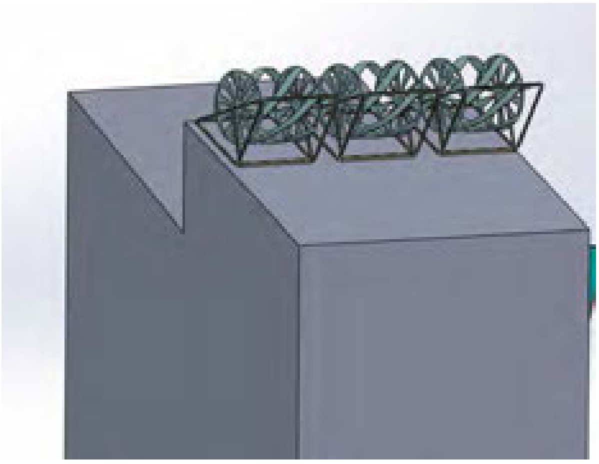


Figure 49. SWT solution for stepped roof situations

4.7 Vibration Damping

Another structural aspect that must be addressed is the issue of vibration.

Many of the solutions above lend themselves to the introduction of dampers between the new supports and the existing buildings.

In the case of the floating bases (flat) roof solutions, it is possible to introduce some vibration isolation solutions between the roof and the slab/ spreader frame. In the case of transfer frames, vibration isolation will be even more critical in this case. Vibration dampers can be installed at the junction of the SWTs support (mast or frame) and the transfer frame itself.

In the case of steel frame supports (of whatever SWT approach), it is more critical to create vibration separation because these structures tend to be more flexible and in general have less self-damping ability. The viscous damping ratio of steel structure with joints is about (0.03 – 0.07) whereas the reinforced concrete structure (no cracking) is about (0.04 – 0.07) if the concrete is cracked the damping ratio can rise to (0.01 – 0.04).

5 Conclusion

It was found that there are only three broad ways to install small scale wind turbines of various kinds on buildings that are typical of Europe's suburban areas.

Research shows that these depend on the original construction, its condition, span, etc and whether the roof has any residual (unused) structural capacity or is constructed in such a way that it could be augmented.

Results suggest that firstly, a floating base can be superimposed on a flat or low slope roof, so that they bear onto but do not penetrate the roof and are kept on place by their own self weight. They can be made of concrete or steel frame (which are lighter).

A second option is to sue transfer frames which may be fabricated and installed so that they bear onto projecting or underlying structural walls or columns of the building assuming they have residual capacity or can be supplemented. In the case of underlying structure, some penetration and later repair of the buildings weatherproofing will be required.

The findings also show that ground mounted support masts may be the best option where the building does not offer either of the above options. In this case a new ground bearing foundation can be made adjacent to the building and the mast carried from there up one of the buildings facades and beyond to support a SWT. In such a condition the host building provides is affected only by the attachment of only a stabilising connection which is less of an impact than were it to support live loads.

Table 24. Matching SWT solution with structural conditions

	Flat Roof (or low slope)	Sloped Roof	Structural walls	None/ Not
Short Span ?	FB	FSR	FB / TF	
Long Span and Has Residual Capacity ?	TF	TF	TF	GM
Walls Have Residual Capacity ?	FB	TF		GM
Walls /Roof is/are Modifiable ?	TF/ FB	TF/ FSR		
FB=Floating Base. TF=Transfer Frame. FSR Frame for sloped roof GM=Ground Mounted				