Saimaa University of Applied Sciences
Faculty of Technology, Lappeenranta
Double Degree Programme in Civil and Construction Engineering
Civil Engineering

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Repairing of underground garage roof water-proofing

Bachelor’s Thesis 2016

Abstract
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The study was commissioned by NCC Real Estate to find out the reasons of underground garage roof waterproofing damages to prevent the repeat of leakages. What is more, the purpose of the thesis was to develop principal works for repairing and determine what should be improved in the design project. For that purpose, basic garages structures and types of operational roofs were learned depending on their implementation, loads and structures. Besides garages were considered as an urban infrastructure object.

Data for this study was collected during the practical training at NCC Real Estate, Saint-Petersburg at Swedish Krona construction site. The information was gathered from the design project, subcontractors’ reports, co-workers’ experience, literature, the Internet, manufacturers’ guides and local and international norms.

The final result of this thesis was the recommendations to the design project and construction works organisation that have the main influence. The weakest sides of construction that could lead to the leakages were determined. The findings have been implemented to the final parking phase construction, so the results show positive development.

Keywords: waterproofing, garages, operated roofs, green roofs

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1 Introduction

Nowadays urbanisation is more and more recognisable in Russia. With the growth of population in the cities, the increase of personal vehicles becomes more and more recognizable.

Like Stockholm, Helsinki and Oslo, Saint–Petersburg is one of the cities suffering from traffic congestion, as there are more than 2 million personal cars and the number is increasing by 200-300 thousand of vehicles per year. Along with that, the number of parking places is less for 20% than the number of cars.

According to the above mentioned, there are three problems that should be solved: road management, organization of car parking and storage and reduction of private cars use in the city center. It is impossible to endlessly widen the roads, and usually there is no place to a multi-storey car park. This is the reason why the solution should be found in another plane, so cars have to be transferred underground.

Parking is a very important part of the infrastructure of any building as mostly market attractiveness of the office and shopping center, hotel or residential building depends on parking's characteristics such as roominess.

State norms and urban planning existing in many countries including Russia determine the minimum number of parking places for different real estate objects. However, usually developers provide more parking places to rise the attractiveness of the project, while in Russia they provide only the minimum number. Due to that the contractor meets more difficult problems and spends more money for their solving.

Saint-Petersburg state committee of transport infrastructure development determined the priority direction of infrastructure development. They are transport objects of center bypass, transport interchange objects (transport hub), FIFA 2018 objects and Lakhta district development.

In 2015 the government of Saint-Petersburg provided the parking area in the city center—area between the Vosstania square and Chernishevskaya. An interactive map was created which shows the amount of free parking places in real time (Figure 1).The fee is about 30-120 rubles per hour (0,5-2,0 euros). The spread of that area is 15,3 km, and the total number of parking places is 2 895. That parking zone covers 27 streets. This solution somehow reduced the number of cars in the center, as many people working there now use public transport rather than private.

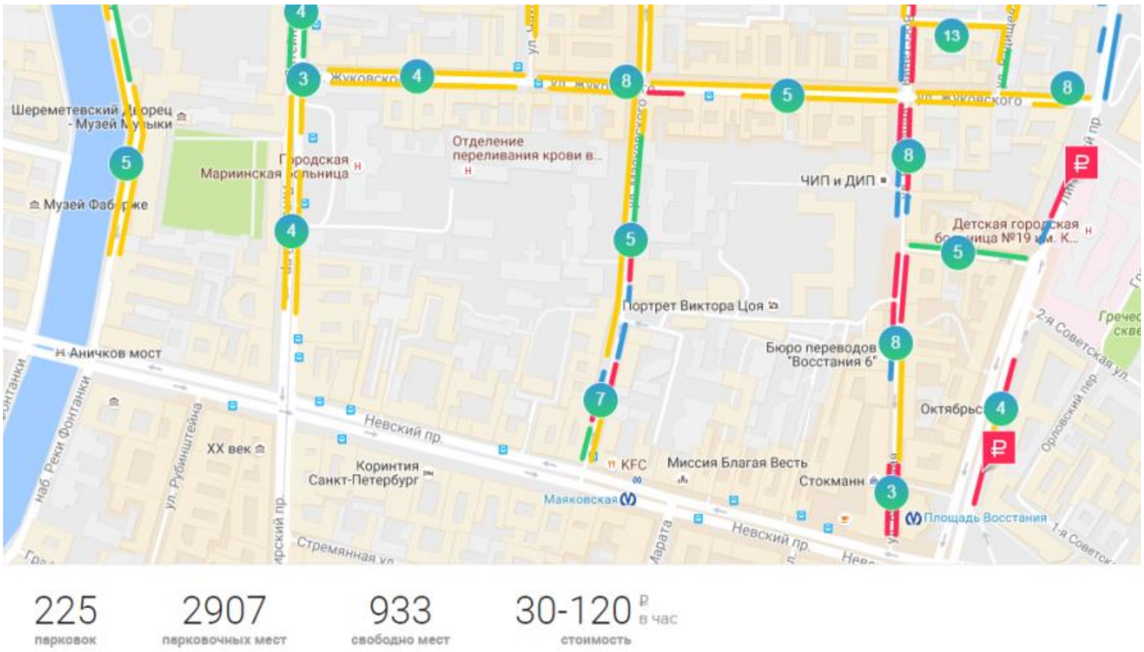


Figure 1. Parking map in Saint-Petersburg (www.parking.spb.ru)

What is more, parking is free of charge from 8:00 pm to 8:00 am, so people who live in the center can park their cars.

In order to save the appearance of Saint-Petersburg and because of absence of the free area in the city center it is forbidden to build the multistorey parkings (in the center), so it is possible to build only underground garages. Unfortunately, a lot of problems could be met due to the climate of Saint-Petersburg, geological conditions and historical value of the city center structures. The technologies that could be applied for the new structures construction in the historical part of the city are very difficult and expensive. The main reason is the geological conditions, as primary soils are loam and clay. The level of ground waters is another problem that could be met as their level is about 1,9-1,5 meters what is about 2,0 meters from the basement footing. The level changes a lot during the year because of rains (635 mm per year) and melting snow. All these difficulties lead to the rise of expenses to the developer and increase of the cost to the customers.

The infrastructure development committee reports that the ability of the reconstruction and new construction of the roads in the city center is exhausted. There are a lot of limitations of construction of new highways and roads such as city appearance, dense building and sanitary norms.

At the moment one of the priority development directions is a center bypass system. It is a road and highway system with better traffic conditions, which passes by the border of the city center (Figure 2). The aim is to take away traffic flows from the center of St. Petersburg, and distribute them to other districts, thus the traffic situation in the center can be improved.

Figure 2. Saint-Petersburg center bypass system (www.krti.gov.spb.ru)

Saint Petersburg embankments are a very important part of the center bypass system as they link the central, south and east districts of the city, and important urban objects as Big Port, Baltic and Vitebsk railway stations, bus station, etc.. Therefore, after the implementation of all activities related with the construction of the center bypass it is planned to introduce a continuous motion mode for transport along the embankments. It will be achieved through the organization of one-way traffic along them, as well as the construction of transport hubs and transport tunnels in areas of intersections with major urban highways (Staro – Petergofsky, Moscow, Ligovsky avenues). Moreover, the Western High-Speed Diameter the last span of which was installed in summer 2016 is going to connect the north district, Vasilevskiy island and south-west district of the city.

2 Garage types and their features

Equipped	Level	Location
• Traditional	• Surface	• Roof
• Mechanical	• Underground	• Build-in
• Automated	• Deep	• Attaged
		• Detached

Table 1. Garages classification

2.1 Equipped garages

Mechanical parking is a type of garage which equipped with special devises.But the process of parking involve the operator of the equipment or driver of the car. Mechanical parking-type of garage with special equipment, where in a parking process have to be involved operator, man who will control mechanism, or driver. Such kind of parking in rather compact.

Automated parking is a mechanical system designed to minimize the area and volume required for parking cars. Once the driver leaves the safety zone incorporated into the parking bay, the system automatically commences the vehicle parking procedure

Surface structure is the simplest parking type, it could be a car lot or a multi-story car park.

Underground garages have a lot of advantages. Firstly, cars are protected from environment and vandalism and secondly underground garages save surface area that could be used for other purposes.

2.2 Examples of parking layout solutions

Single level parking of corridor type could be used to arrange parking at the basement or ground floor of built or under construction structures. Absence of elevators makes this type cheaper than other solutions (Figure 3). Such a parking lot is used to the townhouses. The cost for customers depends on the amount of parking places, but the average price is 200 000-500 000 rubles.

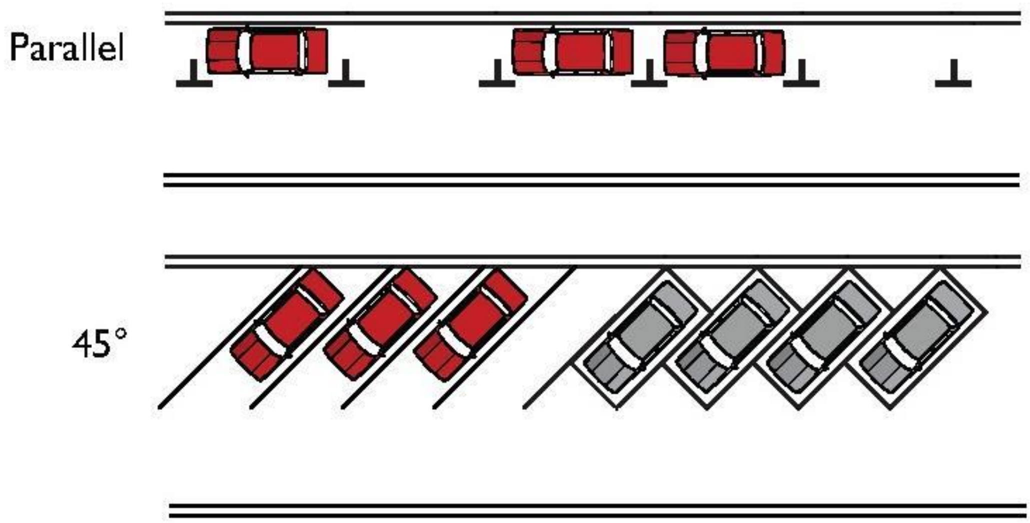


Figure 3. Single level parking of corridor type

Single level parking of puzzle type is a modification of the previous type, but with several corridors. They are designed for larger areas (Figure 4). As the garage has only one level the amount of parking places is limited. Such type is used to the residential houses with less than 9 floors. The price of a car place depends on the class of the residential complex. What is more this garage type could be implemented during the construction of big malls like Ikea in Saint-Petersburg. The area of parking lots is equal to the area of the mall, because it is situated under the building. The cost of parking places in the average is 450 000 - 2 500 000 rubles.

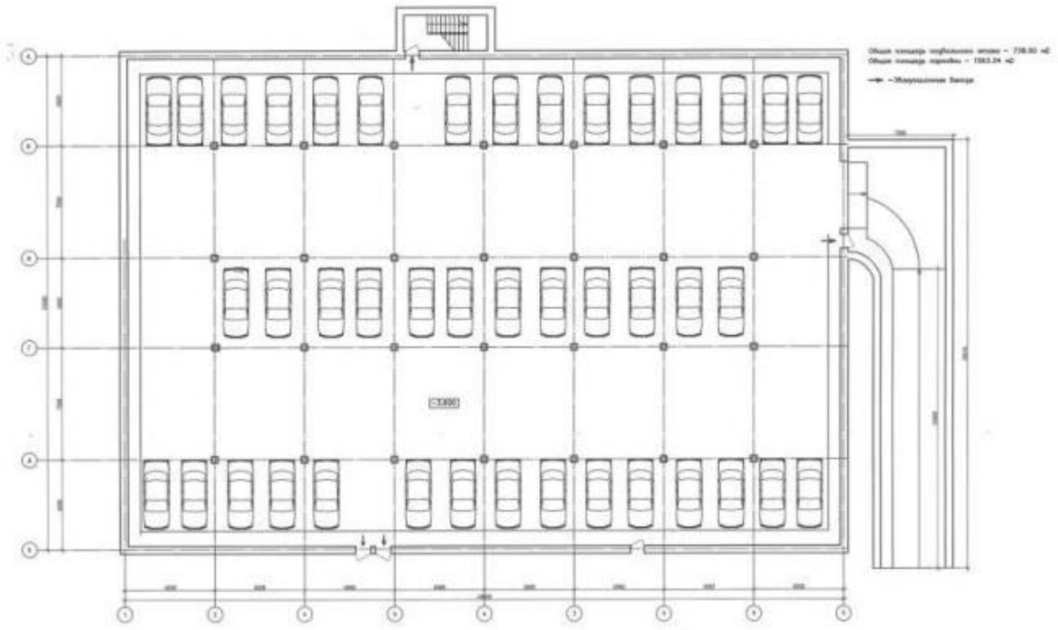


Figure 4. Single level parking of puzzle type

Parking of tower type could be used above the ground with connection to the end of the building (Figure 5). This type of parking is not common in Saint-Petersburg, as the total amount of parking places is limited. Figure 6 shows this type implemented in the resedential complex in Petrogradsky district of Saint-Petersburg, where the parking is situated in the middle of the building. The price of the parking place is about 4 000 000 rubles.

Paternoster parking type is the tow-elevators modification of tower type, which has a similar purpose, but this type is used at areas with the length several times greater than the width. This type is not popular in Saint-Petersburg, unlike Moscow where it became the solution for the reduction of cars in the courtyards. The price of the parking place is 400 000 rubles (Figure 7).

Multistorey parkings of corridor type could be used in a limited area either underground or on surface (Figure 8). This type is used when the length of parking is much bigger than the width.

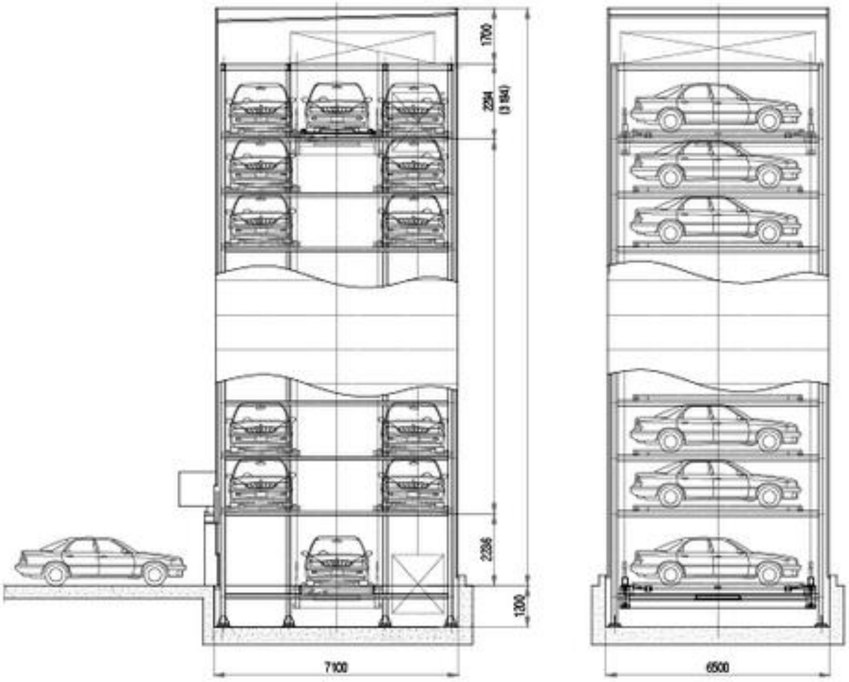


Figure 5. Parking of tower type

Figure 6. 1st floor plan of the residential complex Petrogradec.

Figure 7. Paternoster parking type

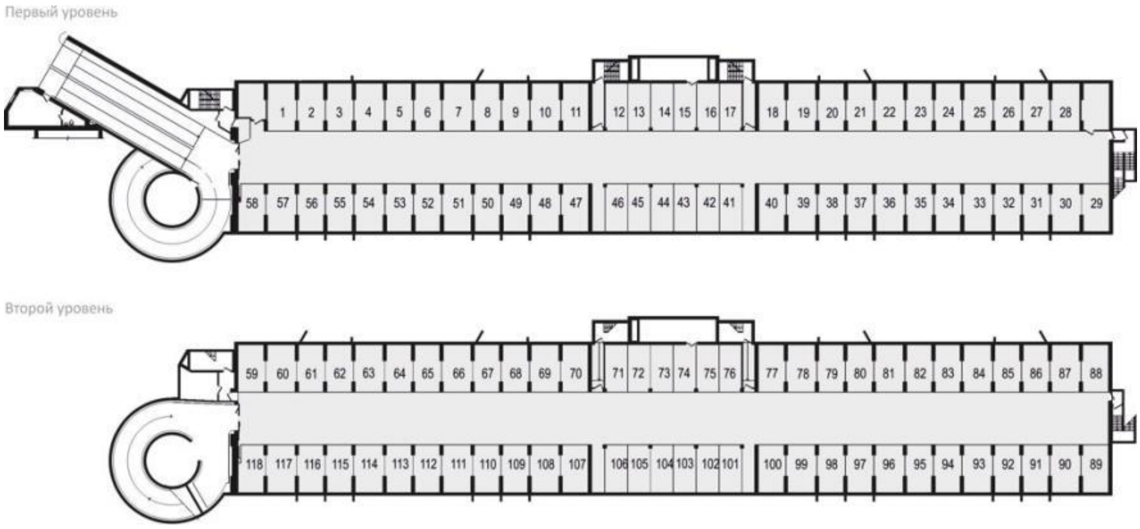


Figure 8. Multistorey parking of corridor type

Multistorey parking of puzzle type is the previous type but with two or more corridors (Figure 9). This type of garages is used for high-rise office centers. In addition, such garages could be arranged in shopping centers which are built in dense housing conditions like Stockman in Saint-Petersburg. The cost of the parking can be equal to half of the cost of the aboveground building.

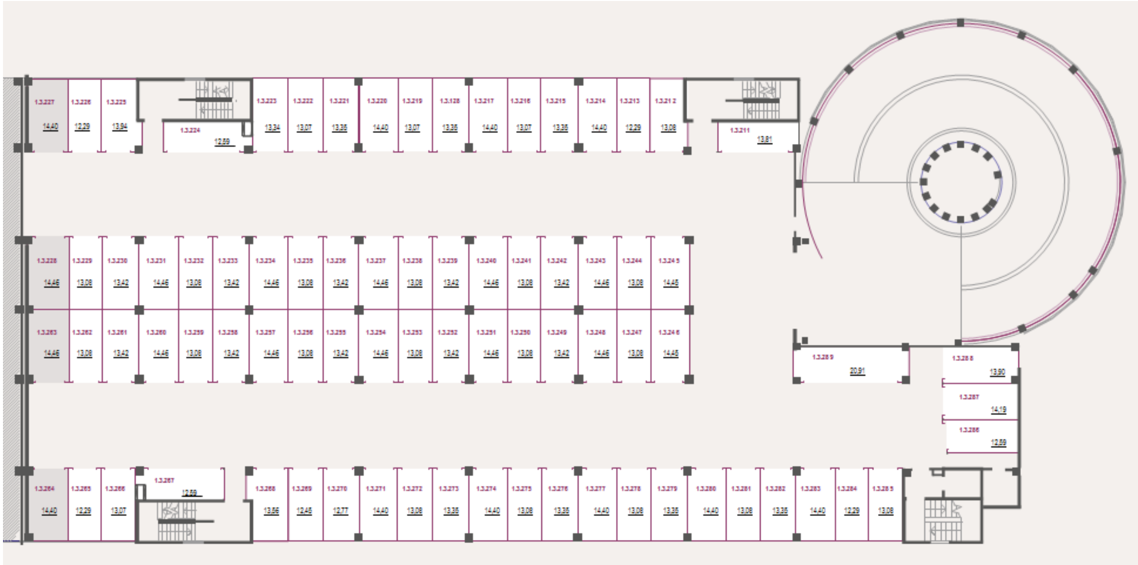


Figure 9. Multistorey parking of puzzle type

Multistorey parkings of puzzle type could be used at unlimited underground or underwater area (Figure 10). The most common type of parking in the developing districts (in St. Petersburg is Parnassus, Devyatkino etc.). Such underground parking is arranged on the area of the residential complex, not under the buildings. The cost of this type depends on the area of the residential complex, in some cases it is up to 1 billion rubles. The lowest cost of parking places in a parking lot is 250 000 rubles, on average, in St. Petersburg, this value is equal to 1 200 000 rubles.

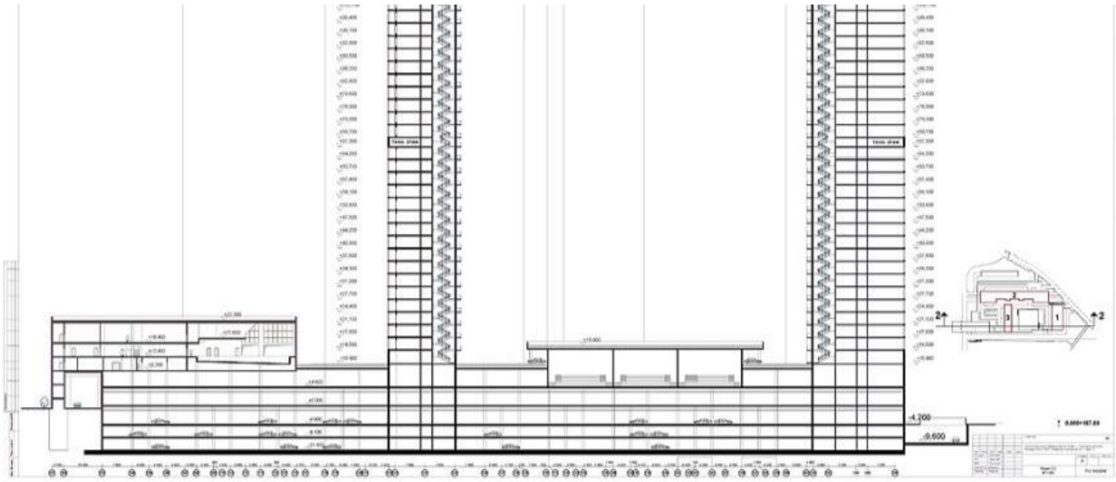


Figure 10. Multistorey parking of puzzle type in unlimited underground or underwater area

3 Underground garages with operating roofs

3.1 Underground garage design features in Saint-Petersburg

During the parking design, many factors should be considered such as safety, ease of access, good quality waterproofing, provision of engineering services HVAC, fire extinguish and smoke removal, lighting, and finally the sufficient ceiling height for all types of vehicles (SP 113.13330.2012). In real urban areas, it is not easy to provide all of these requirements. Another important feature is the need of proper engineering geological survey, especially in case of Saint-Petersburg. Geotechnical and hydrogeological conditions include soil characteristics, and the groundwater level. As the city was found on swamps in the delta of Neva river, the average level of ground waters in the city is 0.5-5.0 meters (and the level is changing during the year) (Sokova 1997). The soils are sab- and lateglacial clays, loams and sandy clays. The ground is weak and unstable, that is why usually it is impossible to implement shallow foundations in Saint-Petersburg and in this case pile foundations are used.

During the design town planning restrictions should be considered, as there could be architectural monuments or engineering nets.

In Russia, underground garages have been built for a long time, so there is enough experience. Unfortunately, there are many blank spaces in local construction norms in the area of new technologies and materials.

3.2 Structure of operated roof

To create long lasting and functioning walkways and driveways on any roofs it is crucial to use the right technique. At a progressing rate, roofs are being used holistically and now almost everything, which can be realised on ground, is possible on roofs as well. Therefore, the following roof classification can be applied to all kind of structures and buildings.

3.2.1 Traditional roofs

In case of traditional roofs a vapour barrier must be installed to reduce vapour penetration into the insulation as vapour ventilation release can hardly be solved technically and would be objectionable for roof gardens from the aesthetic point of view. This type of roof is more vulnerable for internal moisture effects even with such a vapour barrier, therefore its application should be avoided for new roofs. For re-roofing - if the existing thermal insulation and vapour barrier layers are appropriate from every respect (substance protection, thermal comfort, energetics and perfect vapour retardation) this type of construction is acceptable.

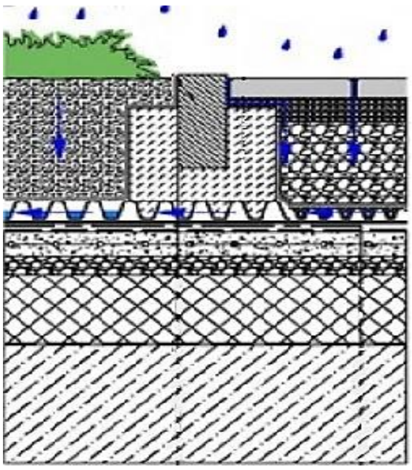


Figure 11. Traditional roofs section. Lawn and driveways

3.2.2 Inverted roofs

The characteristic of an inverted roof is that the insulation is above the waterproofing. The thermal insulation which is used for this kind of roof is impervious to water, but not to water vapour. There is no vapour barrier layer above insulation, so the number of layers is reduced, thus the construction is simpler. At the same time the application of a thermal insulation layer resistant to outside effect is necessary and suitable heat - storage capacity of the structure below the water proof membrane is required. Layers that prevent moisture from diffusing out must not be installed over the thermal insulation layer and the layer above should be vapour permeable.

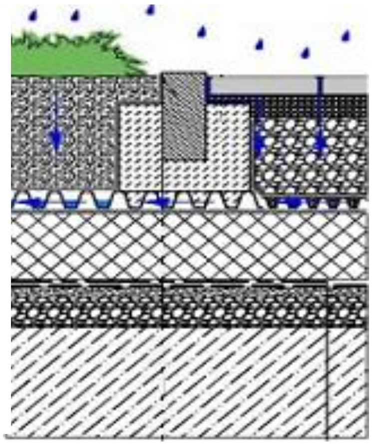


Figure 12. Inverted roof section. Lawn and driveways.

3.2.3 Structural layers

Load bearing structure. There are no special requirements for the load bearing structures, however light construction structures for green roofs are not typical for this purpose. Load bearing capacity and rigidity of roof deck are very important parameters as roof soil and vegetation form the base part of the total load.

Sloping layer. Due to SP 17.13330.2011 it should be 1-2°. Provision of the required slope for green roofs is even more important than for other roof types because damages originating from insufficient water drainage can be repaired later only with difficulties and generally locating the determination of the place of fault is not a simple task.

Vapour barrier. It is very important to protect a structure from vapour penetration especially for conventional roofs.

Thermal insulation layer. For conventional roofs rigid plastic foams or slabs can be used. The advantage of this material could be water resistance and load carrying. For inverted roofs, such materials as polystyrene foam slabs can be used. The insulation layer can situate above the water proofing due to material’s low water absorption, freezing resistance, compressive strength and good thermal insulation.

Separating-protecting layer. This layer would be necessary for inverted roofs - laid between the screed and the water proof membrane. The function of this layer is surface equalization (that is protection of the vulnerable membrane from mechanical impact) or separation of the base and the insulation (if they are incompatible chemically). In case of conventional roofs the separation of the insulation and the membrane can be important.

Waterproofing. A green roof can be installed with any kind of waterproofing system, but single-ply membranes have become very popular in recent years and are specified by nearly all green roof companies for their cost effectiveness and simplicity. As such, the waterproofing layer is typically assumed to be a membrane. It is an advantage if the membrane is resistant to roots as special protection layer against roots is not needed.

Root barrier. Significant damages could be made by plant roots, as they are able to find every gap in order to get water. This layer should be above the water proofing layer.

Water holding-drainage layer. It is a layer through which water can flow from anywhere on the green roof to the structure's drainage system. Figure 13 presents how plastic drain mat allows the water flow in case of walk- and driveways, and how it allows water holding in case of green layer. The advantage is that the same material is used for both types of covering, it is just turned upside down in case of green layer. Some systems simply use a layer of large-diameter expanded clay, but most green roof companies now use a corrugated plastic drain mat with a structural pattern resembling an egg carton or landscape paver. The minimum drain layer thickness is usually less than 20 mm, but a thicker mat can provide additional insulation and root restriction.

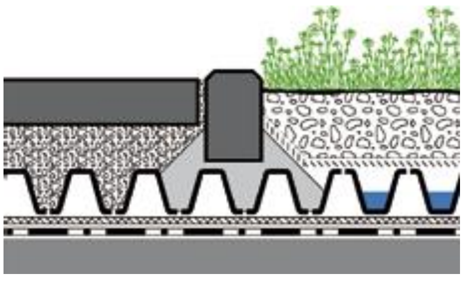


Figure 13. Continuous drainage

Filtering-protecting layer. Between the soil layer and drain layer lies a filter, which not only allows water to flow through while retaining the planting medium, but serves as a root barrier. The filter usually comprises one or two layers of non-woven geotextile, where one of the layers may be treated with a root inhibitor (i.e. copper or a mild herbicide). As in many landscaping applications, filter fabric can also be used to control erosion at the surface of the planting medium.

Roof soil. Selection of soil depends on vegetation, on plant type and height. There is an uncountable amount of soil mixes.

Pavement, bedding layer, gravel base layer (for walkways and driveways). According to FGSV for a gravel base layer a grain size of 0/45 is recommended. Grain size and grain size distribution ensure excellent compactability and stability. Bedding material can come in different grain sizes, but has to harmonize with the jointing material to prevent it from being washed out. Driveways on roofs require both a loadbearing system build-up and a loadbearing roof construction. Figure 14 (www.zinco-greenroof.com) displays the load distribution on layers from the static force.

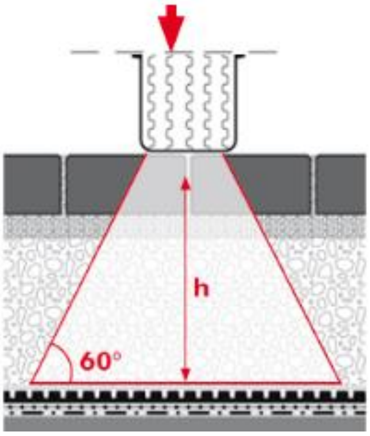


Figure 14. Load distribution

Additionally, to the self-weight and imposed loads on walkways and driveways, horizontal forces and torsional movements may occur through acceleration, steering or breaking as shown in Figure 15 (www.zinco-greenroof.com).

