Maksim Khochinskii

IMPLEMENTATION OF SNOW AND ICE MELTING SYSTEM AND BIOSWALE DISPOSAL SYSTEM

Bachelor's thesis
Building Services Engineering

2019

XAMK

South-Eastern Finland
University of Applied Sciences

Author (authors)	Degree	Time
Maksim Khochinskii	Double Degree Programme in Building Servises Engineering	December 2019

Title	
Implementation of snow and ice melting system and bioswale disposal system	51 pages

Commissioned by

Supervisor

Jukka Räisä

Abstract

Snow and ice interfere with the movement of people and transport. Moreover, in some cases, precipitations during winter and ice formatting could be the reason for such problems like roof caving or accidents on the road. People injuries caused by a fall also apply to these problems. Snow and ice melting (SIM) systems could solve these problems. The main purpose of this paper was to explore what type of SIM system is more advantageous in Saint-Petersburg, Russia. Another less important aim but still worth mentioning was to figure out whether to use or not bioswale disposal system.

To compare different types of SIM systems payback period calculations were applied. Preliminarily, simplified design of hydraulic and electric SIM system was made to calculate equipment, energy source and mounting works prices. The final prices were compared with mechanical and mechanized snow and ice removal cost. Literature review method was applied to explore the bioswale disposal system. On the examples of bioswales implementation in the USA, cost savings were obtained.

It could be concluded that hydraulic SIM system is the most advantageous in Saint-Petersburg. Moreover, it is also beneficial to replace the existing electric SIM system with hydraulic. Joint implementation of bioswales and hydraulic SIM system will not only reduce the price of snow and ice removal but also reduce the price of the water disposal system.

Keywords

Snow and ice melting system, mechanical and mechanized snow and ice removal, bioswale.

CONTENTS

1 INTRODUCTION

It is necessary to create safe environment for humans. It is especially important in winter during snowfalls and periods of iceformating. Accidents due to ice and obstruction of movement are the main problems in winter. Moreover, these precipitations and formations may harm human's health. There is nothing more valuable than human health. It goes without saying that it cannot be valued with money. Implementation of modern technologies could solve this problem.

One of the options is snow and ice melting (SIM) systems implementation. These systems can prevent roof crashes or incidents on roads. Their application is the most convenient way to get rid of ice and piles of snow. However, SIM systems require certain conditions to be economically feasible.

This paper discusses SIM systems implementation in Saint-Petersburg, Russia. Are these systems profitable? What type of system is better to use? Is it worth investing in them or is it better to remove snow and ice in a traditional way? Furthermore, how to ensure high-quality water drainage to prevent re-freezing? The answer could be conventional disposal systems development or greenspace expansion. The answers to these questions will help to decide if the new systems are worth applying.

The first and second parts of this thesis provide basic information about SIM systems and eco-friendly types of water disposal systems. The last chapters include systems designs and payback period calculations where the costs of energy source, equipment and installation for SIM systems compared with mechanical ad mechanized snow and ice removal. The feasibility of greenspace expansion will also be discussed in the last chapters.

2 AIMS

The main aim of this thesis is to explore which type of SIM system is the most advantageous in Russia in term of the payback period. To reach this goal it is necessary to get familiar with different types, components and operating principles of melting systems. The costs of systems equipment, fuel, installation works and maintenance must also be taken into account in payback period calculation.

As the melt water must be removed from the adjacent area, another aim arises. This paper investigates one of the Stormwater Management Practices (SMPs) system, specifically the bioswale disposal system. The aim is to figure out whether to use this system or not. To reach this aim it is also important to understand what the bioswale is and find out how it operates.

3 METHODS

Firstly, this thesis compares hydraulic, electric SIM systems and mechanical snow and ice removal in Saint-Petersburg, Russia. These systems will be compared using the warehouse building and its adjacent areas as an example. Secondly, the total energy demand for SIM system will be calculated according to weather data. Thirdly, all necessary equipment for snow melting system functioning will be selected. Finally, payback period calculations will be made in term of fuel, equipment, mounting works costs and shift wages in Russia.

Literature review method is about the bioswale disposal system. This literature is mostly related to scientific research and official guidance manual. The required volume of the bioswale's storage for adjacent area of warehouse will be also calculated. Relying on materials the advantages and disadvantages of the bioswale system will be discussed.

4 THEORETICAL BACKGROUND

4.1 Basic thermodynamics

According to Evelyn Guha's book "Basic Thermodynamics" /1/ heat is one of the main concepts in thermodynamics. In the middle of the nineteenth century, it was found out that the transfer of something occurs between objects with different temperatures. This thing which transfers from hot body to cold one was called heat. This concept became the bench mark in thermodynamic development. Thereby, the conception of heat capacity and specific heat capacity became clear. As a flow of Q units is the reason for temperature change by ΔT, the mean heat capacity $\bar{C}$ could be estimated through Equation 1.

$$\bar{C} = \frac{Q}{\Delta T} \tag{1}$$

With the Q and ΔT value decreasing the value of heat capacity C' could be obtained through Equation 2.

$$C' = \lim_{\Delta T \to 0} \frac{\delta Q}{\Delta T} \tag{2}$$

When it comes to snow melting systems, it is important to mention the concept of specific heat. It is one of the major indicators since it allows to characterize the material. If the material or system mass is M units the specific heat calculates through Equation 3.

$$c = \frac{C'}{M} = \frac{\delta q}{dT} \tag{3}$$

However, heat is not the only one type of interaction between system and its surroundings. In thermodynamics also takes place work interaction. A typical example of work interaction is piston operation principle. The heated gas pushes the piston which means that it does work. One of the basic thermodynamics laws follows from this interaction. /1./ "The change in a system's internal energy is equal to the difference between heat added to the system from its surroundings and work done by the system on its surroundings /2."

4.2 Snow and ice removal with SIM systems

Snow and ice interfere with the convenient living and working of people in the city. Snow impede the passage of people and vehicles, may cause extra loads on the roofs. Ice at all could lead to accidents. According to the European Commission /3/ for pedestrians it a major health issue as an increase of 25% increase in hospitalization and 33% rise in cases of hip fractures is observed during the winter season. Another investigation was conducted in Great Britain from April 1993 to March 1995. By Bentley and Haslam (1998) 1734 fall cases of the Royal Mail system workers were counted. Around 60 % of the falls were due to snow and ice. /4 p. 7./

Therefore, it is necessary to design systems that can melt snow and prevent ice formation. It is self-evident that it is impossible to spread SIM systems all over. However, they are worth installing in the cases when it can sufficiently simplify movements and make people more comfortable. For example, SIM systems could be installed on the roofs, parking zones, ramp valleys, pavements or steps.

Since SIM systems are considered convenient and safe, they are widely used. This happens because of automation systems applying. Because of them, SIM system operates then it is needed preventing ice formation. Under such conditions, the reducing of system payback period occurs and SIM system becomes economically viable. Moreover, these systems are maintenance free. It is enough to start the operation in winter and turn off the system in spring.

Despite the undeniable advantages of SIM systems, in some cases, it is neglected due to economic reasons. That's why chemicals are still widely used to remove snow and ice. The deicing chemicals such as NaCl or CaCl2 are very effective in ice and snow removal. Moreover, the price of these reagents is low. However, this system causes such negative effects as pavement abrasion and environmental pollution. /5 p. 2./ Another way to remove snow and ice is to use labour and machines. On one hand, this type doesn't affect the environment as chemicals. On the other hand, ice axe and excavator-loader can damage the road surface. This fact will shorten the life of the road and increase maintenance costs.

4.3 Review of hydraulic and electric SIM systems

4.3.1 Hydraulic SIM system

In hydraulic SIM systems water, brine or glycol-water are the heat transfer agents. Heat sources such as gas or oil provide the required heat to these fluids. By the circulating of transfer agents through pipes, which are embedded in concrete, snow and ice melting occurs. /6./

There are three stages of hydraulic ice and snow melting process. They are idling, snow-melting and after-melting processes. During the first one, the fluid is heated to the required temperature. It is important to note that fluid temperature must be above 0 constantly. Process B to C shows the snow melting process. During this process, energy is spent on snow heating to 0 °C and snow conversion to the water. The temperature after the snow melting process must be above 0.33 °C. Otherwise, the melted snow will be re-frozen. Curve C to D represents the evaporation process. This process could be ignored in surface heat output calculations with the disposal system existing. The presence of this system will save energy since there is no need to spent heat on evaporation of water. /6./

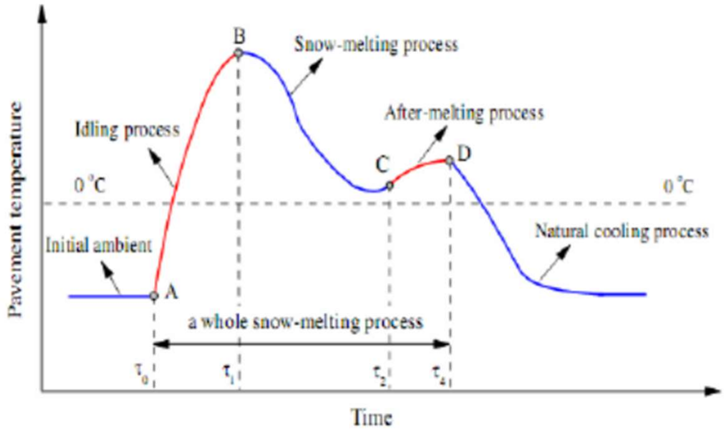

Figure 1. Description of a typical hydronic snow melting process /6 p. 5509/

The main parts of the hydraulic SIM system are heat source, heat exchanging elements, pump, expansion vessel, sensors for humidity, wind speed and temperature measuring and control system. All these parts provide circulation of fluid trough PEX (Cross-linked polyethylene) metal or rubber pipes and proper operation of hydraulic SIM system. /6 p. 5508./

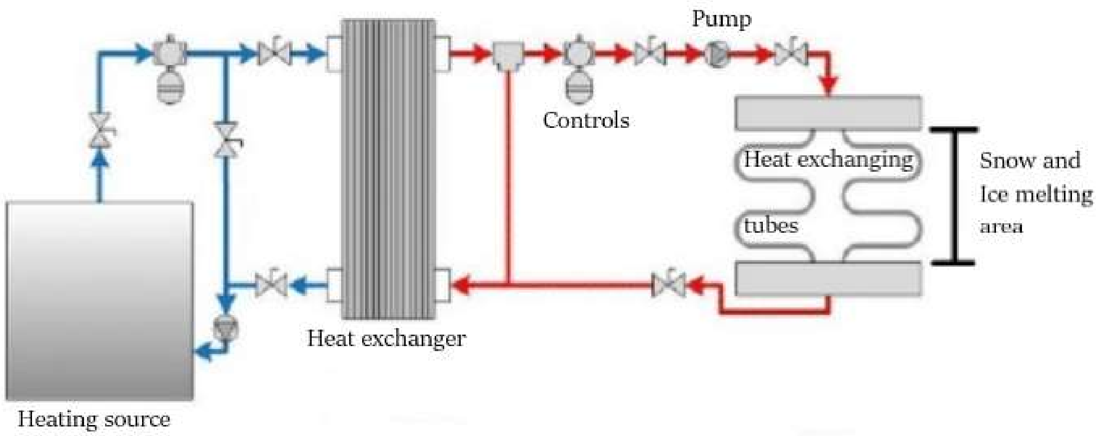

Figure 2. A schematic diagram of a pavement hydronic snow melting system /6 p. 5508/

To achieve maximum efficiency, it is also necessary to install the system correctly. If PEX pipes are used in the SIM system, they can be damaged during the asphalt installation. 120 °C temperature, which is used to get adequate compaction of the asphalt, violates the structure of PEX pipes. So, it is necessary to circulate cold water during this process. Moreover, the process of compaction also may be harmful. To prevent this problem sleeves applied for covering pipes under the asphalt joints. /7 p.13./

Another necessity is to use glycol-water mixture as the fluid in hydraulic SIM systems. Since glycols have low cost and viscosity, they are widely used in snow melting systems /8 p. 49.10/. It is usually used 40 % of glycol in such mixtures /9 p. 2/.

Pipes must be air-tested before the slab installation. The pressure during pipe testing should be 1.5 times greater than the operating pressure. The greatest pressure must be applied. This process should last around 30 minutes to make sure that all leaks have been checked. It is necessary to test system without water, since leaks may not be observed. Overwise, water will freeze and damage the pavement or concrete during the installation process. /7 p. 23./

The design of SIM systems comes down to find the main parameters. They are pipe depth, pipe spacing, inlet temperature and flow velocity./10./ Normally, pipe spacing ranges between 150 mm to 300 mm with a diameter of 18 mm and 25 mm. A higher depth of burial of pipes, of course, leads to lower temperatures on the surface and vice versa. So, a minimum installation depth of 50 mm must be observed./8./ The temperature range from 25 °C to 50 °C is used in hydraulic SIM systems /11/. Fluid flow velocity could be as laminar as turbulent. Floor temperature differences in different types of liquid flows are insignificant. /12 p. 2551./ It means that pipe dimensioning must be based on the optimal value of fluid flow and pressure losses since it effects on pump energy consumption. The correct definition of the main parameters of the system will eliminate striping of snow and increase the efficiency of SIM system.

4.3.2 Electric SIM system

In electric SIM systems, hot wires or electric mats are used to provide required heat for melting. These elements transform electricity into radiant heat. This process occurs because of the electrical resistivity with a high positive temperature coefficient (PTC) which transforms electric energy into thermal energy. /5 p. 3./

This type of system consists of an electrical power supply, humidity, temperature wind speed sensors and a control-monitoring system /13 p.756/. Pavement heated with electricity has such in-pavement elements as resistive cables, heat-mats or conductive material. Each element has it's own design consideration ./7 p. 9./

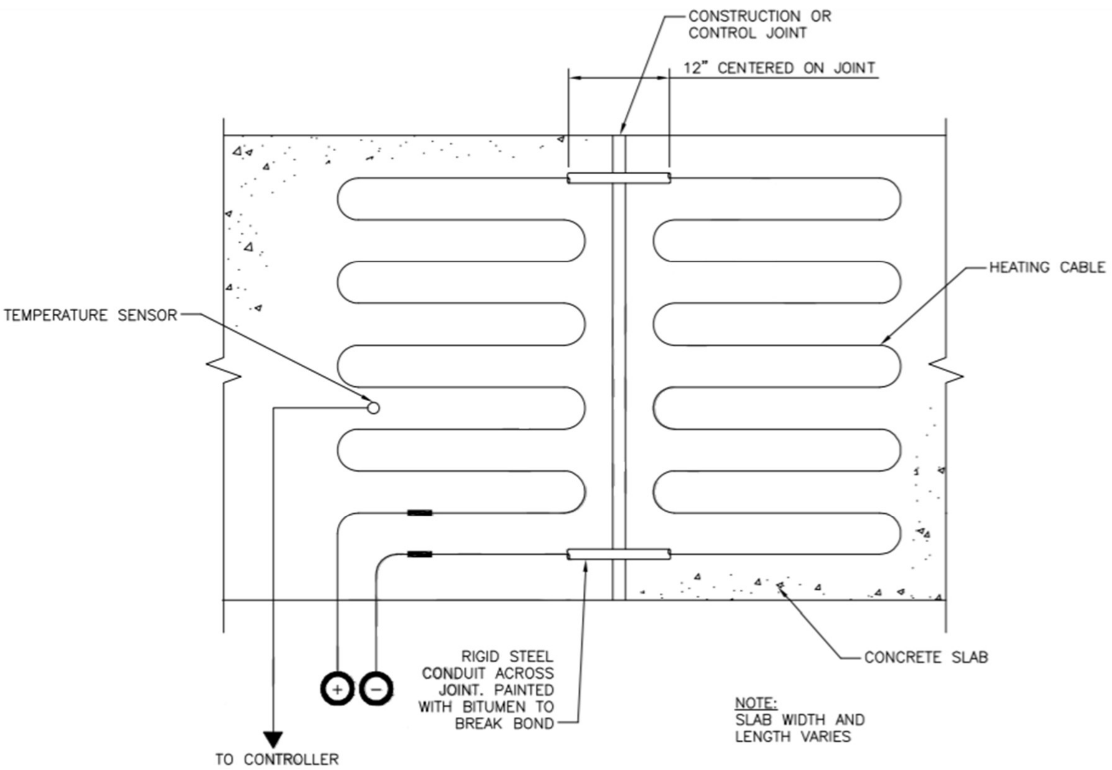

Figure 3. Typical heating cable installation in slab /7 p. 21/

Electric SIM systems with resistive cables must be selected according to type, depth and spacing of the wire. The wires types vary according to a power output per unit length, conductor resistance and type of insulation. /7 p. 9./ Due to heat insulation of the cables significant snow and ice melting effect could be obtained. Layers, which are shown in Figure 4, make wire not only insulated but also waterproof and corrosion resistant. /5 p.3./ The choice must be turned to the wire type that can provide the necessary heat output per square meter.

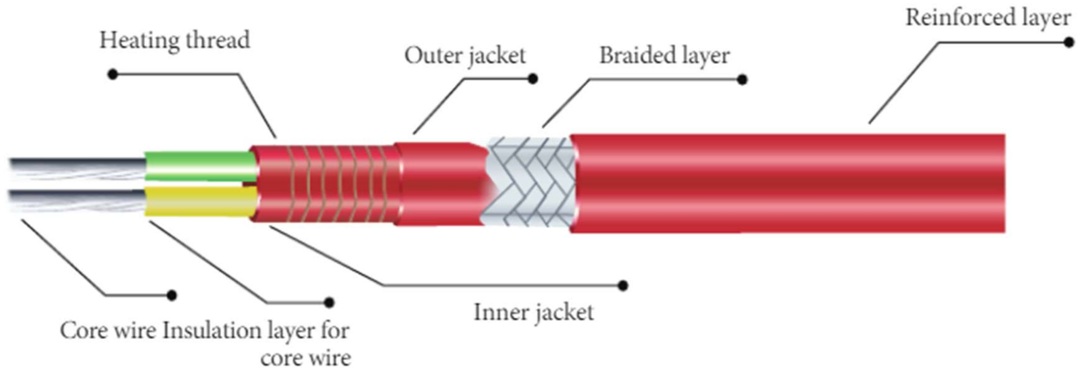

Figure 4. Heating cable composition /5 p.3/

Normally, the wire depth varies from 50 mm to 80 mm below the finished surface with spacing 80 mm to 250 mm. It depends on cable characteristics and surface type. For example, the transmission coefficient of concrete is higher than asphalt. It means that a concrete surface requires wider wire spacing than asphalt. /7 p. 9./

The same design consideration as in the SIM system with resistive cables applies to the electric SIM system with heat-mats. The main difference from the resistive wire is that in pre-fabricated heat-mats wires attached to plastic or fiber mesh. The area of one mat usually does not exceed 5.5 square meters. The depth of the mats should be from 50 mm to 100 mm with spacing 300 mm from pavement edge. /7 p. 9./

To make the system more efficient, conductive materials are incorporated into the surface structure. These materials are graphite, black carbon and aluminium chips /13 p. 756/. One of the people who suggested increasing conductivity in this way was Minsk (1971). During his experiments, 18.3% of graphite particles were incorporated into the asphalt. (all percentages by total weight of mix). As a result, this material produced a resistivity of 1 to 5 Ω per around 25 mm. According to Minsk’s suggestions, this conductive layer with graphite should not be more than 50 mm. However, as the graphite is expensive, it’s implementation will make the system less cost efficient. /4 p. 17-18./ Nevertheless, it was determined that the addition of only one conductive material would increase the cost of surface and reduce the effectivity of SIM systems. And vice versa the use of mixtures of conductive materials could improve the electrical conductivity and decrease the cost of the surface. /13 p. 767./

4.4 Water disposal with the use of SMPs

Water in the cities is the cause of destruction. It percolates through the cracks and destroys materials. It is the reason for pits, washed out roads and other issues which destroy the infrastructure of the city. That’s why it is important to design water disposal systems properly to pass the water off. One of the effective and eco-friendly types of water disposal system are SMPs.

“Urban SMPs are known by diverse names around the world: they are often known as stormwater Best Management Practices (BMPs) and Low Impact Development (LID) in the US, Sustainable Urban Drainage System (SUDS) in the UK, Alternative Techniques (AT) in France, Water Sensitive Urban Design (WSUD) in Australia, and Green Infrastructure (GI) in many other countries /14.” However, all these different names mean the same thing. The SMPs are the whole complex of systems ”that have the potential to reduce peak runoff flow and improve water quality in a natural and aesthetically pleasing manner./15”. In these systems, stormwater is removed in three ways. The part of water infiltrates into the ground, another portion evaporates into the air and remaining water releases into the disposal system. /16 p. 7./ This operating principle allows to decrease the load on the disposal system and to remove water without significant investments.

4.5 Review of SMPs

4.5.1 Location of SMPs

According to Philadelphian Stormwater Retrofit Guidance Manual /16/ to achieve the maximum effectivity of SMPs it is important to choose the place correctly. The main aim of the designer is to construct SMPs in the location where they wouldn't adversely affect adjacent areas. Another significant factor affecting the location of the system is the arrangement of existing utilities. The placement of SMP may interfere with access to a utility. Future repair or maintenance could cause the decrease of effectivity of SMPs. That's why SMPs couldn't be placed above the utilities. The same restriction applies to the location of the systems near houses. Sufficient distance from buildings should be maintained. This prevents building flooding and damage during the infiltration in SMPs. The groundwater table data must be also collected to prevent the construction of the SMP in places where this indicator is high. Otherwise, the infiltration rate would be lower which reduces the effectiveness of the system. However, there are a lot of places there this kind of systems may be installed. For example, the appropriate place for SMPs is the area above the drainage path. If there are no such opportunity diversion structures and conveyance piping may need to be installed. Roofs and turf grass areas can be also appropriate places for SMPs.

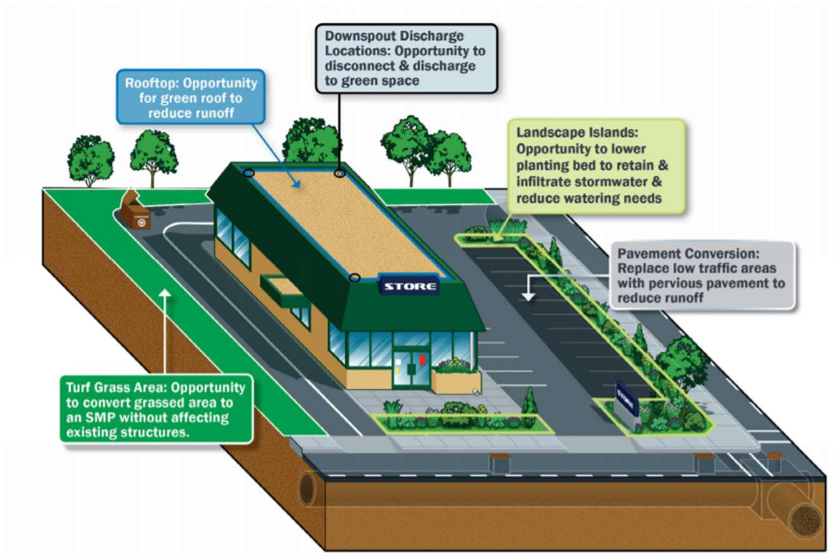

Figure 5. Site Opportunities /16 p. 21/

4.5.2 Components of the SMPs

Each SMP has a different structure and components. However, they all have similar parts where the same operations existing.

Each SMP has the following parts:

- Inflow and Pretreatment System: An inflow system distributes water to the SMP. Stormwater by means of piping, ground slopes, inlets or open channels flows to this system. The pretreatment system serves to prevent unwanted debris, fuel and others pollutant entering the storage. Otherwise, the system operation could be disrupted.
- Storage: For all SMPs, the stormwater must be stored before the infiltration or water discharging into the city disposal system or to a surface water body. The main components of storage areas are soil, sand, stones, geotextile and underdrains.
- Diversion structures: The main purpose of the diversion structure is to regulate the stormwater volume in the storage of SMP. To prevent overflooding of SMPs these structures divert large storm events around storage.
- Outlet Control Structures: A control structure regulates the flow of water out of the storage area.
- Outflow System: This system also prevents overflooding of the storage area and discharges water into the disposal system. This occurs by means of piping or open channels.

Figure 6. Common Elements of an SMP /16 p. 36/

4.5.3 Types of SMPs

There are nine main types of SMPs. This amount is explained by the rainwater removal system necessity to adapt to various places in the urban environment.

As the detailed review of all SMP system types is beyond the scope of this thesis only the main features of these systems will be presented. These types are:

1) Bioretention: Represents shallow deeping with plants and trees. Common components of this system are sandy loam, mulch, vegetation, storage stone separated with non-woven geotextile from the soil and in some cases pipe. Bioretention is virtually maintenance free. As each SMP except porous pavement, it requires 4 times per year inspection to identify problems with vegetation or other parts of the system.
2) Porous Pavement: Porous pavement is an ideal solution for cities because it doesn't require water conveyance and capable of removing water immediately. Stormwater seeps through permeable asphalt, concrete or paver to the storage media which is made for structural support and water storage. Recommended two times per year inspection must be carried out.
3) Subsurface Infiltration: It means a stone-filled channel. This infiltration area locates below the finishing surface like pavement or asphalt. It is recommended to place it near the source of runoff in order not to construct conveyance piping.
4) Planter Boxes: This system reduces peak runoff flow and retains water in its storage stone. Only in cases of over flooding water by means of positive overflow and piping drains to the disposal system. Normally these boxes constructed along buildings, driveways or other impermeable surfaces.
5) Tree Trenches: Represents common urban beautification with the use of trees. However, the implementation of only one type of SMP system as tree trenches wouldn't be effective since this system rather retains water than infiltrates.
6) Green Roofs: This system during the rain operates as lawn providing stormwater volume reduction and filtration on the roof. Green roofs are one of the best solutions for dense urban development. The principle of this system operating is to hold water until it evaporates. Excess water by means of downspouts drains to the disposal system. The main vegetation of these roofs should be sedum. However, other plant species could be implemented in addition to sedum plants.

7) Cisterns-Capture And Reuse: Represents tanks for stormwater detention. The main difference of this system from the other lies in the fact that the stormwater is used. It is widely applied for irrigation and cleaning needs.
8) Dry Extended Detention Basin: Storage and quality improvement of stormwater takes place in detention basins. They require much space and usually constructed in places with large development. However, subsurface detention basins also exist to use city space economically.
9) Swales/Bioswales: As the implementation of the bioswale disposal system is the most suitable for warehouse adjacent area with embedded SIM systems, it will be detailed reviewed further.

4.6 Bioswales

Bioswales or swales represent an open channel with vegetations. A swale serves as a transportation and storage of water where infiltration and treatment occurs.

There are a lot of areas in the city where swales could be installed. For example, this type of SMP usually constructed near parking zones, residential and industrial buildings or along highways. In any case, the presence of these green areas increases the attractiveness of the adjacent areas. Moreover, as all SMPs, bioswales require fewer investments to construct and maintain than traditional disposal system. It is recommended to locate swales in the places with natural slope existing. Otherwise, it would be necessary to create a slope that will inevitably increase the cost. In any case, the slope must be 2-3%.

The typical bioswale consists of such components as:

- Inlet Control
- Pretreatment (Optional)
- Excavated Channel
- Soil& Vegetation
- Check Dams
- Stone (Optional)
- Underdrain (Limited Application)

- Outlet Control

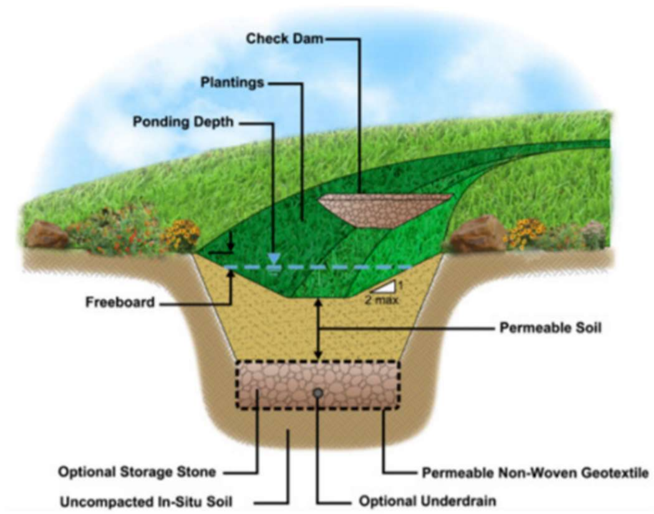

Figure 7. Components of a Bioswale /16 p. 67/

Bioswale’s inlet part doesn’t require complex structures. It is enough to create a slope to the SMP which will allow water to head towards the pretreatment part and channel. The pretreatment system may be installed in cases with a high stormwater load. This solution will make system more durable. Inlet filter inserts or forebays are typical forms of this system delivering purified water to the excavated channel. In this part water storage and infiltration occurs. /16./ The channel volume must be designed considering the volume of filter depth which varies from 600 mm to 1200 mm /17 p. 10-47/. During bioswale design, it is also important to choose soil with infiltration rate between 13 and 254 mm/hour. The soil, which is consists of sand (50-85%), silt (40% maximum), clay (10% maximum) and gravel (15% maximum), must be at least 150 mm thick. It is necessary to comply not only with the required soil composition but also with the required plant species. There is a wide variety of plants that are suitable for SMPs. /16./ As in practice drought or overflooding rapidly occurs in bioswales, plant species must adapt quickly to changing conditions. According to research such plants as Deschampsia flexuosa or Filipendula purpurea are applicable for these conditions and increases bioswales efficiency. /18./ To enhance functions of swales construction of check dams along its length also applies. Check dam, which is made from wood, stone, concrete or other material, retains water in a certain part of the bioswale until overflow occurs. Its hight must be from 150 mm to 300 mm.

Other parts of the system such as stone, underdrain and outlet control installation optional. However, they can improve system performance. Storage stone improves infiltration and increases storage. By placing a stone under the ponding location, system efficiency increases. If necessary, underdrain and outlet control parts could be used to convey water to another SMP. /16./

5 METHOD

5.1 Data obtaining for SIM system design

The adjacent area of warehouse building will be taken as the object of different SIM systems and mechanical snow and ice removal comparison. The area which is required to be cleaned is 160 m^2. It was decided to locate the building in Saint-Petersburg, Russia.

Figure 8. Considered system layout /19 p. 6-7/

All necessary data for SIM system required heat output calculations is tabulated.

Table 1. Data for SIM system required heat output calculations

Weather parameter	Value	Unit
The density of freshly-fallen snow /20/	50	kg/m^3
Snow specific heat capacity	2.1	kJ/kg·°C
Air temperature at the coldest five days of the period November- March /21 p. 13/.	-28	°C
The maximum wind velocity in Saint-Petersburg during January /21 p. 13/.	3.3	m/s
Enthalpy of fusion for water	333.8	kJ/kg
The number of days during the period November-March with the precipitations in the form of snow /22/.	28	days
The average duration of snowfalls	4	hours
The freshly-fallen snow layer	100	mm

5.2 Calculations of SIM system heat output

The required pavement heat output can be defined through Equation 4 /23 p. 51.1/.

$$q_0 = q_s + q_m + A_r \cdot (q_e + q_h) \quad (4)$$

where	q_0	required heat output	[kJ/ m^2]
	q_s	sensible heat transferred to the snow	[kJ/ m^2]
	q_m	heat of fusion	[kJ/ m^2]
	A_r	ratio of snow-free area to total area	[-]
	q_e	heat of evaporation	[kJ/ m^2]
	q_h	heat transfer by convection	[kJ/ m^2]

The required sensible heat to bring the snow to 0°C can be defined through Equation 5 /24 p.1121/.

$$q_s = m_{snow} \cdot c_{p\_snow} \cdot (t_{snow\_top} - t_{air}) \quad (5)$$

where	m_{snow}	mass per unit area	[kg/m^2]
	c_{p_snow}	specific heat of snow	[kJ/kg·°C]
	t_{snow_top}	temperature of water melting	[°C]
	t_{air}	temperature of ambient air	[°C]

It is assumed that the freshly-fallen snow layer is 100 mm. The density of this snow is 50 kg/m^3. The snow mass per one square meter can be estimated by Equation 6.

$$m_{snow} = h_{snow} \cdot \rho_{snow} \quad (6)$$

Where	h_{snow}	snow height	[m]
	ρ_{snow}	snow density	[kg/m^3]

$$m_{snow} = 0.1\ m \cdot 50 \frac{kg}{m^3} = 5 \frac{kg}{m^2}$$

According to SNIP 23-01-99* air temperature at the coldest five days of the period November- March in Saint-Petersburg is -28 °C /21 p. 13/. Snow specific heat capacity is 2.1 kJ/kg·°C. By Equation 5,

$$q_s = 5 \frac{kg}{m^2} \cdot 2.1 \frac{kJ}{kg} \cdot {}^\circ C \cdot \big(0 - (-28)\big){}^\circ C = 294 \frac{kJ}{m^2}$$

Enthalpy of fusion for water equals to 333.8 kJ/kg. Heat of fusion can be estimated through Equation 7 /23 p. 51.3/.

$$q_m = h_f \cdot m_{snow} \quad (7)$$

Where	h_f	enthalpy of fusion for water	[kJ/kg]
	m_{snow}	mass per unit area	[kg]

$$q_m = 333.8\,\frac{kJ}{kg}\cdot 5\,kg = 1669\,\frac{kJ}{m^2}$$

Since it is assumed that the system should constantly melt snow without snow accumulation, the ratio of snow-free area to total area is equal to 1 /23 p. 51.1/. With the disposal system existing it does not necessary to spent heat on water evaporating. It means that q_e equals to 0 kJ/m^2. The value of heat transfer by convection can be defined through Equation 8. As this equation applies to the English system of measures, the final value will be converted to the metric system. According to SNIP 23-01-99* the maximum wind velocity in Saint-Petersburg during January is 3.3 m/s (6.7 mph) /21 p. 13/.

$$q_h = 11.4\cdot(0.0201\cdot V_{wind} + 0.055)\cdot(t_{rec} - t_{air}) \tag{8}$$

where	q_h	heat transfer by convection	[kJ/s·m^2]
	V_{wind}	wind velocity	[m/s]
	t_{rec}	water film temperature	[°C]
	t_{air}	temperature of ambient air	[°C]

$$q_h = 11.4\cdot(0.0201\cdot 6.7 + 0.055)\cdot(33-(-18{,}4)) = 111.14\,\frac{Btu}{h\cdot ft^2} = 0.35\,\frac{kJ}{s\cdot m^2}$$

According to the GISMETEO website /22/, the number of days during the period November-March with the precipitations in the form of snow is 28. It is assumed that the average duration of snowfall is 4 hours. Therefore, 28 days · 4 hours · 3600 sec = 403200 seconds. By Equation 4,

$$q_o = \left(\frac{294\,\frac{kJ}{m^2} + 1669\,\frac{kJ}{m^2}}{403200}\right) + 1\cdot 0.35\,\frac{kJ}{s\cdot m^2} = 0.355\,\frac{kJ}{s\cdot m^2} = 355\,\frac{W}{m^2}$$

5.3 Hydraulic SIM system design and costs calculations

The scheme of the hydraulic SIM system shown in Figure 9. Boiler, pump, safety valve, expansion vessel and manifold will be designed to obtain payback period.

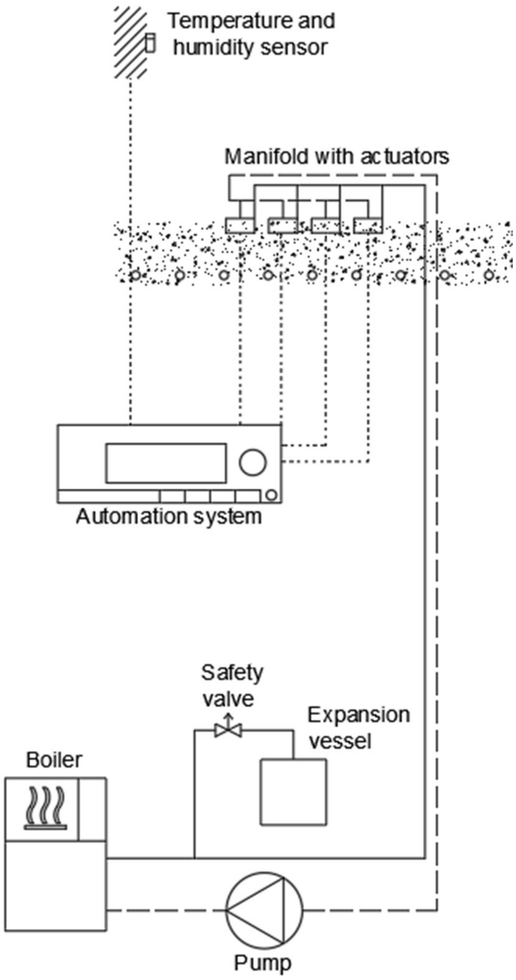

Figure 9. Scheme of the hydrulic SIM system

5.3.1 Pressure loss calculations and pipe dimensioning

The required fluid flow could be estimated through Equation 9 /25 p.3/.

$$\varphi = \rho \cdot c_p \cdot q_v \cdot (t_{supply} - t_{return}) \tag{9}$$

where	φ	heat capacity	[kW]
	ρ	fluid density	[kg/l]

c_p	fluid specific heat	[kJ/kg·°C]
t_{supply}	supply fluid temperature	[°C]
t_{return}	return fluid temperature	[°C]

The required fluid characteristics are summarized in Table 2.

Table 2. Fluid parameters

Fluid parameters	Value	Unit
Temperature range	45/35	°C
Percent of propylenglycol	40	%
Density of water-glycol mixture /26/.	1.026	kg/l
Specific heat of water-glycol mixture /26/.	3.79	kJ/kg·°C

The required flow could be derived from Equation 9 /25 p. 3/.

$$q_v = \frac{\varphi}{c_p \cdot \rho \cdot (t_{supply} - t_{return})} = \frac{0.355\,\frac{kW}{m^2} \cdot 160\ m^2}{1.026\,\frac{kg}{l} \cdot 3.79\,\frac{\mathrm{kJ}}{\mathrm{kg}} \cdot {}^{\circ}\mathrm{C} \cdot 10\ {}^{\circ}\mathrm{C}} = 1.46\,\frac{l}{s}$$

In this thesis, pipes of manufacturer “Uponor” accepted with 250 mm spacing and 160 m length. It means that the area which covers one loop is 160 m · 0,25 m = 40 m^2. Therefore, 160 m^2/ 40 m^2 = 4 similar loops requires with 1.46 l/s / 4 loops = 0.365 l/s flow per loop. With the use of “Uponor” nomogram /27 p.10/, it was decided to choose PEX pipe 25 x 2.3 with 0.7 kPa/m pressure loss which means 0.7 kPa/m · 160 m = 112 kPa per loop. To simplify the calculations, the local pipe resistance is equal to 0 kPa.

In this design there is one manifold with 5 m distance from the boiler room. According to “Uponor” nomogram /27 p.11/, PEX pipe 50 x 4.6 with 0.38 kPa/m pressure loss was chosen with fluid velocity 1.25 m/s. It means 0.38 kPa/m · 5 m = 1.9 kPa per collection pipe.

5.3.2 Equipment selection

- Heat exchanger

It is supposed that there are two heating boilers in the building of the warehouse. The first one is for space heating and the second one for hydraulic SIM system. Therefore, it was decided to neglect the heat exchanger installation for hydraulic SIM system.

- Heating boiler

The required heat output of the hydraulic SIM system equals to 0.355 kW/m^2 · 160 m^2 = 56.8 kW. To provide this energy, the hot water heating boiler “Vitodens 200-W, B2HA 80, 285” by manufacturer “VIESSMANN” was chosen. The declared heat capacity of this heating boiler varies between 19 kW and 76 kW. As the fluid flow is 1.46 l/s (5256 l/h) the total pressure drop is 36 kPa (3.7 m). /28 p. 4-10./

- Safaty valve and expension vessel

The expension vessel volume could be estimated through Equation 10 /29 p. 8/.

$$V_{ex} = \frac{\Delta V}{\eta} \tag{10}$$

where	V_{ex}	expension vessel volume	[l]
	ΔV	volume change	[l]
	η	active expansion volume factor	[-]

The active expansion volume factor could be defined through Equation 11 /29 p. 8/.

$$\eta = \frac{p_2 - p_1}{p_2} \tag{11}$$

where	p_2	opening pressure of the safety valve	[kPa]

	p_1	static pressure	[kPa]

It was decided to choose the “Flamco” manufacturer’s expansion vessel “Cubexpak A & B” for small systems with maximum operating pressure 300 kPa /30 p. 9/. To prevent overpressure and expansion vessel breakage, the safety valve “Giacomini R140R” was chosen with operating pressure 300 kPa /31/. Static pressure is 100 kPa. The pre-pressure of the expansion vessel is 50 kPa higher than static pressure. /29 p. 9/. By Equation 11,

$$\eta = \frac{(300 + 100)\ kPa - (50 + 100) kPa}{(300 + 100) kPa} = 0.625$$

The value of volume change could be estimated through Equation 12 /29 p. 10/.

$$\Delta V = n \cdot \frac{V_a}{100} \qquad (12)$$

where	n	active expansion factor	[-]
	V_a	network volume	[l]

The total length of the heating PEX pipes with inner diameter 20.4 mm is (160 m · 4 loops) = 640 m. The length of collection PEX pipes with inner diameter 40.8 mm is 5 m. /27 p. 10-11/. Therefore, the volume of the heating network equals to (640 m · (3.14 · 0.0204^2 / 4)) + (5 m · (3.14 · 0.0408^2 / 4)) = 0.215 m^3 = 215 l. The expansion coefficient of water with 40 % propylenglycol with mean temperature of 40 °C equals to 2.07 /32/. By Equation 12,

$$\Delta V = 2.07 \cdot \frac{215\ l}{100} = 4.45\ l$$

With the reserve 25 % the expansion volume is 4.45 l · 1.25 = 5.56 l. By Equation 10,

$$V_{ex} = \frac{5.56\ l}{0.625} = 8.9\ l$$

It means that 8.9 litres need for expansion.

- Manifold pre-setting

To provide proper system operating it is necessary to balance this system. As the pressure drop on each loop is the same, the pre-setting value will be the same too. According to Uponor nomogram /19 p.22/, with the flow 1.46 l/s / 4 loops = 0.365 l/s per one loop and water density 990.22 at the temperature 45 °C , the pre-setting value equals 11 with pressure drop 30 kPa.

- Pump

With previous calculations of pressure losses and required flow, it is possible to select an appropriate circulating pump. The total pressure losses for pump selecting is 112 kPa + 1.9 kPa + 30 kPa + 36 kPa = 179.9 kPa and required fluid flow is 1.46 l/s. The ”Grundfos” manufacturer was chosen in this design. With the use of ”Grundfos product center” the pump ”CM 5-3 A-R-A-E-AVBE F-A-A-N” was chosen /33/.

5.3.3 Hydraulic SIM system cost estimation

- Gas consumption

The gas price in Saint-Petersburg is 6367.75 rub per 1000 m^3 /34/. The calorific capacity of 1 m^3 of gas is 8.8 kW/m^3 /35 p. 3/. As the estimated time of snowfall per year is 28 days · 4 hours = 112 hours and required heat output is 56.8 kW, the system will consume 56.8 kW · 112 hour = 6361.6 kW annually. Therefore, natural gas demand per season is 6361.6 kW / 8.8 kW/m^3= 723 m^3. It means that the price for natural gas per year will be (723 m^3 · 6367.75 rub) / 1000 m^3 = 4604 rub.

- Pump energy consumption

According to “Grundfos” manufacturer /33/ the pump ”CM 5-3 A-R-A-E-AVBE F-A-A-N” energy consumption is 0.504 kW. As the period of precipitations in the form of snow is 28 days and avarege duration of snowfalls is 4 hour, hydraulic

SIM system must be turned on 28 days · 4 hours = 112 hours. It means that annual pump energy consumption is 0.504 kW · 112 hours = 56.45 kW·h. The price for the October 2019 in Saint-Petersburg for 1 MW·h is 5650.3 rub /36/. Therefore, the price for a year for electricity is 0.05645 MW·h · 5650.3 rub/MW·h = 319 rub.

- Equipment prices

Table 3. Prices for the equipment

Equipment	Amount required	Price for unit	Total price
PEX pipe 25 x 2.3	640 m	199.67 rub per m /37 p. 52/	127788.0 rub
PEX pipe 50 x 4.6	5 m	16 rub per m /37 p. 5/	80.0 rub
Hot water heating boiler "Vitodens 200-W, B2HA 80, 285	1 unit	4420 euro per unit* /38 p. 7.3-35/	311698.4 rub*
Safety valve Giacomini R140R	1 unit	451 rub per unit /39/	451.0 rub
Flamco expansion vessel Cubexpak A & B	1 unit	63.67 £ per unit** /40/	5240.0 rub**
Manifold Uponor Vario plus	1 unit	2063.10 rub per unit /37 p. 55/	2063.1 rub
Manifold actuator	4 units	2297.70 rub per unit /37 p. 60/	9190.8 rub
Controller for automation system	1 unit	6387.10 rub per unit /37 p. 60/	6387.1 rub
Sensor	1 unit	1436.35 rub per unit /37 p. 60/	1436.3 rub

Pump Grundfos CM 5-3 A-R-A-E-AVBE F-A-A-N	1 unit	60613.00 rub per unit /41/	60613.0 rub
Total			**524948 rub**

*Euro exchange rate against ruble is 70.52 rub at the time November 21 /42/

** GBP exchange rate against ruble is 82.30 rub at the time November 21 /42/

- Additional components prices

In this design it was decided to use construction type which is shown in Figure 10.

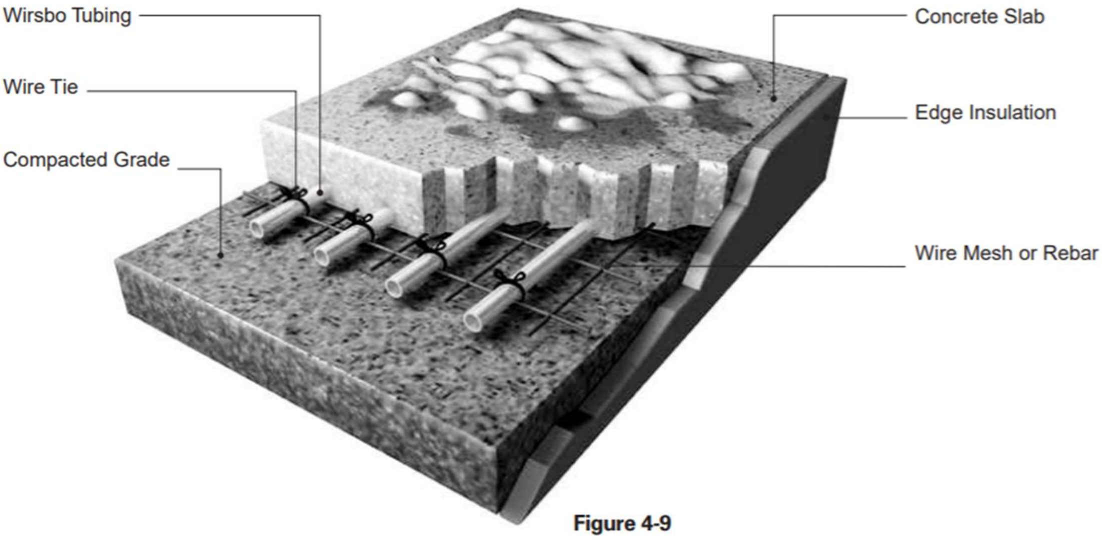

Figure 10. Slab on grade with edge insulation /43 p. 25/

Table 4. Additional components prices

Component	Amount required	Price for unit	Total price
Wire mesh	160 m^2	558 rub per 3 m^2 /44/	30132 rub
Wire tie	640 units	12.78 per unit /37 p. 52/	8179.2 rub
Edge insulation	52 m	70.97 rub per 20 m /37 p. 48/	212.9 rub

Angel locks for pipes under manifold	8 units	123.77 rub per unit /37 p. 8/	990 rub
Compression fitting	8 units	506 rub per unit /37 p. 17/	4048 rub
Total			**43562 rub**

- Mounting works prices

All mounting works prices are presented in Federal Unit Rates standards. It is also necessary to multiply the final price by price increase predictive indices which are updated by the Ministry of Construction of Russia every quarter. For Federal Unit Rates standards for Saint-Petersburg, increase index is 5.53 for mounting works and 16.64 for equipment adjustment /45/.

Table 5. Mounting work prices

Type of work	Required work scope	Mounting prices	Total price
Wire mesh installation with asphalt covering	160 m^2	642.43 rub per 100 m^3 /46 p. 6/	5684.2 rub
Pipe	645 m	414.41 rub per 100 m /47 p. 14/	14781.4 rub
Hot water heating boiler	1 unit	713.98 rub per unit /48 p. 4/	3948.3 rub
Expansion vessel	1 unit	61.42 rub per unit /48 p. 5/	345.2 rub
Pump	1 unit	144.75 rub per unit /48 p. 6 /	800.5 rub
Control system	4 channels	93.23 rub per channel /49 p. 7/	1551.4 rub
Equipment adjustment	-	4764 rub /50 p. 4-12/	79272.0 rub
Total			**106383 rub**

- Design works price

The price for design work could be estimated through Equation 13 /51/.

$$С_{пр(б)} = \frac{С_{стр(б)} \cdot \alpha_i}{100} \tag{13}$$

where			
	$С_{пр(б)}$	design work price	[rub]
	$С_{стр(б)}$	construction price	[rub]
	α_i	normative design cost	[%]

According to previous calculations, total construction price consist of equipment, additional components and mounting work prices. Therefore, the construction price is 524948 rub + 43562 rub + 106383 rub = 674893 rub. The normative design cost is 8.24 % /50/. By Equation 13,

$$С_{пр(б)} = \frac{674893\ rub \cdot 8.24\ \%}{100} = 55611\ rub$$

5.3.4 Hydraulic SIM system total price

The average total price for hydraulic SIM system with operation duration 7 years presented in Table 6. It is necessary to count on the fact that prices increase due to inflation. The average inflation rate for 7 last years is 6.5 % /52/.

Table 6.Hydraulic SIM system total price

Price factor	Price
Gas consumption	32228 rub
Electricity consumption	2233 rub
Equipment	524948 rub
Components	43562 rub
Mounting work	113297 rub*
Design work	59226 rub*
Total	**775494 rub**

*Including inflation rate

5.4 Electric SIM system design and costs calculations

5.4.1 Wire type selection for electric SIM system

It was decided to use the manufacturer's "DEVI" components for electric SIM system. Accepted spacing between wires is 80 mm. Therefore, 160 m^2 / 0.08 m = 2000 m of wire requires. To select wire type correctly it is necessary to obtain the value of required heat output per meter length. It is equal (355 W/m^2 · 160 m^2) / 2000 m = 28.4 W/m. Resistive heating wire DEVIsnow with maximum heat output 30 W/m^2 is accepted in this design /53 p. 9/.

5.4.2 Electric SIM system cost estimation

- Electrical energy consumption

The price for the October 2019 in Saint-Petersburg for 1 MW·h is 5650.3 rub /36/. As the period of precipitations in the form of snow is 28 days /22/ and avarage duration of snowfalls is 4 hour, electric SIM system must be turned on 28 days · 4 hours = 112 hours with heat output 56.8 kW. Therefore, the annual price for electricity is 112 hours · 5650.3 rub/MW·hour · 0.0568 MW = 35945 rub.

- Wire DEVIsnow

As it was mentioned above, the required wire length is 2000 m. The price for 190 m of this wire is 42992 rub /54/. It means, that 2000 m / 190 m = 10.5 ≈ 11 kits required. The total price for wire is 11 kits · 42992 rub = 472912 rub.

- Control system

To provide proper snow and ice melting, control system DEVIreg 610 with 4 sensors was chosen. The price of the controller is 7200 rub. /55./ It is also required 4 sensors with the price 1600 rub each /55/. The total price for control system is 7200 rub + 4 · 1600 rub = 13600 rub.

- Additional components prices

Most commonly during wire installation, construction type which is shown in Figure 11 applies.

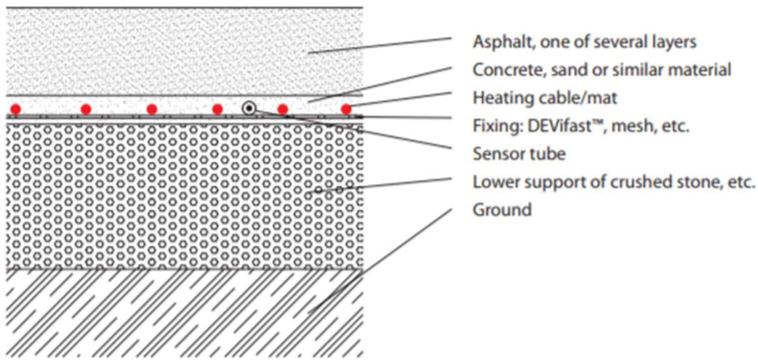

Figure 11.Heating cable with asphalt surface /53 p. 12/

According to DEVI manufacturer /53 p. 12/, the minimum height of sand layer is 2.5 cm. It is required to prevent wire breakage due to asphalt heat. Therefore, the required sand volume is $0.025\ m \cdot 160\ m^2 = 4\ m^3$. Fixing elements must be installed with the spacing 50 cm /53 p. 14/. It means that it is necessary to install $160\ m^2 / 0.5\ m = 320\ m$ of fixing elements.

Table 7. Additional components prices

Component	Amount required	Price for unit	Total price
Fixing	320 m	540 rub per 5 m /57/	34560 rub
Sand	4 m^3	300 per 1 m^3 /58/	1200 rub
Total			**35760 rub**

- Mounting works

Mounting work prices are calculated in the same way as in paragraph 5.3.3.5. Increase index for mounting works is 6.19 and 8.77 for equipment adjustment /45/.

Table 8. Mounting work prices

Type of work	Required work scope	Mounting prices	Total price
Sand compacting	4 m^3	59.71 rub per 1 m^3 /59 p. 2/	1478.4 rub
Wire installation and fixing	160 m^2	916.52 rub per 100 m^2 /60/	9077.3 rub
Control system installation	4 channels	93.23 rub per channel /49 p. 7/	1551.4 rub
Equipment adjustment	-	3559.3 /61 p. 18-19/	31215.1 rub
Total			**43322 rub**

- Design works price

Price for design works is calculated in the same way as in paragraph 5.3.3.5. According to previous calculations, construction price is 472912 rub + 13600 rub+ 35760 rub + 43322 rub = 565594 rub. The normative design cost is 8.24 % /51/. By Equation 13,

$$C_{пр(6)} = \frac{565594\ rub \cdot 8.24\ \%}{100} = 46605\ rub$$

5.4.3 Electric SIM system total price

The average total price for electric SIM system with duration of operation 7 years presented in Table 9.

Table 9.Hydraulic SIM system total price

Price factor	Price
Electricity consumption	251615 rub
Equipment	486512 rub
Components	35760 rub
Mounting work	46138 rub*

Design work	49634 rub*
Total	**869659 rub**

*Including inflation rate

5.5 Mechanical and mechanized snow and ice removal cost estimation

For mechanical snow and ice removal, it was decided to use excavator-loader JCB 4CX, truck Volvo FMX and production workers. The necessary information for cost estimation is given in Table 10.

Table 10.Technique data

	Excavator-loader JCB 4CX	Truck Volvo FMX
Shovel/Loader capacity	1.3 m^3 /62/	26.1 m^3 /64/
Lease cost	1625 rub/hour /63/	1750 rub/hour /65/

Area clearance operations in winter are divided into two stages. The first stage is to remove snow. Normally, in this case, all type of technique required. The second stage is to remove ice. During ice removal, technique is practically not used. Mainly, manual labour applies.

5.5.1 Snow removal

It is assumed that 100 mm of snow must be removed from the area. It means that the amount of snow on the whole territory is 160 m^2 x 0.1 m= 16 m^3. As the maximum loader capacity of the excavator-loader is 1,3 m^3 the number of shovels is 16 m^3 / 1,3 m^3= 12.3. As the shift is 7 hours the production worker should remove 12.3 / 7 h = 1.8 shovels per hour. According to the calculations, one excavator-loader requires.

As the amount of cubic meters of snow (16 m^3) less than truck loader capacity (20.2 m^3) one Volvo FMX requires.

It is accepted that 1 hour is enough to remove snow. The price for snow removal is (1 h x 1 excavator x 1625 rub) + (1 h x 1 truck x 1750 rub)= 3375 rub. According to GIMETEO website, the number of days with the precipitations in the form of snow in Saint-Petersburg is 28 /22/. For snow removal for the whole season, the total price is 3375 rub x 28 days = 94500 rub.

5.5.2 Ice removal

It is accepted that one production worker can remove 50 m^2 of snow per one hour. It means that 160 m^2 / 50 $m^2 \approx$ 3 production workers required. According to Regional Unit Prices /66 p. 118/ production worker's salary for 1000 m^2 of ice removal is 5162.04 rub. It is necessary to multiply the final price by price increase predictive indices which is 6.38 /45/. For 160 m^2 area it is required (160 m^2 · 5162,04 rub) / 1000 m^2 · 6.38= 5269 rub per whole work. For ice removal it is also needed 1 excavator-loader and 1 truck. The price for ice removal is (1 h x 5269 rub) / 3 workers + (1 h x 1 excavator x 1625 rub) + (1 h x 1 truck x 1750 rub) = 5131 rub. For ice removal for the whole season the total price is 5131 rub x 28 = 143668 rub.

5.5.3 Total price for mechanical and mechanaized snow and ice removal

The approximate total price for 7 years of mechanical and mechanized snow and ice removal presented in Table 11.

Table 11.Total price for mechanical and mechanized snow and ice removal during 7 years

Price factor	Price
Snow removal	661500 rub
Ice removal	1005676 rub
Total	**1775542 rub***

*Including inflation rate

5.6 Bioswales implementation examples

It goes without saying, that before the installation of any system it is necessary to familiarize yourself with it. Implementation of the bioswale system requires the same approach. System advantageous and disadvantageous must also be considered before making a decision.

Greenspace expansion and SMPs setting up proved its effectiveness of the example of Philadelphia. Philadelphia is the city where the risk of coastal and river flooding is high. To solve this problem and to decrease the cost of water disposal system expansion, it was decided by the Philadelphia Water Department (PWD) to create the program Green City, Clean Waters. This program obligates to design new buildings and infrastructure with the opportunity to utilize precipitations. To achieve this goal all over the city so called SMPs were installed. It allowed to expansion green spaces, decrease the amount of floods and increase money revenues to the city. For instance, this program allowed to replenish the budget of Philadelphia at the rate of $57 million annually /67 p.16/.

Another example of efficient use of SMP system is swales and bioretention implementation in Auburn Hills Subdivision, Southwestern Wisconsin. To obtain percent of savings, comparison between the costs of the traditional disposal system and SMPs or Low Impact Development (LID) was made. The total savings accounted approximately 56% in the case of LID development. /68 p. 13-14./

Item	Conventional Development Cost	Auburn Hills LID Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$699,250	$533,250	$166,000	24%	22%
Stormwater management	$664,276	$241,497	$422,779	64%	56%
Site paving and sidewalks	$771,859	$584,242	$187,617	24%	25%
Landscaping	$225,000	$240,000	–$15,000	-7%	-2%
Total	**$2,360,385**	**$1,598,989**	**$761,396**	—	—

* Negative values denote increased cost for the LID design over conventional development costs.

Figure 12. Cost Comparison for Auburn Hills Subdivision /68 p.14/

Relying on the information above it is possible to determine the most significant advantage of LID systems. SMPs existing impossible without common disposal system. However, planter boxes, swales or bioswales requires smaller drainage infrastructure. This is the main reason for high savings percent. Moreover, these systems are very easy to maintain compared to traditional ones. No less important advantage is a positive impact on the environment. Stormwater does not adversely affect water bodies. /69./

However, there are also disadvantages of LID systems. For instance, it is impossible to determine the life cycle of SMPs. It is also difficult to implement these systems due to limitations. /69./

Having regard to the above, it was decided to design bioswales in the warehouse adjacent area.

5.7 Bioswale design

As the example of the bioswale disposal system application, the same warehouse adjacent area applies. The catchment area is 160 m^2 (1722 sf).

Figure 13.Considered bioswale layout

Via the Philadelphian Stormwater Retrofit Guidance Manual, it is possible to design bioswale /16/. Through Equation 14 required bioswale volume could be obtained. As this equation applies in the Philadelphian Stormwater Retrofit Guidance Manual, the final value will be converted to the metric system.

$$WQ_h = (\frac{P}{12}) \cdot (IA) \tag{14}$$

where	WQ_h	water quality volume	[m^3]
	P	inch of rainfall	[mm]
	IA	impervious area managed	[m^2]

$$WQ_h = \left(\frac{1\ inch}{12}\right) \cdot (1722) = 143.5\ cf = 4\ m^3$$

As the cross section of the bioswales is the trapeze, the main parameters as length, bottom and top width could be estimated through Equation 15.

$$WQ_h = \mathrm{L} \cdot \frac{(B_{top} + B_{bottom})}{2} \cdot H \tag{15}$$

where	WQ_h	water quality volume	[m^3]
	L	bioswale length	[m]
	B_{top}	width of the top part	[m]
	B_{bottom}	width of the bottom part	[m]
	H	bioswale height	[m]

The recommended height of the bioswale varies between 600 mm to 1200 mm. As the catchment area is insignificant, it was decided to accept 600 mm height. The top and bottom parts width were taken 500 mm and 300 mm in compliance. /16./

$$\mathrm{L} = \frac{WQ_h \cdot 2}{(B_{top} + B_{bottom}) \cdot H} = \frac{4\ m^3 \cdot 2}{(0.5 + 0.3) \cdot 0.6} = 17\ m$$

6 RESULTS

6.1 Payback period estimation

To figure out what kind of system is more profitable in Saint-Petersburg, it is necessary to obtain payback period. This information presented in Table 12.

Table 12. The payback estimation

	Hydraulic SIM system	Electric SIM system	Mechanical and Mechanized snow and ice removal
Total price during 7 years of operation	775494 rub	869659 rub	1775542 rub
Price difference	1000048 rub	905883 rub	-
Payback period	≈0.8 years	≈1 years	-

In accordance with the data from Table 12, it is possible to conclude that the most expensive way of ice and snow removal is mechanical and mechanized. Therefore, the payback period estimation is based on price differences between mechanical and mechanized snow and ice removal and other SIM systems. Dividing price difference by total price it is possible to obtain payback period.

There is also could be the opportunity to replace the existing electric SIM system with hydraulic.

Table 13. SIM system cost comparison

	Hydraulic SIM system	Electric SIM system
Total price during 7 years of operation	775494 rub	869659 rub
Price difference	94165 rub	
Payback period	≈8.2 years	

In this case without system dismantling cost, the payback period is around 98 months.

Due to relatively high cost of electricity in Saint-Petersburg, the total price of electric SIM system is higher than hydraulic. Moreover, from year to year, the price difference between electric and hydraulic SIM systems will rise.

6.2 Bioswales implementention

According to the literature review it possible to notice the tendency to the cost of the disposal system reduction almost in each case. SMPs development affords to save $57 million annually /67 p. 16/ in citywide. Relatively small-scale project in Auburn Hills Subdivision, Southwestern Wisconsin saved $761396 /68 p.14/.

Soil ability to infiltrate water and evaporating processes afford to reduce load on disposal system. It means that pipe cross section and the whole disposal system require to be smaller, which entails cost reduction. Moreover, the cost of SMPs development is almost less than traditional disposal system expansion.

7 DISCUSSION

This study was designed mostly to figure out what type of SIM system is more profitable in Saint-Petersburg, Russia. To understand the feasibility of bioswale development was less important aim but still worth mentioning.

Regarding the main aim, it was found out that the most advantageous type of SIM system in Russia is hydraulic. It is also obvious that in the regions with relatively low energy sources SIM systems will be preferable to mechanical and mechanized snow and ice removal. Moreover, it makes sense to replace existing electric SIM with hydraulic. Especially considering that the payback period of 8.2 years will be reduced due to source energy cost differences. It is also worth understanding that without snow melting system installation it is necessary to remove snow and ice manually. In this case vehicles interferes with the passage of people and obstructs traffic.

However, the payback periods which were submitted earlier could change. These changes may be related to not precise weather data, equipment and mounting costs. The inability to determine the exact price for energy source must also be taken into account. Therefore, future research needed to clarify payback period.

Data on the topic of bioswales implementation proved the effectiveness of this system. Moreover, it is also important to note that bioswales have a positive effect on the environment.

In conclusion, joint implementation of bioswales and hydraulic SIM system will not only reduce the price of snow and ice removal but also reduce the price of the water disposal system.

REFERENCES

1. Guha,E. Basic Thermodynamics. Pangbourne: Alpha Science International Ltd. 2000.

2. Encyclopedia Britannica. Thermodynamics. WWW document. Available at: https://www.britannica.com/science/thermodynamics [Accessed 15 November 2019].

3. The European Commission. About the autonomous and energy-efficient snowmelt technoklogy for lightly and heavily traffickes pavement surfaces. WWW document. Available at: https://cordis.europa.eu/project/rcn/218617/factsheet/en [Accessed 15 November 2019].

4. Jonathan,F., Joshua,F., Matthew,K., Alex,L., Thoi,N., Kyle,R., Anthony,S., Charlie,S., Travis,W. 2010. Design and evaluation of a retrofittable electric snow melting system for pavements. University of Maryland, College Park. Thesis. PDF document. Available at: https://drum.lib.umd.edu/bitstream/handle/1903/10090/SnowMelt.pdf?sequence=1 [Accessed 5 November 2019].

5. Jinxing,L., Junling,Q., Jianxun,C., