Structural Means for Fire-Safe Green Façade Design on Multi-Storey Buildings

Thomas Engel[1],

Stefan Winter[1]

Technical University of Munich; TUM School of Engineering and Design; Chair of Timber Structures and Building Construction

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1 Introduction

In recent years, green façades (also called vertical greenery systems) have become increasingly important. Although cities occupy only 2% of the global land area, more than half of the world's population lives in cities and urban agglomerations. Three-quarters of Europe's population live in urban areas, and this proportion is forecast to increase sharply (United Nations 2019). The resulting need for sustainable urban development requires a sufficient amount of green and recreational space. However, the increasing shortage of residential areas often stands in the way of the creation of new public green spaces and thus creates major challenges for the responsible authorities.

One possible solution would be the greening of the numerous existing horizontal and vertical building surfaces. Green façades offer multiple benefits, including improving air quality, minimising the heat island effect (or urban heat island = significantly warmer area in cities than surrounding rural areas), improving the thermal performance of the building, reducing noise through absorption and providing additional oxygen (Alexandri, E.& Jones, P. 2008), (Perini, K. et al. 2011).

However, the fire safety aspects of green façades have not yet been investigated in detail.

Figure 1 shows the various types of green façades. In principle, a differentiation can be made between direct greening on the exterior wall using climbing plants, indirect greening controlled by trellises and climbing aids set off from the exterior wall, or greenery wall systems using shrubs and bushes in boxes or substrate systems (living wall). Mixed types are also possible, (Köhler, M.; Ansel, W. 2012), (Mahabadi, M.; et al. 2018), (Pfoser, N. 2018).

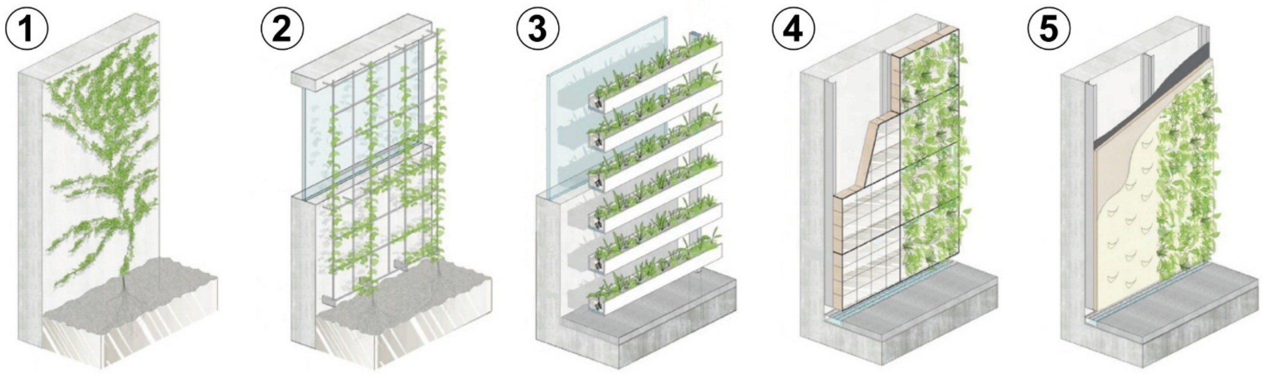

Figure 1: Types of green façade design. 1 Direct growth with self-climbers, ground-based, 2 Growth on climbing aid/trellis, ground-based, 3 Plant boxes, horizontal vegetation surfaces, wall-based, 4 Modular system (living wall), vertical vegetation surfaces, wall-based, and 5 Planar system (living wall), vertical vegetation surfaces, wall-based; based on (Pfoser, N. 2018)

For ground-based growth on climbing aid/trellis, wall distances of 50 to 200 mm to the climbing aid have become established, depending on the growth thickness (Köhler, M.; Ansel, W. 2012), (Mahabadi, M.; et al. 2018). In addition to the growth of the plant, a sufficient distance is also necessary due to the otherwise possible overheating of the climbing plant by the outer wall (Pfoser, N. 2018).

Wall-based green façades (living walls) are characterised by built-in irrigation systems, plants of various sizes and the interchangeability of plants. These enable an extensive greening of the façade from the moment the building is completed through module or shelf systems (Pfoser, N. 2018). Wall-based green façades as "living walls" are a complete rear-ventilated façade system. It consists of a rear-ventilated void cavity, supporting structure, cladding panels, substrate, fleece, irrigation system and the plant itself. The systems differ significantly between the manufacturers.

The use of climbing plants for green façades has many regional peculiarities (Köhler, M.& Ansel, W. 2012), (Mahabadi, M.; et al. 2018), (Pfoser, N. 2018). The species potential for climbing plants in the central European climate region consists of approx. 150 species and varieties (Köhler, M.& Ansel, W. 2012). The range of possible plant species for wall-based planting systems encounters only a few restrictions and is, therefore, much more extensive. For the central European climate region, approx. 100 species and varieties are listed in (Mahabadi, M.; et al. 2018). A differentiation is made between perennials, grasses and woody plants (Pfoser, N. 2018).

Figure 2 and Figure 3 show examples of realised green facades.

Figure 2 Ground-based growth on climbing aids (Swiss Re office building in Munich); (Source: Bundesverband GebäudeGrün)

Figure 3 Wall-based modular system (living wall) (Municipality of Venlo, Netherlands); (Source: Bundesverband GebäudeGrün)

2 Fire safety assessment of the various types of green façades

As described in the previous section, "living walls" are complex façade systems that differ significantly from manufacturer to manufacturer. The manufacturer-specific systems can only be analysed in a product-specific manner through full-scale fire tests on the respective overall system (Engel, T. 2023). The situation is different for climbing plants on climbing aids. These can be generally analysed and evaluated in terms of fire safety. General principles for fire safe use can be developed from these tests (Engel, T. 2023). (Bielawski J, et al. 2024) shows the critical fire behaviour of a corresponding living-wall-system based on fire tests.

3 State of the art

There is currently little international research available on the fire behaviour of green façades and the resulting fire spread along the façade. A detailed overview of the current state of research into the fire behaviour of green façades can be taken from (Engel, T. 2023) and (Engel, T. & Werther, N. 2024).

To summarise, it can be stated that medium and large-scale fire tests on green façades have so far been carried out primarily in Austria and Germany. However, these tests have mainly been carried out on standardised façade fire test stands, which were originally designed for a different application and do not correspond to the effects of real fire incidents (Engel, T. 2023). The current challenge for green façades is therefore that the results of scaled test methods, such as those according to (ÖNORM B 3800–5) or (DIN 4102-20), in conjunction with assessment criteria that were also designed for other building materials, are directly transferred to reality or measures are derived based on them. This approach can lead to unrealistic results and involves risks without a holistic view (Engel, T. 2023).

Analysing the state of research provides two key findings: Firstly, regular care and maintenance is an important basis for fire-safe green façades. Large areas of dead plants must be recognised and removed quickly. Secondly, if the green façades are exposed to fire, the plants can be expected to dry out and, in the further course of the fire, an abrupt, short-term fire spread ("flare-up") can be expected in areas outside the primary fire (Engel, T. 2023), (Engel, T. & Werther, N. 2024).

4 Flammability of the plants

An initial part of the FireSafeGreen (FireSafeGreen 2024) research project investigated the fire behaviour of green façades. The focus here was on the flammability of the plants, which was determined in 43 calorimetric fire tests on a medium scale using the Single Burning Item (SBI) test method (EN 13823). The study focussed on a total of 25 climbing plant species. The main factor influencing the fire behaviour of plants is the moisture content of the plant (Engel, T. & Werther, N. 2024). A comparison of the heat release rate of vital plants (normal moisture content) shows similar behaviour, as shown in Figure 4.

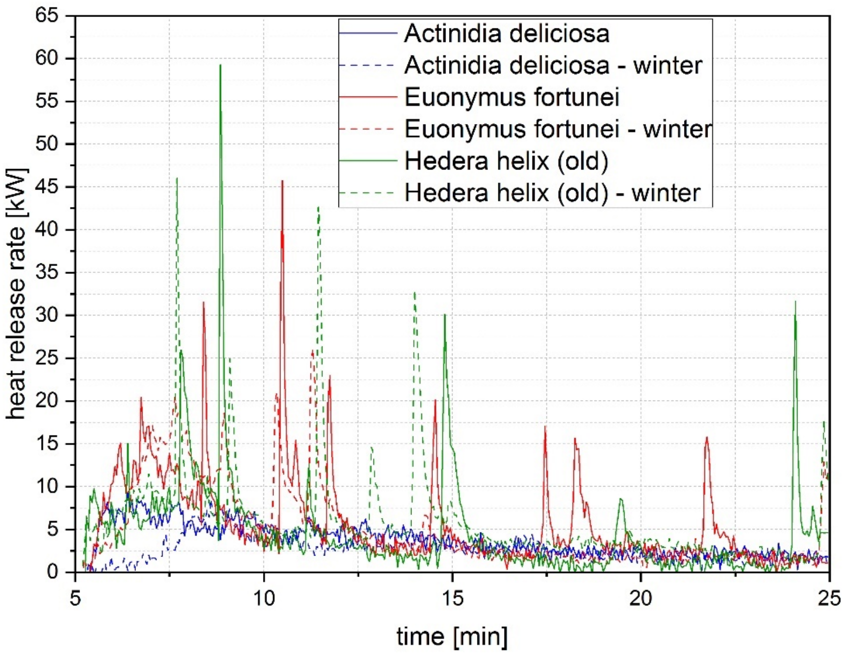

Figure 4: Comparison of the heat release rate of Actinidia deliciosa, Euonymus fortunei and Hedera helix in summer and winter

In the course of exposure, there are short peaks in the heat release rate. These peaks are the "flare-ups" known from previous studies. They occur when parts of the plants dry out due to the fire exposure and then ignite abruptly. The plant species itself has no significant influence on the fire behaviour. In all tests, only a very small amount of horizontal fire spread occurred with vital, maintained plants and self-extinguishing occurred after the burner was switched off. A direct comparison between young and old plants as well as a comparison of the seasonal influence between summer and winter also showed no significant difference for vital, well-tended plants (Engel, T. & Werther, N. 2024).

There was a significant difference for dried plants. Here, an abrupt heat release occurred at the beginning. Dead plants and unmaintained plants with a high content of dead wood therefore represent the most critical case. Figure 5 shows the heat release rate of a 42-day dried, a vital young and a vital old ivy (Hedera helix) in comparison to a 13 mm chipboard and a 9 mm plywood panel (Engel, T. & Werther, N. 2024).

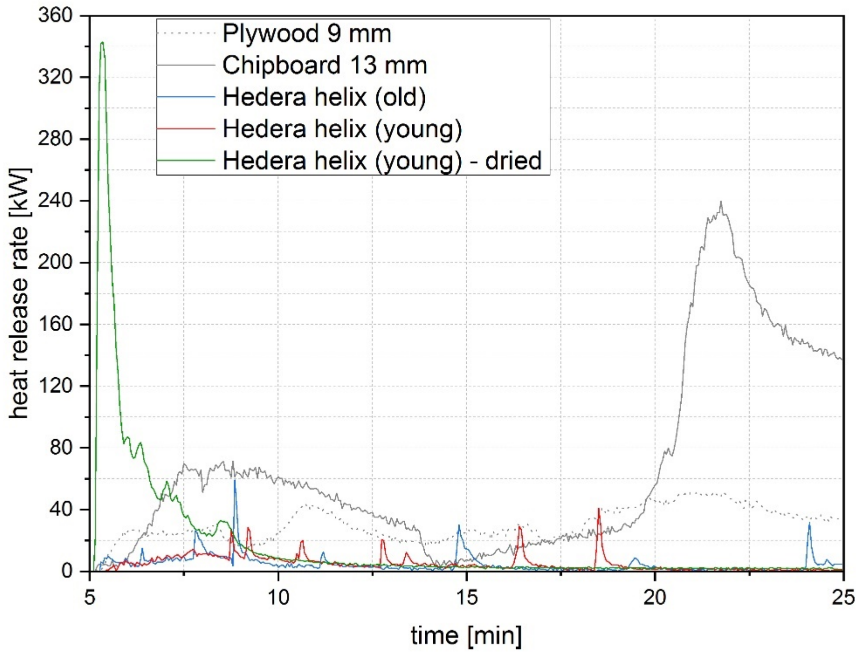

Figure 5: Heat release rate of a 42-day dried, a vital young and a vital old Hedera helix compared to a 13 mm chipboard and a 9 mm plywood panel

The care and maintenance of a green façade is therefore the most important factor for maintaining fire safety. Dead wood in the form of dead leaves, branches or bird nests must be removed regularly. It is also necessary to constantly check whether the plants are still vital and have a normal moisture content. The plants should also be cut back regularly. Uncontrolled growth can lead to a lot of deadwood - especially in the case of light-fleeing plants (Engel, T. & Werther, N. 2024).

In the next step, it is necessary to verify the findings from the medium-scale tests in full-scale tests; in particular, the vertical fire spread must be analysed in more detail (Engel, T. 2023), (Engel, T. & Werther, N. 2024).

5 Combination of wooden and green façades

A central question for the realisation of combined wooden and green façades are the resulting interactions in case of fire. The focus of the investigation was whether the heat flux of burning climbing plants is sufficient to ignite a wooden cladding and whether the burning climbing plants lead to fire spread on the wooden façade above the fire stops (Engel, T. & Werther, N. 2023).

Medium-scale fire tests were carried out to investigate this question (Engel, T. 2023), (Schoofs, N. 2023), as shown in Figure 6.

Figure 6: Photo documentation of the fire test (Test 3) with wooden and green façade in the 3rd test minute

As part of the tests, a distance of 110 mm was set between the trellis and the wooden cladding. This choice is intended to generate a critical fire impact of the green façade due to the small distance to the wooden cladding. It is known that wall distances of 50 mm to 200 mm from the climbing aids are common for ground-based climbing plants (Mahabadi, M.; et al. 2018), (Pfoser, N. 2018). These guide values are based on typical mineral external walls without fire stops. A sufficient minimum distance to the external wall is necessary, as plants with heavy leaf mass in particular can promote heat build-up and consequently die. To prevent overheating, air circulation on the façade must be possible without restriction due to sufficient distance between the trellis and the outer wall (Pfoser, N. 2018).

In many European countries, fire stops (Engel, T. & Werther, N. 2023) are required in each storey for wooden façades on multi-storey buildings. These fire stops define a minimum distance between the greenery and the external wall, as the plant cannot grow through the fire stop on one side and a sufficient minimum distance to the steel fire stop is required on the other side to prevent the plant from overheating in this area. As the projection of the fire stop increases, the distance between the trellis and the wooden cladding also increases; consequently, the effect of the burning plants reduces due to the greater distance. This is the reason why a tongue-and-groove wooden cladding with a relatively small projection of the fire stops was chosen for the fire tests which were described in more detail in (Engel, T. 2023), (Schoofs, N. 2023).

In the tests, the greenery was placed directly in front of the 100 mm projecting fire stop. Furthermore, the area between the wooden cladding and the trellis was filled with plant shoots of an over 15-year-old ivy (Hedera helix) (Engel, T. 2023). Ivy was chosen as it has a high leaf mass and a relatively large shoot diameter. The test arrangement and the plant density were intended to simulate an unmaintained and therefore critical green façade in terms of fire exposure, which did not have large masses of dead wood, but was also not regularly cut back.

The medium-scale test setup is representative in this case, as the plant mass and arrangement determine the possible area-related fire load or maximum heat release of the green façade and not the size of the test stand or the size of the fire exposure (Engel, T. 2023).

In both tests with arranged greenery, there was no independent burning on the wooden cladding above the fire stop either during the test or during the following observation period (Engel, T. 2023). This can best be seen on the wooden cladding at the end of the fire tests, as shown in Figure 7.

Figure 7: Photo documentation of the wooden cladding above the fire stop after completion of the test and the observation time for test 3

Colouration and charring occurred in some areas of the wooden cladding due to the fire exposure from the greenery. The charring was most intense in the central, lower area of the façade directly above the fire stop. This is due to the fact that individual wooden shoots of the wire-fixed ivy fell off the trellis after the leaves and young shoots had burnt down and then burnt on the fire stop (Engel, T. 2023). Even this fire exposure did not lead to an independent burning of the wooden façade. The direct fire impact on the lower area of the wooden cladding caused by burning plant parts on the fire stop would be more critical for open claddings than in the present case due to the three-sided fire exposure on the wooden cross-section. However, due to the greater distance between the greenery and the wooden cladding and the greater projection of the fire stops described above, a fire exposure directly on the wooden cladding is not to be expected with open cladding (Engel, T. 2023).

To summarise, it can be stated that the burning green façade in the tests [6] did not lead to ignition the wooden façade. Requirements for this are a minimum distance of 110 mm between the trellis and the wooden cladding and regular care and maintenance of the greenery, during which dead wood is removed.

6 Full-scale fire tests

The final full-scale fire tests serve as proof of the findings made during the FireSafe-Green (FireSafeGreen 2024) research project and as a basis for verifying the fire safety objectives.

The investigation focussed on evaluating the fire spread through the green façade under the influence of a representative fire exposure. In addition, the influence of a short-term heat flux of the burning green façade on the exterior walls, windows, balconies, roof overhangs and the areas behind them and the associated risk were analysed. Particular focus was placed on the influence of living and dead (dry) plants on the fire spread and fire behaviour along the façade. One specific question is, for example, whether the heat flux of a dry green façade (worst case) is sufficient to ignite the furnishings directly at the opening within the window is open. In addition, the vertical fire spread in particular is to be analysed in more detail.

Eight fire tests were carried out in total in three different test series (as shown in Figure 8). These three test-series included an wall test, an balcony test with central fire exposure and an balcony test with a fire exposure in the inner corner. A reference test without greenery (plants) was carried out for each test series in order to quantify the influence of the plants in more detail and to validate the results. In the test series, one test was also carried out with vital and one with dried (dead) plants, as shown in Figure 9 and Table 1.

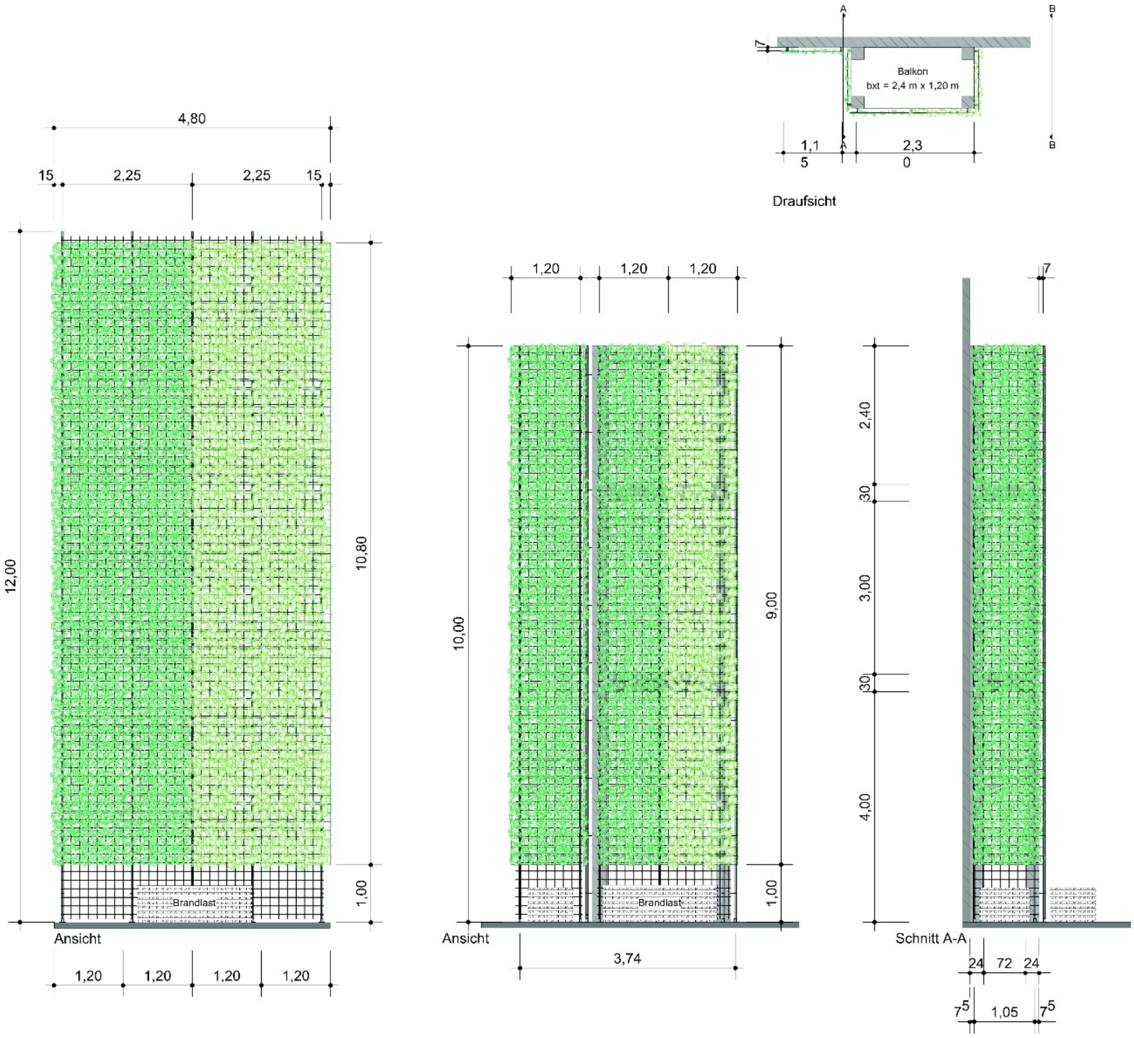

Figure 8: Left: Wall test stand (12m high) for tests V0, V1 and V2; right: balcony test stand (10m high) for tests V3, V4, V5, V6 and V7 [15]

Figure 9: a) Wall test with vital plants (V1); b) Wall test with dried (dead) plants (V2); c) Balcony test with fire exposure in the corner with vital plants (V6)

Table 1. Requirements to sound insulation.

Test	Test description	Fire load
V0	Wall test without plants (reference test)	4 × 35 kg (140 kg)
V1	Wall test with vital plants	
V2	Wall test with dried (dead) plants	
V3	Balcony test with central fire exposure without plants (reference test)	3 × 35 kg (105 kg)
V4	Balcony test with fire exposure in the corner without plants (reference test	1 × 35 kg
V5	Balcony test with central fire exposure with vital plants	3 × 35 kg (105 kg)
V6	Balcony test with fire exposure in the corner with vital plants	1 × 35 kg
V7	Balcony test with central fire exposure with vital dried (dead) plants	3 × 35 kg (105 kg)

Hedera helix with a plant density (vital) of approx. 1.85 kg/m2 (left side, in Figure 9) and Euonymus fortunei with a plant density (vital) of approx. 2.55 kg/m2 (right side, in Figure 9) were arranged on the trellis of the test stand.

Figure 9 shows the wall test with vital plants (V1), the wall test with dried (dead) plants (V2) and the balcony test with fire exposure in the corner with vital plants (V4).

During the fire tests with plants, regardless of the plant species (Hedera helix or Euonymus fortunei) and their moisture content, vertical fire spread occurred in the form of "flare-ups". The moisture content had a significant influence on their intensity. The findings of (Engel, T. & Werther, N. 2023) could be confirmed in the full-scale test. In the case of vital plants directly in front of an external wall, a burn-off of the green façade in the ratio of approx. 2.5 times the actual primary flame (wooden crips) was observed. In an open arrangement in front of a balcony (external wall further away), the factor was approx. 1.5. In general, self-extinguishing of the greenery was observed. The detailed test evaluation is currently still being processed and can be found in (Engel, T. 2024).

7 Conclusion and outlook

Currently, there are only a few principles for a fire safety assessment of green façades. Medium-scale fire tests as part of the FireSafeGreen research project (FireSafeGreen 2024) showed that the main factor influencing the fire behaviour of plants is the moisture content. The plant species itself plays a subordinate role in terms of fire behaviour and, according to these findings, is of minor relevance - at least for the tested variants. The direct comparison of young and old plants and the comparison of the seasonal influence of summer and winter also showed no significant difference for vital, well-maintained plants. During fires on green facades, short heat release peaks occur. These peaks are known as "falre-ups". They occur when parts of the plants dry out due to the fire exposure and then ignite abruptly. For vital, well-maintained plants, horizontal fire spread occurs only to a very small area. Furthermore, vital green façades are self-extinguishing after the end of the primary fire (Engel, T. 2024), (Engel, T. & Werther, N. 2023).

For a combination of wooden and green façade, it can be stated that the burning green façade does not lead to the ignition of the wooden façade behind it. The requirement is a minimum distance of 110 mm between the trellis and the wooden cladding and regular care and maintenance of the green façade (Engel, T. 2024).

The final full-scale tests also showed that correct care and maintenance are the key factor for fire-safe green façades. The conclusions from the full-scale tests can therefore be summarised as follows.

- "Living walls" or wall-based systems can behave critically from a fire safety perspective. Full-scale fire tests and corresponding certificates of applicability are required here in the medium term. At the moment, it is important to carefully check which materials are used.
- Climbing plants on non-combustible climbing aids can be generally evaluated and represent a lower risk from a fire safety point of view.
- The decisive factor for a fire-safe green façade is care and maintenance. Standard green façades generally require one maintenance cycle per year.
- A distance of 50 cm should be maintained from components such as horizontally projecting wooden roof trusses (combustible building materials).
- If climbing plants are arranged across several storeys on non-combustible climbing aids on balconies, closed balustrades made of non-combustible building materials should be chosen.

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