Wind loads on solar energy roofs

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This paper presents an overview of the wind loads on roofs, equipped with solar energy products, so called Active Roofs. Values given in this paper have been based on wind tunnel and full scale measurements, carried out at TNO, and on an interpretation of existing rules and guidelines.

The results are presented in the format of the new Eurocode on Wind loads, EN 1991-1-4. A classification of active roofs is presented, with respect to wind loads. Finally, a proposal for rules to design of fixings and substructures for these products against wind loads is defined. Future work is recommended, which will partially be carried out in the ongoing project in the EU-FP6, EUR-Active Roofer.

Key words: Wind loads, pressure coefficients, solar energy systems

1 Introduction

There is a recent trend to increase the number of functions on the traditional roof. The products which fulfil these additional functions are defined as active roof products. Over the last decades, the use of roofs for solar thermal or photovoltaic solar energy has increased substantially. New solutions and new products have been added.

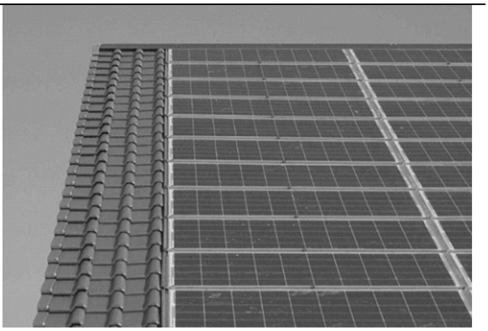
These new functions have a much greater economical value than traditional roof covering products. Since these products are relatively new, the wind loads on these products are hardly covered by current wind loading standards.

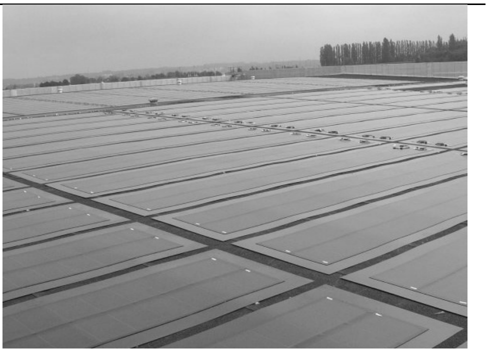
In Europe, wind loads on structures will be determined from the Eurocode, in particularly EN 1991-1-4. Besides the overall load bearing structure, elements for cladding or roof covering, and their fixings, should be designed against the wind. The loading on these elements is found by applying local wind loads. In the Eurocode, values for the local loads can be found for standard shapes, and to a small range of traditional solutions. Active roof products do not always fall into the limits of application of the Eurocode. This paper describes recent results from research carried out to find appropriate rules for active roof products. The results have been described in such a way that future implementation in EN 1991-1-4 is straightforward.

2 Active roofs

An active roof is defined as a roof, which not only fulfils the initial requirements (e.g. water tightness, structural strength, durability against climatic influences), but also includes additional functions for the building underneath.

Table 1: Typical examples of active roof products

Products attached mechanically to buildings, as an add-on, for which the wind loading is determined strongly by the shape and dimensions of the product itself, together with the effect the building on which it is mounted, has on the wind. Examples are chimneys, lucarnes and vent outlets. Also, products as local wind turbines etcetera can be placed into this group.	
Products, integrated in the building envelope. These products may also fulfil functions other than being an energy resource. Examples are PV panels integrated between roofing tiles (or full roofs with PV panels).	
Products, which are placed on top of flat roofs, for which the resistance is provided by the self-weight + additional ballast. These systems are widely spread, therefore an individual, custom made set of loading rules might lead to efficient structures.	

Products, attached to the roof, parallel to the roof surface, with a short distance to the roof surface. Examples are retrofit systems for photovoltaic systems on pitched roofs.	
Flexible solar energy systems (solar foils), which may serve as roof covering for flat and pitched roofs; often glued onto a substructure.	

An important group of new functions is the application of solar energy products. Within Europe, these applications are growing steadily. Trend studies indicate that by 2015 solar energy will be competing with traditional energy sources. From that moment, these applications will become a standard application for roofs and facades. Typical examples for roofs are presented in Table 1. These additional products have an economical value which is far exceeding the value of traditional products. Damage to these active products not only damages the roof, but also influences the energy delivery to the building underneath. Storm damage to active roofs may therefore have much higher consequences than storm damage to traditional products.

3 Wind loads in the Eurocode

The model applied in the Eurocode defines the wind loads from a peak dynamic pressure which is multiplied by one or more aerodynamic coefficients, and by factors that account for dynamic response. The peak dynamic pressure contains the effect of wind statistics and terrain effects, and depends on geographical location, terrain roughness and height above ground. Information on this parameter should be given in the National Annexes to EN 1991-1-4, which are currently under construction in the various CEN countries. The aerodynamic coefficients depend on shape of the building and shape and dimensions of the structural element (e.g. active roof product) under consideration. Finally, correction factors are applied to account for the effect of e.g. dynamic response. The general expression of EN 1991-1-4 for the specification of the wind effect W is:

$$W = \frac{1}{2}\rho v_b^2 c_e(z) c_W c_s c_d = q_p c_W c_s c_d \tag{1}$$

In which:

W is the wind effect, e.g. an external pressure, internal pressure, force, moment or friction;

c_W is the aerodynamic coefficient for the wind effect under consideration; this coefficient may be an external pressure coefficient (c_{pe}), a force coefficient (c_f), an internal pressure coefficient (c_{pi}), a pressure coefficient for the net pressure difference ($c_{p,net}$), or a friction coefficient (c_{fr});

c_s is a size factor, taking the lack of correlation of the wind pressures on a building into account. Usually, this factor is equal to 1 for roof components;

c_d is the dynamic factor, taking the effects of resonance into account. This factor is explicitly defined for the overall load bearing structure of a building. For local loads, this factor is usually equal to 1;

c_e is the exposure factor, in which the effects of terrain roughness are included;

v_b is the basic wind velocity;

ρ is the density of air, with a value of about 1,25 kg/m^3.

q_p $= c_e \frac{1}{2}\rho v_b^2$ is the peak dynamic pressure.

The aerodynamic coefficients may give information on the external pressures, overall forces or internal pressures. For roofs and walls with multiple layers, pressure equalization of the external pressures may become important. This situation occurs also for active roofs, e.g. the second situation of Table 1. In this paper, the pressure difference over the outer layer, where the active components are mounted, is expressed by the external pressure coefficient c_{pe} and a pressure equalization factor c_{eq} :

$$c_W = c_{pe}\, c_{eq} \tag{2}$$

This pressure equalization factor is defined as the ratio between the representative value for the loading on the element under consideration and the representative external pressure. This value is defined in the Dutch code NEN 6702, and also EN 1991-1-4 gives rules to account for this effect.

4 Wind loading on active roof products

The wind loading on active roof components is the result of a pressure difference over the roof product. It is described by the peak dynamic pressure and the aerodynamic coefficient. The aerodynamic coefficient on the following parameters:

- shape and dimensions of the components;
- shape and dimensions of the building on which the components are mounted;
- location on the building;
- and for integrated products on the permeability of the layers of the roof.

The first three aspects are usually dealt with by properly choosing a value for the pressure or force coefficients, together with a choice of the wind loading zones on the roof. In case of a product integrated in the roof of a building the following situations are relevant:

- roofs consisting of one, impermeable, skin; Examples are glass roofs, where solar energy products are directly integrated. The loads are the same as for a glass roof without additional functions.
- roofs consisting of one layer, which is water tight, but air permeable. Examples are roofs of attics or shelfs with roofing tiles without under-roof .
- roofs consisting of at least two layers, where the outer layer is air permeable, and the inner layer is impermeable (or has a permeability which is much less then the outer layer). An example is a roof with roofing tiles, and a under-roof , consisting of wooden panels or otherwise. Within this class, two subclasses are defined:

    - the under-roof is stiff;
    - the under-roof is flexible.
- roofs consisting of at least two layers where the outer layer is a flexible, airtight layer. Examples are flexible roof covering products, such as EPDM, Bitumen and PVC. This type has two subclasses:
    - the under-roof is air impermeable;
    - the under-roof is air permeable.

These situations are taken into account in the definition of the active roof classes.

5 Classification of active roofs

Within the EUR-ACTIVE Roofer [2] project, possible solutions to achieve active roofs have been analysed, and a classification with respect to wind loads on such roofs, has been derived. Based on the considerations presented before, 3 main classes have been defined for active roofs with respect to wind loading:

Class A: Products which are attached to a building, without being part of the roof covering. Usually this class is found when a traditional roof is available, with the solar energy products as additional features. The aerodynamic coefficient of these products, in relation to the position on the building, is the key parameter to find the wind loads.
Class B: Products which are integrated in the roof, fulfilling also one or more of the traditional functions of the roof covering. In this case, the amount of pressure equalization that can be taken into account is relevant.
Class C: Products which are directly fixed (bonded) to the roof covering material. These products simply must be fixed sufficiently to the base material.

These three classes cover all solutions in the market now, and those expected in future. For wind loading calculations, these have been divided into 10 subclasses:

Class A: Active roof products, attached to a traditional roof.

1. Add-ons to buildings, not falling in sub-class 2 or 3;
2. Systems placed on flat roofs;
3. Systems mounted on pitched roofs.

Class B: Active roof products, integrated in the outer layer of the roof.

4. Integrated in permeable skin, with a stiff, impermeable, under-roof;
5. Integrated in double permeable skin, with a flexible, impermeable, under-roof;
6. Integrated in a single, flexible skin.

Class C: Active roof products, forming an integral part of the roof.

7. Integrated in single closed skin;
8. Integrated in single permeable skin;
9. Mounted on a flexible outside skin, closed under-roof;
10. Mounted on a flexible outside skin, with permeable under-roof.

An extended description of these classes with respect to wind loading is given below. Relevant results are presented in a form applicable to EN 1991-1-4.

6 Application of EN 1991-1-4 for active roofs

Active roofs should, like all structures, be designed to withstand the wind loads. Active roofs and active roof products however are not explicitly taken into account in the current wind loading codes. The model to calculate wind loads on these subclasses is presented below. The calculation model of the Eurocode, EN 1991-1-4, is used as basis. For all subclasses, the specific wind loading model is given, and reference is made to data available, if any.

*6.1 **Rules for products, attached to a traditional roof (class A)***

The products included in this class are attached as an additional feature to the building as it would be without active products. Most of these solutions can be found on existing buildings which are upgraded with active products. This class is divided into three subclasses: one for frequent solutions on flat roofs, one for frequent solutions on pitched roofs, and a third, including all other solutions.

Subclass 1: Add-ons

The wind loads on add-ons is independent on the roof structure underneath. It is assumed that there is no relation with the definitions of wind zones on the roofs, as defined in many wind loading codes. The wind loads are described with specific force coefficients for the products. The effect of the building on which they are mounted is however to be taken into account.

Within this class, following the rules of EN 1991-1-4, the wind loading on the active roof components is described by a peak dynamic pressure, together with a force coefficient, specific for this component. The coefficient $c_s\, c_d$ may be taken equal to one, for products that are limited in size and which are stiff enough to avoid dynamic response effects. The wind load on subclass 1 products is described as:

$$W = c_e(z)\, c_f\, \frac{1}{2} \rho\, v_b^2 \qquad (3)$$

Force coefficients depend strongly on the shape and dimensions of the product applied, and in case of add-ons also on the flow field around the building. General values for such elements are not given in standards. These require both product-specific research (e.g. in wind tunnel) and project-specific research (effect of building size and dimensions), or the use of safe, conservative values. A value for c_f equal to 2 which is an upper limit for structural elements in EN 1991-1-4, while applying a value of c_e at z = (ridge) height of the roof, is regarded as sufficiently conservative. Products like roof vents, but also small scale wind turbines, may also be regarded in this group.

Figure 1: Example of an add-on to a building

Subclass 2: Systems placed on flat roofs

A special, frequently occurring, case of add-ons on buildings is the group of solar energy systems which are placed on flat roofs, both as stand alone systems on dwellings as well as mounted in large scale solar energy plants. The large potential in Europe of both existing and new flat roofs makes this case a very important one. The wind loads may be described using the following expression:

$$W = c_e(z)\, c_{p,net}\, \frac{1}{2} \rho\, v_b^2 \tag{4}$$

for the net pressure over a solar energy element, or

$$W = c_e(z)\, c_p\, \frac{1}{2} \rho\, v_b^2 \tag{5}$$

for the pressure on a surface.

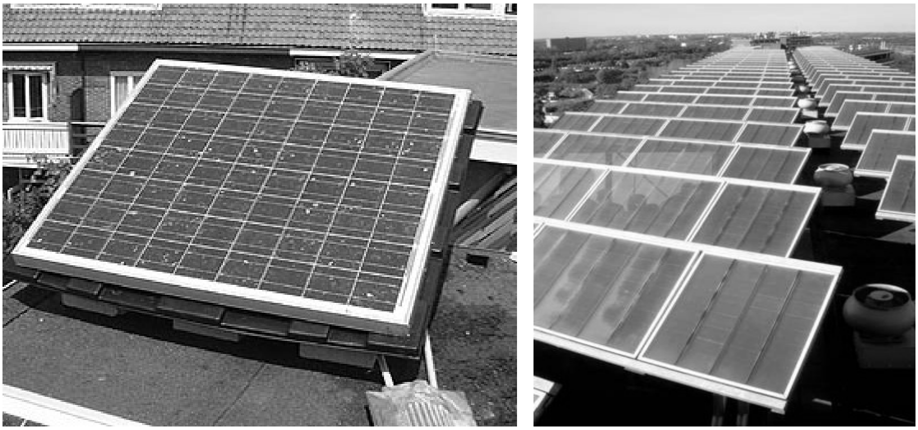


Figure 2: Examples of solar energy systems placed on flat roofs, both small scale and large scale solutions

Wind loading codes do not give any values specific for these cases. Wind tunnel work has been performed by TNO. This work has been presented in detail in [1, 4]. A brief overview is presented here. The wind loads on solar energy systems on flat roofs have been studied on a model scaled 1:50 of a building with rectangular plan, with full scale height of 10 metres, width of 30 metres and depth of 40 metres. The roof of this building was divided into four quarters to make optimal use of symmetry. One of these quarters was not covered with solar energy systems, but with pressure taps in the roof, as a reference to compare the data with existing standards. Solar energy systems have been modelled with a dimension of 1,20 meters deep, and an inclination angle of 35 degrees.

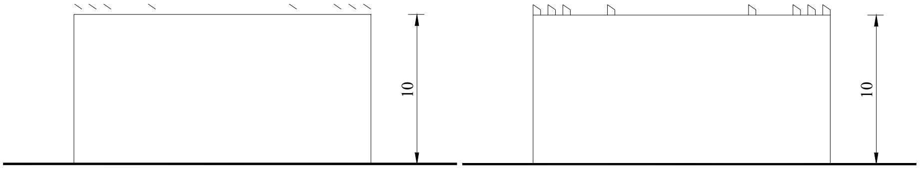
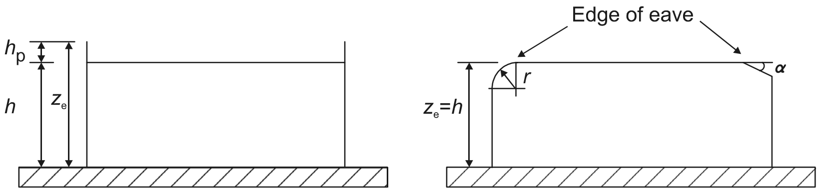


Figure 3: View of a wind tunnel model of a 10 metre high building, with solar energy systems with open substructure (left figure) and closed substructure (right figure)



Parapets

Curved and mansard eaves

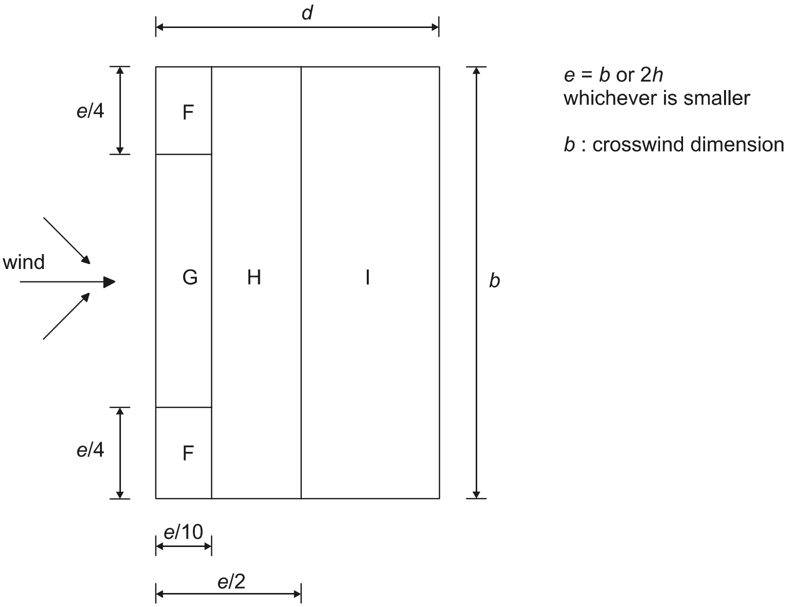


Figure 4: Definition of wind loading zones on flat roofs, from EN 1991-1-4

Measurements have been carried out on four different configurations of the building and solar energy systems. Two types of solar energy systems have been modelled; one with an open substructure, allowing the wind to blow underneath, and one with a closed substructure, where no wind is allowed underneath. The inclination of the solar energy systems in the models was 35 degrees. Both measurements have been done with and without parapet (of 200 mm in full scale).

Within these configurations, the effects of the location of the systems on the roof, the effects of shielding of the solar systems with respect to each other and also the effect of orientation relative to the prevailing winds have been studied.

Values for c_f for these systems are given in Table 2 and 3, following from wind tunnel work [1]. The results have been presented in relation to the wind loading zones, defined in EN 1991-1-4, see Figure 4.

Values for design pressure coefficients are presented in Tables 2 and 3. These values are given for four situations, Situations I to IV refer to the following circumstances:

I. systems in corner and edge zones with the high end directed towards the wind;
II. systems in corner and edge zones with the low end directed towards the wind;
III. systems in edge zones with the sides directed towards the wind;
IV. systems which are sheltered by other systems.

Table 2: Values for aerodynamic coefficient $c_{p,net}$ for solar energy systems placed on an open frame on flat roofs. The resulting force will act on ¼ of the span, measured from the windward side. Situation I is for wind approaching on the higher side of the system, Situation II from the lower side and Situation III from the inclined side. A sheltered situation means that at least one row of systems is placed on the upwind side of the systems (values based on [4])

Zone on the flat roof	Roof Parapet ≤ 100 mm		Roof Parapet ≥ 200 mm	
	Upward	Downward	Upward	Downward
Corner (G), situation I	-1.8	+0.2	-1.5	+0.2
Corner (G), situation II	-1.0	+1.2	-0.9	+1.0
Edge (F), situation I	-1.8	+0.2	-1.2	+0.2
Edge (F), situation II	-1.0	+1.0	-0.9	+0.5
Edge (F), situation III	-1.4	+1.4	-1.0	+1.2
Centre (H, I)	-1.4	+0.9	-1.2	+0.7
Centre (H, I), sheltered	-0.6	+0.6	-0.6	+0.6

Similar values are available for closed systems. These values are given as local pressure coefficients $c_{pe;1}$. Values found in the wind tunnel experiments are valid for loaded areas of 1 m² or more.

Table 3: Values for local pressure coefficients $c_{pe;1}$ for solar energy systems placed on flat roofs on open substructures. Table 3A: low roof parapets. Table 3B: roof parapet 200 mm or more (values based on [4])

Table 3A	Roof Parapet ≤ 100 mm			
Zone on the flat roof	under pressure on upper surface	over pressure on upper surface	over pressure on vertical surface	under pressure on vertical surface
Corner zone (G), situation I	-1.7	+0.2	+0.7	-0.7
Corner zone , situation II	-1.0	+0.2	+0.3	-1.2
Edge zone (r), situation I	-1.4	+0.2	+0.5	-0.7
Edge zone (r), situation II	-0.9	+0.2	+0.4	-0.8
Edge zone (r), situation III	-1.4	+0.2	+0.5	-1.1
Centre zone (t)	-1.2	+0.2	+0.5	-1.0
Centre zone (t), situation IV	-0.8	+0.2	+0.3	-0.8

Table 3B	Roof Parapet ≥ 200 mm			
	under pressure on upper surface	over pressure on upper surface	over pressure on vertical surface	under pressure on vertical surface
Corner zone (G), situation I	-1.7	+0.2	+0.7	-0.7
Corner zone , situation II	-1.0	+0.2	+0.3	-1.2
Edge zone (r), situation I	-1.6	+0.2	+0.5	-0.7
Edge zone (r), situation II	-0.9	+0.2	+0.4	-0.8
Edge zone (r), situation III	-1.2	+0.2	+0.5	-1.0
Centre zone (t)	-1.2	+0.2	+0.5	-1.0
Centre zone (t), situation IV	-0.8	+0.2	+0.3	-0.8

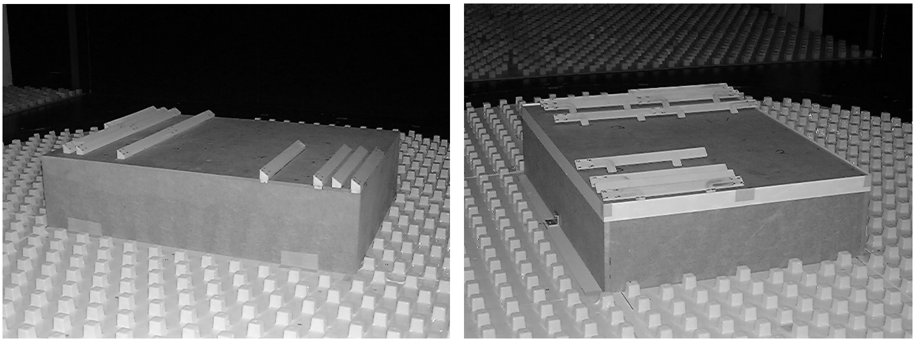


Figure 5: View of the wind tunnel model Left: with closed structure, and no parapets. To the right: solar energy systems with open structure, roof with parapet.

Subclass 3: Systems on pitched roof

Another frequently applied group of systems, often to existing roofs with roofing tiles, are the so-called retrofit systems. These systems are mounted by a hook-construction to the under-roof, and active roof products are mounted parallel to the existing roofs, often with a distance in the order of 100 to 200 mm. The wind loads are related to the wind loads on the existing roof. However, near the corners and edges, these products may be prone to extra wind loads due to local wind effects around these corners. These effects are yet not very well understood, and not included in current codes and guidance.

Here, the values for the wind loading may be defined using the following expression:

$$W = c_e(z)\, c_{p,net}\, \frac{1}{2} \rho v_b^2 \tag{6}$$

Current wind loading standards do not give values for this situation. No experimental data are available. BRE Digest 489 [5] recommends to use the following net pressure coefficients for modules in the central roof areas for the design of modules mounted above and parallel to pitched roofs:

- Where the module is > 300 mm from the roof surface:
  - $c_{p,net}$ for wind uplift = -0.7
  - $c_{p,net}$ for downward pressure = 1.0

- Where the module is < 300 mm from the roof surface or where the space between the roof and underside of the module is blocked or there is any possibility of it becoming blocked by leaves or other debris:
  - $c_{p,net}$ for wind uplift = -1.3
  - $c_{p,net}$ for wind pressure = 1.0

These pressure coefficients are for modules mounted in the central regions of a pitched roof. If the module is close to the roof periphery (eaves, ridge or gable), the wind loads are likely to be significantly higher. No values are given for those situations. In current standards, this periphery has typically a width of about 1 meter.

Figure 6: Examples of systems parallel to pitched roofs

Figure 7: Test house for full scale experiments (left), and corresponding wind tunnel model (right)

The values given in the BRE Digest are assumed to be safe. To obtain design data for such situations, full scale and wind tunnel experiments are being performed in the EUR-ACTIVE Roofer project. A full scale measurement in the Netherlands will be accompanied by model tests on the same house in the wind tunnel of BRE. After comparing these tests, parametric studies will be performed in the wind tunnel.

6.2 *Wind loads on active roof products, integrated in the outer layer of the roof (class B)*

Subclass 4: Outer permeable skin, stiff under-roof– integrated

Active roof systems which are integrated as roof covering products, similar to traditional roofing tiles, may be calculated by the same rules as roofing tiles, under certain conditions. These conditions concern the detailing at the extremities of the roof, and the connections between active roof products and traditional roof covering product. The basic formula for these systems is:

$$W = c_e(z)(c_{pe}\,c_{eq} - c_{pi})\tfrac{1}{2}\rho\, v_b^2 \tag{7}$$

When the stiff under-roof is air tight, c_{pi} is equal to 0. The values for c_{pe} are given in EN 1991-1-4. This yields:

$$W = c_e(z)(c_{pe}\,c_{eq})\tfrac{1}{2}\rho\, v_b^2 \tag{8}$$

Values for c_{eq} are not available in the wind loading codes, these could be derived from experimental results. Full scale experiments will be used to obtain design data for these products.

Figure 8: Examples of integrated products

Subclass 5: Double permeable skin, flexible under-roof-integrated

Active roof systems which are integrated as roof covering products, similar to traditional roofing tiles, may be calculated by the same rules as roofing tiles, under certain conditions. These conditions concern the detailing at the extremities of the roof, and the connections between active roof products and traditional roof covering product. The basic formula for these systems is:

$$W = c_e(z)(c_{pe}\, c_{eq} - c_{pi})\tfrac{1}{2}\rho\, v_b^2 \tag{9}$$

For flexible under-roofs, c_{pi} is taken equal to the value for the room of the building underneath the roof; changes in internal pressure in this room will be followed by the pressure in the air cavity because of the flexible under-roof. The values for c_{pe} are given in EN 1991-1-4. Values for c_{eq} are not available in the wind loading codes, but may be derived from experimental results of appropriate experiments. Examples of this solution look similar to those in 5.5.6. The difference is the (invisible) roof structure.

Subclass 6: Single, flexible skin

Products which are attached to e.g. tents should normally be fixed sufficiently tight, so that the wind loads do not have an additional effect. The tent structure itself should of course have enough wind resistance. However, many tent type structures are not explicitly covered in our wind loading standards. The basic formula for these structures is:

$$W = c_e(z)(c_{pe} - c_{pi})\tfrac{1}{2}\rho\, v_b^2 \tag{10}$$

Where c_{pi} follows from the Eurocode, c_{pe} is usually taken from appropriate results available in literature, or from project based research, e.g. in a wind tunnel.

6.3 *Wind loads on active roof products, forming an integral part of the roof (class C)*

Subclass 7: Single closed skin integrated

Products which are integrated in e.g. glass layers and used as single skin roofs should be calculated as if these were single skin products. This means that the wind loading follows directly from the difference in internal and external pressure:

$$W = c_e(z)(c_{pe} - c_{pi})\frac{1}{2}\rho v_b^2 \tag{11}$$

The values for c_{pe} depend on the size of the product. When this size is less than 1m², the local pressure coefficients should be used. When the size is larger, appropriate values should be determined from EN 1991-1-4. Values for c_{pi} are given in EN 1991-1-4 as well. No additional research is needed, since these values essentially are similar to those obtained from e.g. glass windows.

Figure 9: Example of solar energy systems in single skin; similar to glass facades

Subclass 8: Single permeable skin – integrated

Products which are integrated in permeable roof structures are designed using the internal and external pressure difference. The basic formula is:

$$W = c_e(z)(c_{pe,1} - c_{pi})\frac{1}{2}\rho v_b^2 \tag{12}$$

Values for $c_{pe,1}$ are given in EN 1991-1-4. Values for c_{pi} may depend on the permeability of the roof, and may be larger than for closed buildings. The provisions of EN 1991-1-4 make calculation of these systems possible. This situation is typical for old buildings, not having any thermal insulation. These situations will not occur very frequently for new and for active roofs.

Subclass 9: Flexible outside skin, closed under-roof

When products are mounted on a flexible skin, again the skin should have enough wind resistance. When the skin is flexible and the under-roof is air tight, the internal pressure inside the building plays no role, and pressure equalization may be taken into account. This leads to the following formula:

$$W = c_e(z)(c_{pe}c_{eq})\frac{1}{2}\rho v_b^2 \qquad (13)$$

Values for c_{eq} are not explicitly available. Values could be obtained from EN 1991-1-4, based on the recommended values.

Figure 10: Application of flexible product in the outside building skin

Subclass 10: Flexible outside skin, permeable under-roof

When products are mounted on a flexible skin, again the skin should have enough wind resistance. When the skin is flexible and the under-roof is permeable, the internal pressure inside the building will load the outside skin. Pressure equalization may be taken into account more or less, depending on the permeability of this under-roof . This leaves the following formula:

$$W = A c_e(z)(c_{pe} c_{eq} - c_{pi}) \tfrac{1}{2} \rho v_b^2 \tag{14}$$

Values for c_{pe} and c_{pi} follow directly from EN 1991-1-4, values for c_{eq} are not explicitly known. The values for c_{pi} may be reduced, based on the fact that a permeable under-roof may still be able to 'damp' the peaks in the internal pressure. This has e.g. been applied in NEN 6707, the code for fixings of roof coverings in the Netherlands.

7 Application in standards and guidelines

The calculation model and values given in this paper will be presented at the end of the EUR Active Roofer project in a pre-standardization document. This document will follow the framework of EN 1991-1-4, and presents the values in a form that can be included in National Annexes or directly into EN 1991-1-4 in near future. The prestandardisation document will also include assessment methods to verify the wind resistance of these products. Additionally, a practical guideline will be drafted for the International Federation of Roofing Contractors (IFD), and training programs for installers and roofers will be developed. This enables a solid introduction of these new elements in the roof, in all relevant levels, in design and construction stage.

A very simple way to include the results for these classes into design guidelines, is by including the aerodynamic coefficients, the effect of pressure equalization and also the partial safety factor. This has successfully been applied in the Netherlands in NPR 6708: Fixing of roof covering products, which serves as an example for the EUR Active Roofer guidelines. This guideline simplifies the calculation of the wind loading into a simple formula:

$$W_d = C_s q_p = C_s c_e(z) \tfrac{1}{2} \rho v_b^2 \ , \tag{15}$$

The coefficient C_s is defined as:

$$C_s = \gamma_{f;d}(c_{pe}\,c_{eq} - c_{pi})\text{, or } C_s = \gamma_{f;d}\,c_f\text{, or } C_s = \gamma_{f;d}\,c_{p,net} \quad (16)$$

Note that pressure equalization only occurs in situations where the internal pressure in the building does not act on the outside skin, so when c_{eq} < 1, then c_{pi} = 0.

The values for c_{pe}, c_{eq} and c_{pi} have been given before. Table 4 summarizes the results. The value for $\gamma_{f;d}$ is equal to 1,5 x 0,9 = 1,35 following EN 1990.

Table 4: Coefficient C_s for classes of active roof products.

Class	$\gamma_{f;d}$	c_{pe}	c_{eq}	c_{pi}	C_s
A: Active roof products, mounted loose from a traditional roof.					
1	1,35	= c_f	1	0	1,35 c_f
2	1,35	= c_f	1	0	1,35 c_f
3	1,35	= $c_{p,net}$	1	0	1,35 $c_{p,net}$
B: Active roof products, integrated in the outer layer of the roof.					
4	1,35	EN 1991-1-4	< 1	0	$\gamma_{f;d}\,c_{pe}\,c_{eq}$
5	1,35	EN 1991-1-4	1	EN 1991-1-4	$\gamma_{f;d}(c_{pe} - c_{pi})$
6	1,35	EN 1991-1-4	1	EN 1991-1-4	$\gamma_{f;d}(c_{pe} - c_{pi})$
C: Active roof products, forming an integral part of the roof.					
7	1,35	EN 1991-1-4	1	EN 1991-1-4	$\gamma_{f;d}(c_{pe} - c_{pi})$
8	1,35	EN 1991-1-4	1	EN 1991-1-4	$\gamma_{f;d}(c_{pe} - c_{pi})$
9	1,35	EN 1991-1-4	< 1	Reduced value of EN 1991-1-4	$\gamma_{f;d}(c_{pe}\,c_{eq} - c_{pi})$
10	1,35	EN 1991-1-4	≤ 1	EN 1991-1-4	$\gamma_{f;d}(c_{pe}\,c_{eq} - c_{pi})$

8 Conclusions and further work

This paper describes a uniform approach to the wind resistant design of active roofs. This approach is based on the recently published Eurocode, and this paper presents the values to apply in designing specific active roof components. The following conclusions are drawn:

1. Current wind loading standards are not sufficient to include the most common types of active roofs.
2. Recent research has been carried out which can be included in a European approach; a proposal is defined, which can form a basis for both design guide lines and normalization documents.
3. Some research is still needed, to achieve economical and safe values for the wind load on active roofs.

Further work is being performed in the framework of EUR Active roofer. This work is dealing with the following specific items:

1. Full scale and wind tunnel testing of products falling in subclass 3;
2. Computational Fluid Dynamics analysis is carried out at the University of Berlin. CFD is a tool to support experimental techniques, and to do parametric studies. Goal within this project is to validate CFD analysis against some wind tunnel tests and to formulate the boundary conditions for use of this tool.

Additionally, assessment methods are being developed to determine the uplift resistance of active roof products.

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