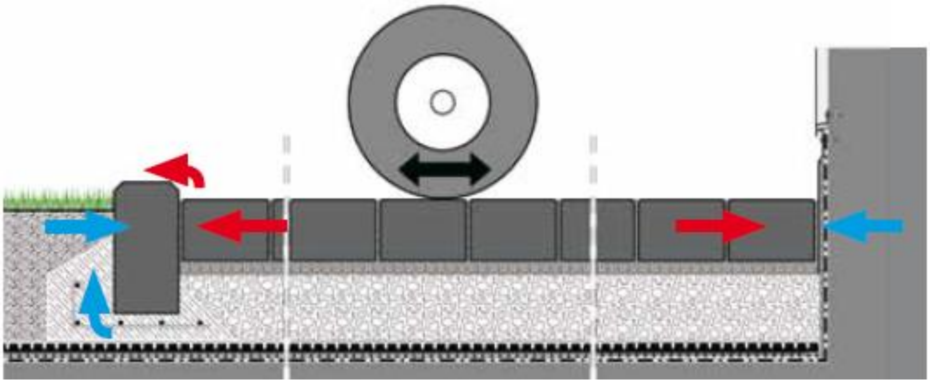


Figure 15. Steering, breaking and accelerating (www.zinco-greenroof.com)

3.2.4 Extensive roofs

Generally, there are two basic types of roofs due to the loadbearing variants: extensive roofs and intensive roofs.

Extensive green roofs are well suited to roofs with little load bearing capacity and sites which are not meant to be used as roof gardens. The costs are lower than intensive roofs. The mineral substrate layer, containing little nutrients, is not very deep but suitable for less demanding and low growing plant communities. They cope with the conditions on the roof (sun, wind, drought, etc.) by nature. After establishment of the vegetation, the maintenance is limited to one or two inspections a year.

3.2.5 Intensive roofs

Intensive roofs can most easily be compared to building a garden on a roof. They are usually multifunctional and accessible. Walkways, benches, playgrounds or even ponds can be established as additional features on the roof. They require more weight and a deeper system build-up. The maintenance should be regular and depends on the landscape design and the chosen plant material.

3.3 Purposes of operated roofs used in Saint-Petersburg

The purposes of operated roofs are the following:

1. Green roofs-type of roofs (Figure 16) covered with vegetation: grass, flowers or plants. Cover type should be designed due to size and kind of vegetation (Oberndorfer 2007).
2. Terrace-garden on the roof (Figure 17). Place for rest or other activities. Terrace could be covered by both natural and artificial materials (Oberndorfer 2007).
3. Parking (Figure 18) - this type can be used at hotel complexes or private houses. This kind is similar to the terrace but additional loads should be considered during the design.

Figure 16. Green roof

Figure 17. Terrace

Figure 18. Parking on roof

3.3.1 Advantages of operated roofs

- Improve the microclimate. Green Roofs cool and humidify the surrounding air. Thus, they contribute to improving the microclimate in urban centers. This cooling effect significantly increases the performance of air-conditioning systems, reducing carbon emissions.
- Increase rainwater retention strength. A Green Roof can reduce water run-off by 50–90% (Beliaev 1997); any water flows from the roof with a delay. Outlets, pipes and drains can be reduced in capacity, thereby saving construction costs. Sewer costs can be reduced in some areas.
- Reduce of Energy Costs. A Green Roof has the ability to buffer temperature extremes and improve the buildings energy performance.
- Protect the waterproofing. A Green Roof protects the waterproofing from climate extremes, UV exposure and mechanical damage. This greatly increases the life expectancy of the waterproofing and results in reduced maintenance and replacement costs.
- Provide additional space. Green Roofs offer additional space for numerous uses. Whether you want a relaxing garden, a playground or a golf course, it all can be achieved as part of the existing footprint.

3.3.2 Disadvantages of operated roofs

- The complex structure and high quality materials for this type of coverage influence on the cost.
- Mindful drains design required.
- Under certain weather conditions, snow should be removed from the roof.

3.4 Problems occurred during underground garages construction

Nowadays most office centres and residential complexes have 1 or 2 level garages, as construction of extra level is very expensive. Moreover, there could be local limits to the maximum possible depth of construction. In general, the following problems could be met:

1. Atmosphere precipitation that getting inside the parking through the roof. Considering Saint-Petersburg is one of the rainiest cities in Russia and

with little experience in construction of underground parking this problem is very common.

2. Groundwater and karst formations which can limit the depth of construction and complicate excavation process. There is a need to carry out works on installation of pile field, making additional drainage, temporary drains. In addition, the developer carries enormous costs for work related to the waterproofing of structures. All this increases the cost of construction.
3. Great amount of the utilities, especially in the historical center of Saint-Petersburg. Metro lines, old foundations of houses standing side by side requiring the strengthening significantly increase the cost of construction of underground parking.

In general, an underground parking lot is a technically complicated and expensive construction, so the prices are quite high. Despite of the fact that in Russia underground parking is already a common element of the infrastructure of a modern building, the experts have concluded that not all cases, they comply with the high-class cars, which use that parking.

Underground parking must meet the following requirements:

1. Safety.
2. Ease of entry and exit, which should be separated.
3. The availability of systems:
    - Waterproofing;
    - Ventilation and gas control;
    - Firefighting and smoke removal;
    - Communications;
    - Lighting;
4. The micro-climate (warm and dry; air curtains, which "inhibit" the cold air to the outside, which is especially important in winter).
5. Excellent overview.
6. Sufficient for all types of vehicle ceiling height and width of the entrances and exits, trips, parking spaces.

In Europe garages should be provided with washing, snow cleaning, dryers, elevators, anti-icing systems located at the entrance or exit. Although Russian norms are strict as European, there are a lot of blank spaces connected with implementation of new technologies. In this case application of international standards is needed, but it could complicate the approval of the regulatory authorities.

Another problem is a mismatch of norm requirements for underground parking parameters and vehicles size. According to SP 113.13330.2012 the standard parking place must be 2300x5000 mm, it is possible to place a car there, but not to park or turn. A similar disadvantage is connected with parking height. As a result, most professional developers began to design underground parking lots in accordance with their own list of requirements, based on customers' preferences.

4 NCC Swedish krona underground garage

Data for this study was collected during the practical training at NCC Real Estate, Saint-Petersburg at Swedish krona construction site.

4.1 General information

NCC is one of the leading construction and property development companies in Northern Europe, with the sales of SEK 57 billion and 18,000 employees (www.bonava.ru). With the Nordic region as its home market, NCC is active throughout the entire value chain – developing and building residential and commercial properties, and constructing industrial facilities and public buildings, roads, civil engineering structures and other types of infrastructure. NCC also offers input materials used in construction and accounts for paving and road services. NCC creates future environments for working, living and communication based on responsible construction operations that result in sustainable interaction between people and the environment.

Figure 19. Swedish Krona residential complex

Developer: NCC Real Estate

Start of construction: February 2010

Completion: December 2015

Total area: 35702 m^2

Total area of residential buildings: 8344.2 m^2

Number of stages: 5

Number of buildings: 14 (from 9 to 14 floors)

Total number of units: 890

The underground parking: yes

The total area of the parking lot: 11770 m^2

Number of parking spaces: 397

The cost of the apartments varies from 5 585 000 to 15 808 000 rubles (103 000 - 160 000 rubles per square meter)

The cost of the parking place is about 1 200 000-1 700 000 rubles.

This complex is located in Russia, St. Petersburg, Fermskoe Highway 22, letter B. It is the north district of the city, a ten-minute walk from the subway and railway station Udelnaya. This area is good for the residential house location as it is close to the city centre (7 km) and surrounded by park (a very important element in urban conditions).

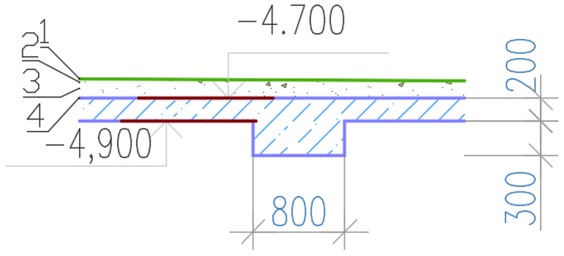
Residential complex Swedish Krona was conceived as a European home - a place to relax, work, communicate. It provides everything the customer could need in a modern metropolis for a comfortable life: a secure landscaped area, modern engineering systems, efficiently budgeted living spaces, prams- and storerooms, shops and services, kindergarten, an underground garage. The house was twice voted as the best in the All-Russian competition for eco-development Green Awards, also one of the buildings was the first in the city which received an international certificate of environmental efficiency BREEAM. Swedish krona was included in the rating of "Strong buildings of Russia."

4.2 Underground parking lot general information

The residential complex's underground lot has 4 sections that were completed at different times. The total number of the parking places is 397. The parking is a semi-underground structure, which is situated between the buildings of the residential complex. It has one floor with the height of 2,9 meters. The high mark of the floor is -4 500. The garage is equipped with a tow-ways sloping ramp for cars, also there are entrances to the parking lot directly from the buildings and 3 extra exits due to the fire safety norms.

The geological conditions of the site are presented by sands, sandy loam and glacial loam, the depth is 20.5 meters. The core layer is a loam; its thickness is about 11 meters. There is also groundwater in a layer of sand at the depth of 0.83-2.15 meters from the ground. Due to that a decision was made to use prefabricated concrete piles as the building foundation. They are made of concrete B25 F100 W6 and their length is 14 meters.

For the parking loads are smaller, that is why the foundation of the garage is the cast-in-place concrete ribbed slab (Figure 20).



1- Master TOP-100
2- polymer coating with quartz sand
3- concrete screed
4- concrete slab

Figure 20. Section of the foundation slab

All the bearing structures of the garages are made of reinforced cast-in-place concrete B25. The column size is 500x500 mm and their spacing is 7.8 or 4.5 meters. Beams' size is 500x750 mm. They were cast with the roof concrete slab with the thickness of 250 mm. The part of roofing slab formwork is shown is Figure 21.

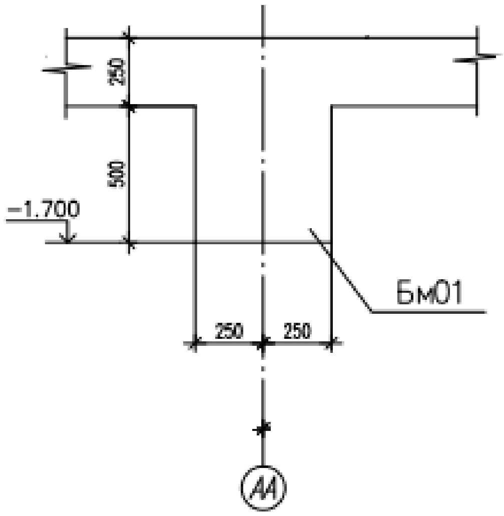
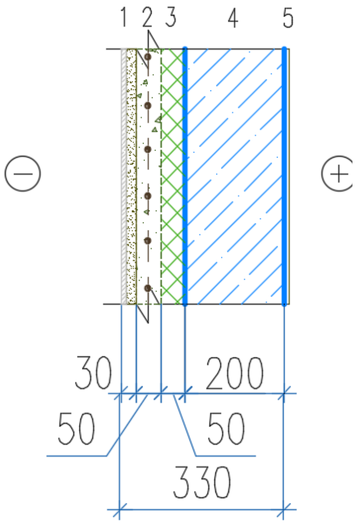


Figure 21. The section of parking roof slab

The external walls are concrete and their thickness is 200 mm. The walls have consoles for beams bearing. (Figure 22. External wall section)



1- granite tiling thickness 10 mm, special glue – 20 mm;
2- plastering on a cement-sand mortar M150 on a metal grid 50x50 mm;
3- thermal insulation Penoplex PP35 (U_{value}=0,031 W/(m×°K));
4- concrete wall;
5- finishing due to the project

Figure 22. External wall section

Figure 23 shows the section of the external wall which is semi-underground.

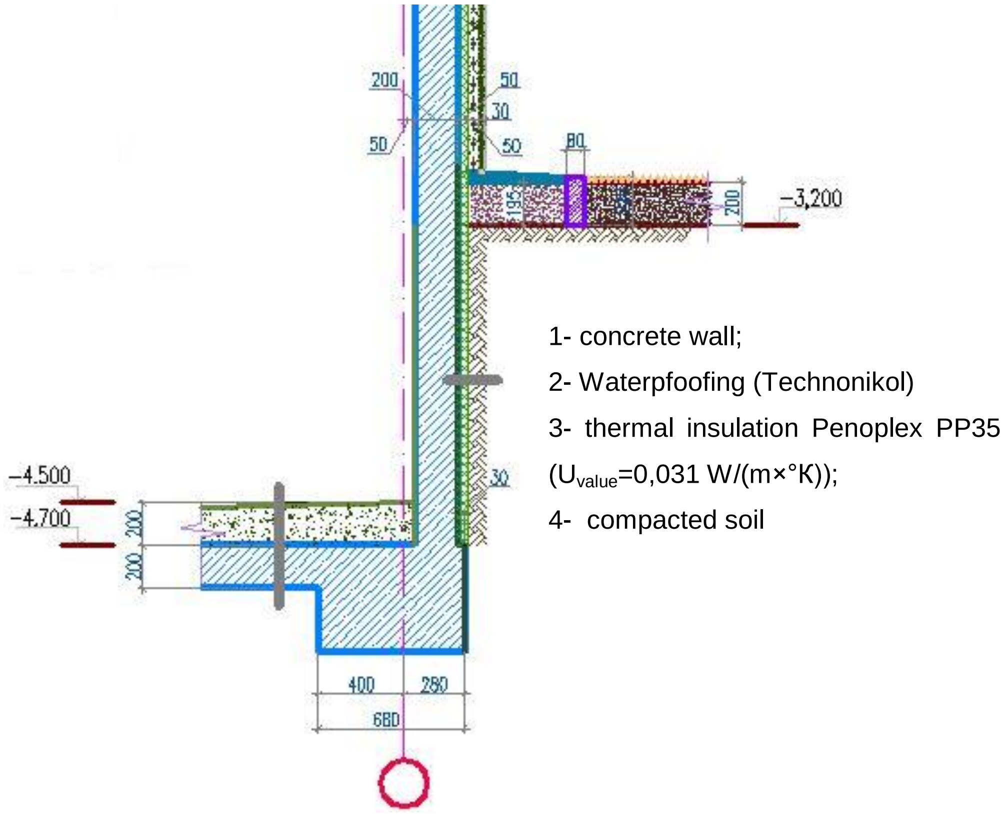


Figure 23. External wall section (parapet wall)

4.3 Water leaks in parking

Unfortunately, after one year of operation several problems were identified. There were water leakages found in some parts of the visible surface of the ceiling near drains (Figure 24 and Figure 25), deformation joints (Figure 26), and attachments to the walls (Figure 27).

Figure 24. Water filtration through drainage system

Figure 25. Water filtration through drainage system

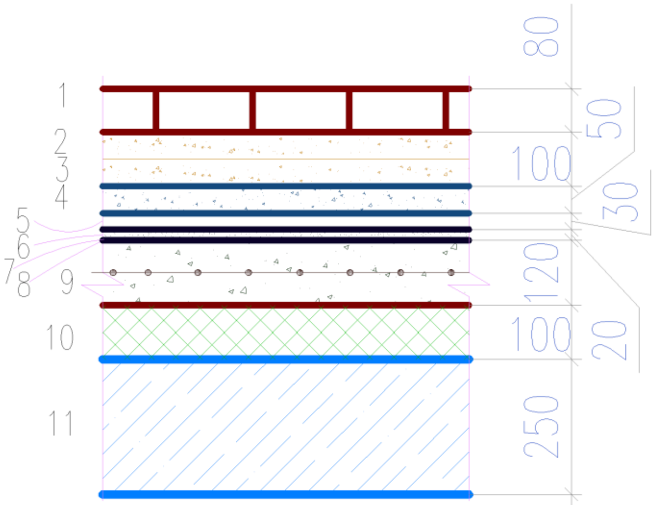
Figure 26. Deformation joints

Figure 27. Water filtration through attachment to the wall

In addition, water filtrated under the tiling of external walls of the garage. At the onset of winter, all the remaining water under the tiles turned to ice. Consequently, wall tiles start to fall off (Figure 28. Wall tiling). But the area of damaged spots with lining amounted to approximately 1.5% of the total area of the walls parking.

Figure 28. Wall tiling

All these problems took place before the finishing of the last garage phase. Of course, the developer made a decision to find out the reasons of water filtration and prevent mistakes repeat.



1. Surface layer (pavement)
2. Bedding layer (sand 2.0-3.5mm)
3. Bedding layer (sand 2.0-2.5mm)
4. Gravel base layer
5. Water holding-drainage layer
6. Waterproofing (slope 1:50)
7. Pressure equalization mat (locally with bitumen)
8. Condensate drain system
9. Cement screed (Sloping)
10. Thermal insulation
11. Concrete slab

Figure 29. Walkways roof section

Garage roof is a traditional roof, with waterproofing under the insolation layer, and it is designed for human and car loads, that means that it is intensive roof.

4.4 Underground parking diagnostic

The decision was made to lead water proofing diagnostic to detect leakages. For that purpose EFT method (www.texplor.eu) was chosen.

The EFT technology is a method used to investigate sealing systems in buildings and in civil engineering. An electrical tracer detects and outlines the tightness of the sealing system (Figure 30). The EFT measurements were done pointwise with a measuring stick and touch panel computer with integrated data-logger. The measuring grid varies between 0.3 m and 2-5 m. Appendix 2 shows that in this case the measuring grid was 0.8 m and the location of detects.

Figure 30. The detectors installation

Figure 31. Measuring grid location

The measuring grid was done on the diagnosed field. The employees of the NCC Construction dismantled of the roof covering where it was needed to locate points of measure grid. To provide contact of sensor electrode with the surface of waterproofing lawn, pavement and asphalt covering were removed locally.

During the process of investigation of operated roof a directional electric field was created. The surface of the waterproofing was examined with different levels of electrical signal. The trace signal was recorded by a data recorder module in which the signal after passing through the low-pass filters and analog-to-digital conversion, values are entered into the electronic database for further analysis.

Analysis of the data is carried out based on the study of abnormal changes in the value of the signal trace. Appendix 3 visualizes the results of diagnostics using a specialized software package. The most likely filtering sections are highlighted.

4.5 Description of EFT-technology used

Electrical flux tracking is a method which has the following range of application:

- Cellars: concrete and brick walls, bottom slabs, pipe lead throughs.
- Building joints
- Flat roofs, balconies and terraces.
- Underground car parks
- Swimming pools, ponds
- Tanks and reservoirs.

The method was created by Texplor (www.texplor.eu). EFT leak detection method is developed for linear, surface and spot filtrations localization in waterproofing systems. Unlike other technologies available on the market, EFT-method is a method of non-destructive testing. During the diagnosis, it is not necessary to dismantle the existing structural elements. While using this method directing the electric field is created in the body structure. Determination of filtering sections is conducted based on the analysis of the electrical signal value at various points of the surface diagnosed with a portable or stationary equipment sensor (Figure 32).

Figure 32. Diagnostic equipment and implementation

In those places where waterproofing is broken, abnormal changes in the electrical signal values are fixed. Figure 33 shows the measurement principle. Signal sending to the waterproofing is carried out from inside where the filtering is visible, as described above, and fixed outside by the data logger module.

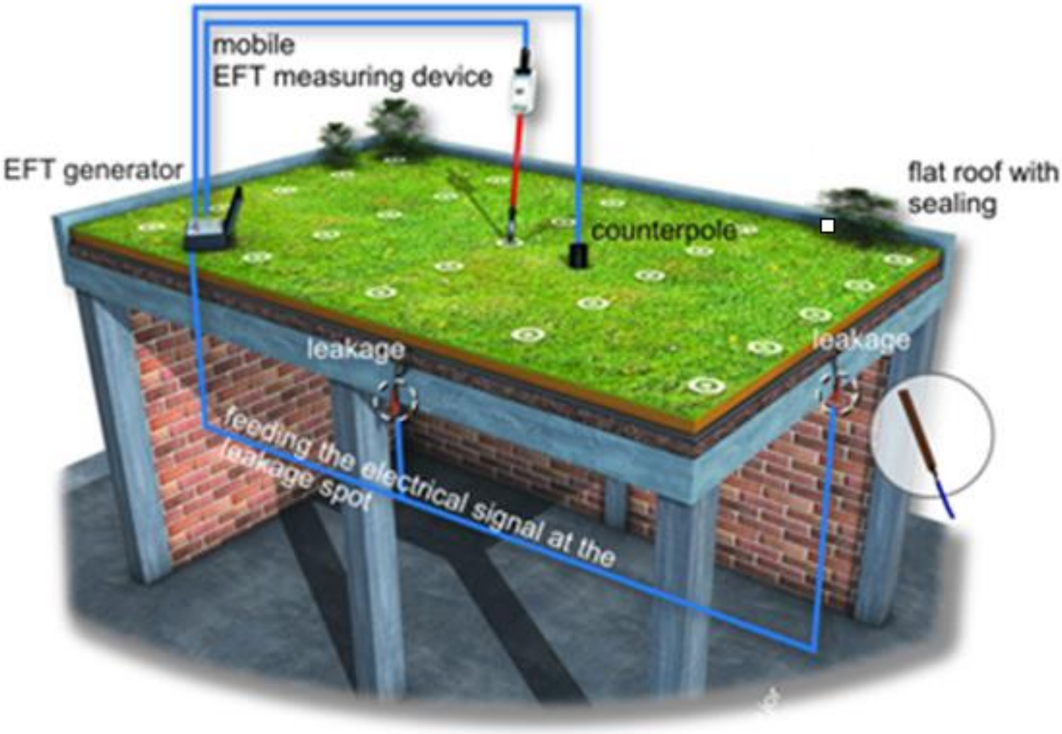


Figure 33. EFT measurements on a flat roof (www.texplor.eu)

EFT-method allows detect the leakages and filtering at waterproofing which exist only at the time of measurement (appeared in the past). It is impossible to predict environment (for example ground water increase) or mechanical intervention (future renovation) which could influence on diagnostic surface. The processed data is attached only to the time point of measurement. In this connection, it is impossible to guarantee long-term reliability of the received data.

It is not excluded that in the unexplored areas hidden filtration areas could locate, which in the future adversely effect on the condition of diagnosed design.

All internal communications should be pre-tested by representatives of the customer and be in working order, as the filtration of water from the communications affects the measurement results.

4.6 Diagnostic conclusions

The main mistakes influenced on the waterproofing were determined. They were connected as well with the basic design as with the construction process. Unfortunately, assembly architecture was weak. There was lack of details such as joints of walls and slabs, joints of different roof covering, proper description of installation technologies. The list of mistakes connected with construction the is following:

During the construction, the safety margin of the waterproofing layer was not considered. For that reason, the violation of the integrity of the waterproofing took place.

Drainage problems. According to the design project on the parking roof HL 616.1 drains (Hutterer & Lechner production) were installed. There could have been two reasons that caused the leakages. Firstly, it was found out that for some reason, the operation company did not provide the maintenance of the drains, so gravel guard elements were clogged with sand and gravel. For that reason, water could not flow properly from the surface and created excess pressure on the bitumen flange of the drain and damaged the joint between roof waterproofing and drain. When water injected into the layers of the parking roof, it could net get into the funnel and filtered through leaks in the parking roof (for example, through the expansion joints). Secondly, the technology could have been disturbed during the drains installation. For example, the gravel guard should be installed when all roof covering is ready not to flog it with construction waste.

The slope of the parking roof screed was 1:50. It is enough for normal water flow, unfortunately for some reason when water got in the roof structure puddles appeared on the waterproofing and bearing structure. So, the direct water flow was impossible.

A significant mistake was to hire different subcontractors for different layers of the roof pie. Thus, adjoining to the buildings, waterproofing, insulation, land-scaping all this work was made by different companies. During carrying out their work the sub-contractor often violated the work performed by the previous sub-contractor.

4.7 Problem fixing

After diagnosis and determination of leakages location the decision was made to remove the layer of roof covering (Figure 34) including waterproofing and provide a new covering using another supplier material (Figure 35).

Figure 34. Removing of roof covering

Figure 35. Roof waterproofing with Ultranap membrane slope (1:70)

Three layers of water proofing were installed on the roof. The bottom layer is bitumen membrane Icopal H, then the additional bitumen membrane Icopal Ultranap, then Icopal bitumen primer and Ultranap membrane.

Additionally, new waterproofing was made at adjoining with building walls as Figure 36 shows. Firstly the surface was dried and prepared, then the brick wall width of 120 mm and height less than 600 mm was performed. Then a sloping rim on side wall junctions to the slab was made of mortar M150 after that liquid waterproofing (waterproofing material Kalmatron, thickness not less than 2 mm) was applied. The bottom layer of waterproofing was performed with Icopal H, then additional membrane Ultranap. After that the thermal insulation XPF 35 with the thickness of 100 mm was installed. Thermal insulation was covered by reinforced concrete B20 with the thickness of about 100 mm.

Figure 36. Building walls waterproofing with Icopal H

In the places of water filtration through expansion joints, a subcontractor performed depressurization of them and provided new hermetic sealing of expansion joints.

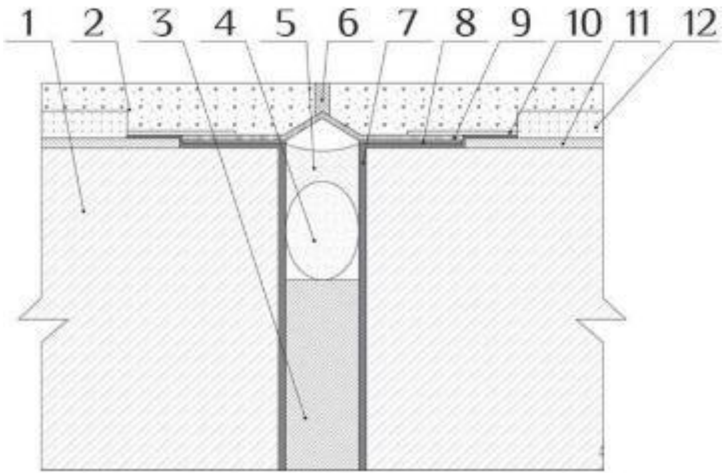


Figure 37. Expansion joint

1. Concrete slab.
2. Asphalt cover.
3. A sealing material (foam).
4. The elastic cord.
5. Mastic.
6. Waterstops.
7. Primer.
8. Waterproofing ribbon.
9. Metallic compensator.
10. Waterproofing ribbon.
11. Existing waterproofing.
12. Existing asphalt cover.

Technology of expansion joints depressurization:

1. Existing asphalt layer removing at places of expansion joints location 200 mm (Ataev 1984) from each side. Asphalt layer should be removed avoiding damage the waterproofing.
2. Waterproofing should be removed on width of 300-600 mm from both sides of expansion joints.

3. Expansion joint should be cleaned by the elastic cord as Figure 37(4) presents, that means above sealing material.
4. Cleaning of the surface that will be pressurized from stones, asphalt, removed waterproofing. It also could be needed to dry the surface.
5. The quality of the surface preparation is checked visually. It should be dry, clean, without liquid spots.

The requirements of expansion joints pressurization were the following:

1. Primer (Figure 37 (7)) was applied at one layer on the inner surface of the expansion joint on width of 150-200 mm from both sides of expansion joint.
2. The elastic cord (Figure 37(4)) should be wider than joint for 25-30%. twisting and stretching of the cord are not allowed (Ataev 1984).
3. Expansion joints should be filled with mastic by the top. The recommended thickness of the mastic layer is 20-30 mm.
4. During the applying of covering water or moisture should be avoided.
5. A waterproofing ribbon should be applied on joint of metallic compensator and waterproofing, so the ribbon should be wider than 150-200 mm. The tape was applied to the overlap of the tape segment to another along the length of 20-30 mm.

During repairs of drainage funnels it was found out that the heating cable (Figure 38 (5)) did not work. Thus, the water filtering through the foam core (Figure 38 (9)) has no time to dry by heat generated by heat cable.

After works of the repairing of heating elements there was no water filtration observed.

In addition, the drainage funnels were replaced to 3-level. Thus water enters the funnel at any level of cake cover parking.

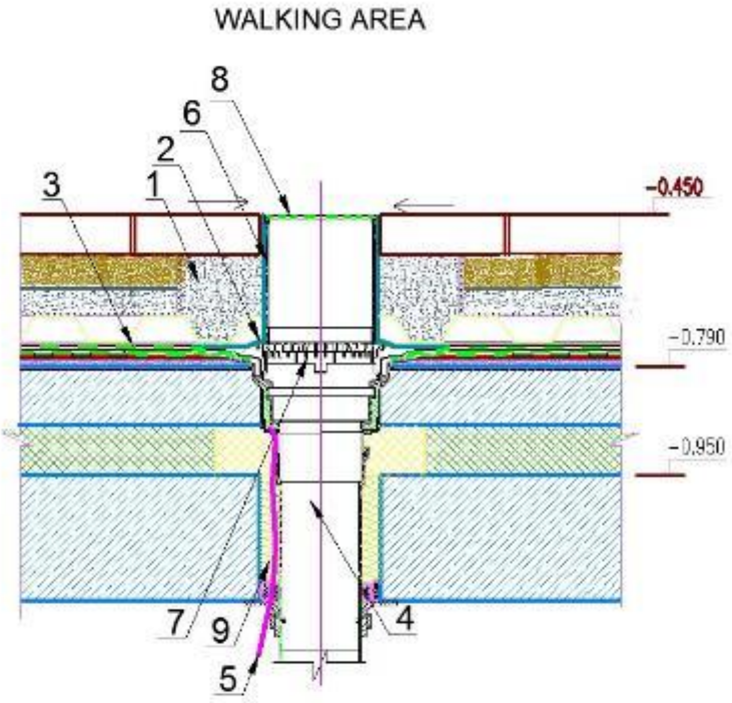


Figure 38. Drainage funnels after repairing

1. Gravel.
2. Membrane.
3. Water proofing.
4. Funnel.
5. Heating element.
6. Extension funnel element.
7. Drain flange.
8. Protection grid.
9. Foam.

4.8 Garage after repairing

Due to made decisions and actions of the construction site water filtration to the parking area was completely stopped. A year after the repair works filtrations were not found.

Figure 39. Drainage funnels

Figure 40. Expansion joints

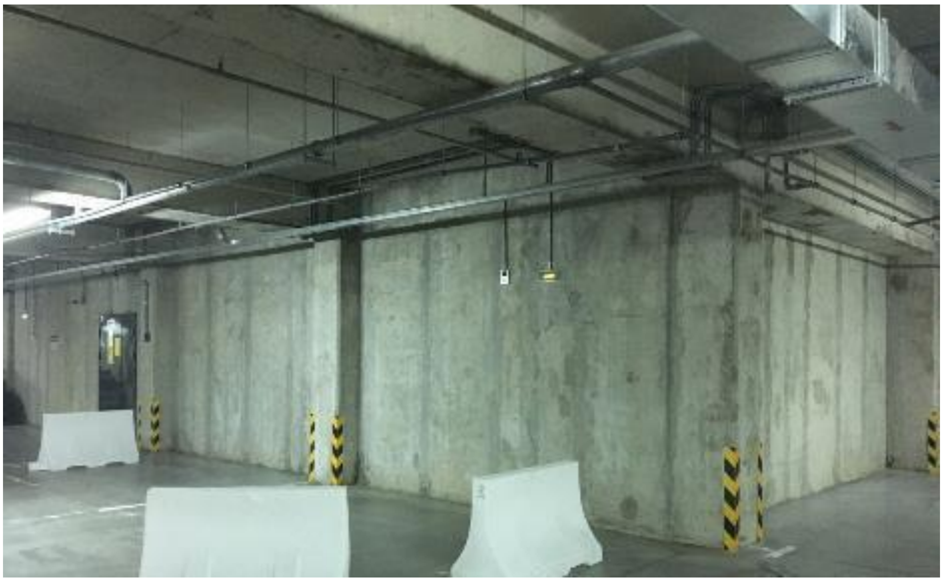


Figure 41. Adjoining to the building

4.9 Final parking section development

Before starting the construction, all previous mistakes were considered. A new design was developed which was more detailed than the previous one, including lots of necessary details such as sections of adjoining to the buildings, extension joints of walk- and driveways, drain funnels and etc.

Moreover, all works were performed by one subcontractor and were strictly supervised by NCC employees.

After finishing the waterproofing layer an examination was held, that took 3 days. No water filtration was observed (Figure 42).

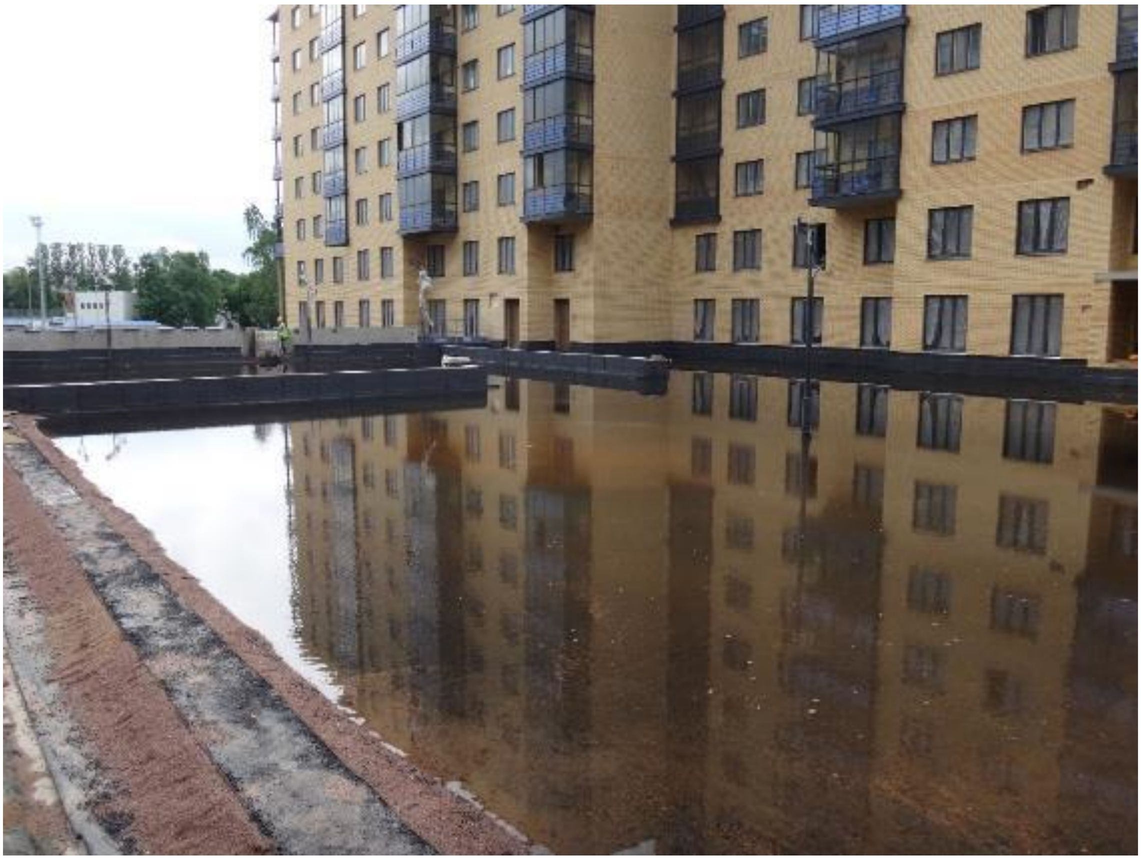


Figure 42. Waterproofing testing

5 Summary and Discussion

The thesis has investigated garages with operational roofs. Garages were considered and classified. Their features, advantages, implementation and technologies. Structures of operational roofs were learned depending on their implementation, loads applied and principal structures.

The data for this thesis was collected at the real project which met parking operated roof structure imperfections. According to the project learned common conclusions were made. The reasons of problems occurred during construction were determined.

1. Location factor should be considered. For example, Saint-Petersburg is one of the rainiest cities in Russia. That is why it is a difficult task to avoid moisture penetration indoors.
2. Control of design documentation. It should contain detailed architecture, section, details. Unfortunately, very often designers refer to the manufacturer's design, but do not provide it with a proper explanatory note. That led to mistakes during construction.
3. During the project execution the developer could change materials incorporated in the basic design. This increases the risk that a new material would have another physic-mechanical characteristic.
4. Low qualification of executors. The general contractor must strictly supervise such kind of works.
5. The whole complex of works connected with roof covering should be executed by one subcontractor. Unfortunately, the bottom roof layers could be damaged by the subcontractor which responsible only for upper layers.

Based on the gained experience the weakest sides of the project were revealed.

1. Expansion joints.
2. Adjoining of concrete slab to the engineering units.
3. Adjoining of concrete slab to the building walls, caused by decompressed concrete.
4. Roof draines

5. Proper slope.

NCC Real Estate is a developer oriented company that always perform the best quality of the product, that is why every experience good or not that the company gets is a chance for improvement in some area. All the imperfections connected with garage operated roof were removed. Experience was shared with other projects. For example, at Skandi Klabb (NCC residential complex in the Petrogradskaya district of Saint-Petersburg) the developer prevented any problems connected with operational roofs that could take place, and what is more introduced terrace roof at the apartment.

Figure 43. Skandi Klubb. View to the garage operated roof and apartment terrace

NCC has a great tool that is called NCC Platform. It is a database of NCC Building system. It consists of a process platform for example a management and technical platform, which considers and collects customer values, standardized system for production, clear calculation of costs, unity of planning, estimation and production. Pre-defined technologies simplify planning and make production more efficient. The complete housing concepts form specific solutions for parts of a building. In general NCC platform has 3 levels: project description, typical drawings and typical task. Typical drawings helps to save time to the developer and subcontractor, as the first can show the final target of the design. NCC can show a list of specific drawings that must be included in the basic or detailed design, examples of wiring networks drawings, examples of drawing layout, which should be applied in the project. Typical technical tasks make the costs of general elements understandable. They are combined technical tasks for all segments, perform technical tasks in Excel files, and make the cost estimation inside a technical task possible.

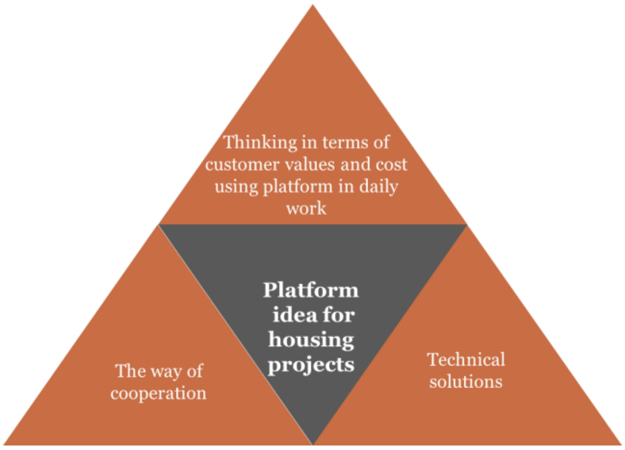


Figure 44. Process of design and construction with Platform

All data to the platform was collected from different departments and projects, including Swedish krona experience. Moreover, Platform provides the quality control and project supervision through listing all norms of SP, SNiPs, GOSTs per the type of work. That surely would improve the construction site supervision.

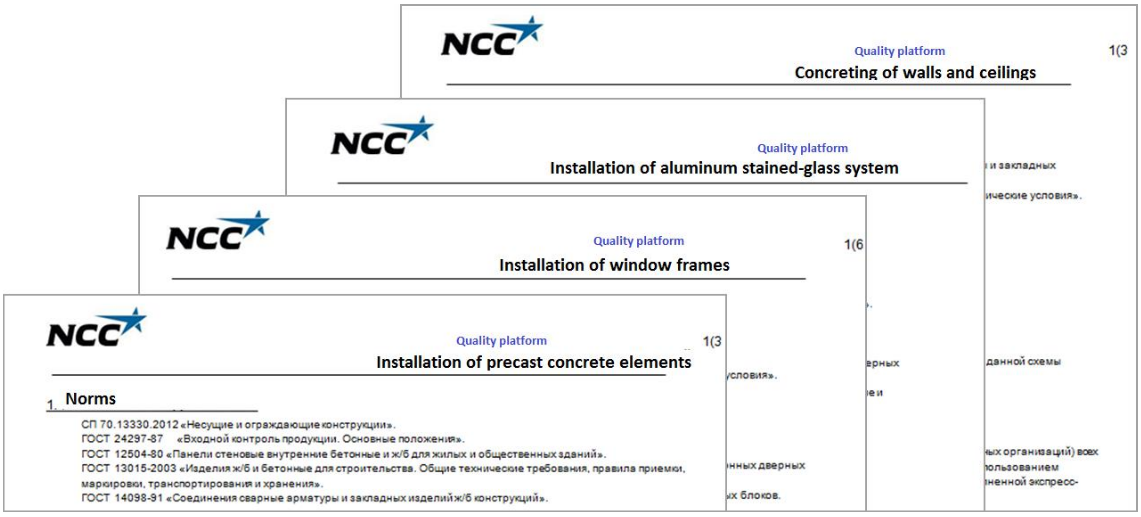


Figure 45. Quality platform

In short, the data collected could be useful for future projects design and construction work organization and supervision. Moreover, the real work shows that the improvement of Russian norms covering operated roofs design and construction technologies is required.

Figures

Tables

List of references

Al-Sanea S. Thermal performance of building roof elements. Building and Environment // 2002. — P. 665–675;

Ataev S., Danilov N., Prykin B. Construction technology // StroyIzdat — 1984. — P. 142–151;

Beliaev L. Increased durability of roofs // Real estate — 1997. — №11 — P. 19;

Chernoivan V. Repair of combined roll roofing // Brest — 2004. — P. 84;

Denardo J., Jarrett A., Manbeck H., Beattie D., Berghage R. Green roof mitigation of stormwater and energy usage // ASAE, St. Joseph, Michigan —ASAE Meeting Paper No. 032305 — 2003;

Hans P. Flat roof insulation. Construction systems, materials, technology, details // Business Media — 2007. — P. 207–247;

Oberndorfer E., Lundholm J., Bass B. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services // BioScience. — 2007. — P. 823—833;

Official Bonava site (https://www.bonava.ru). (Referred 24 July 2016);

Official site of specialists in detecting leakages in building-sealing systems (http://www.texplor.eu). (Referred 12 September 2016);

Official site ZinCo (http://www.zinco-greenroof.com). (Referred 1 September 2016)

Sokova S. Influence of underlay carpet moisture on the waterproofing // Real estate — 1997. — №9 — P. 9–11;

SP 104.13330.2011. Protection of Sites Against Flooding and Underflooding;

SP 113.13330.2012. Parkings;

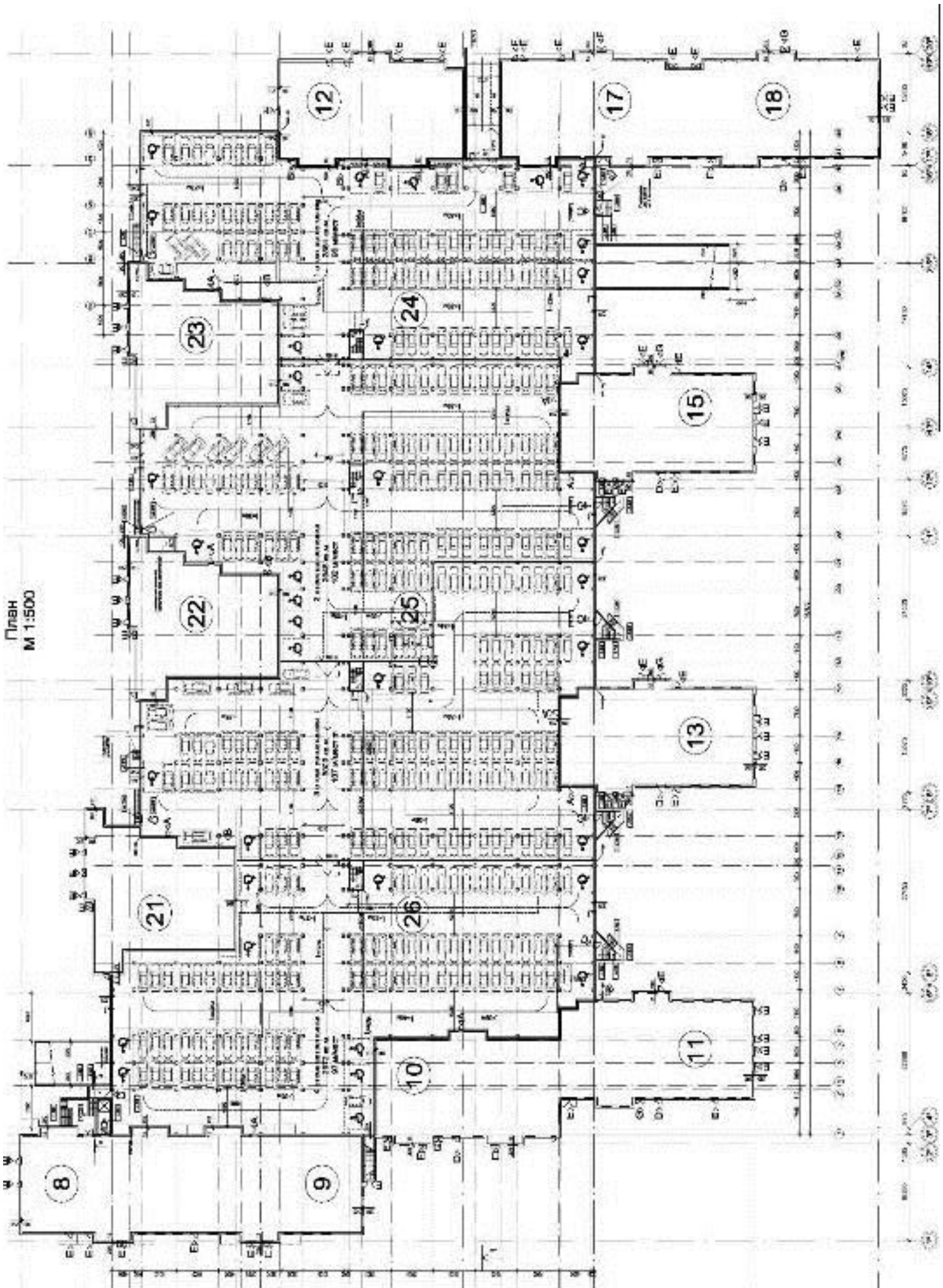
SP 17.13330.2011. The roofs;

SP 23.101.2004. Thermal performance desing of buildings;

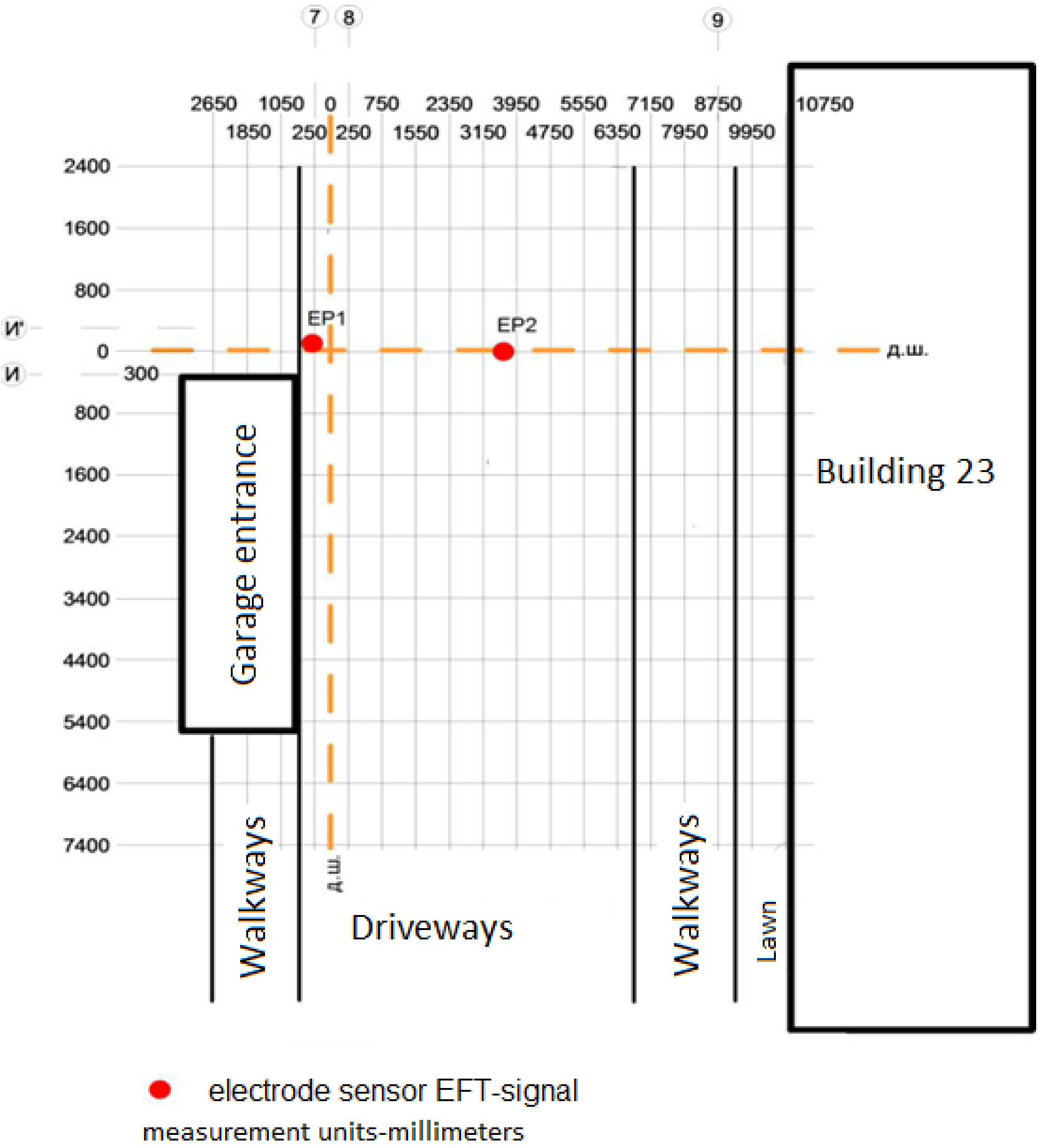
Web site: www.greenroofs.com. (Referred 6 September 2016).

Appendices

Appendix 1. NCC Swedish Krona parking plan



Appendix 2. Leakage test in NCC Swedish Krona parking. Electrode sensors and measuring grid location



Appendix 3. The result of diagnostic.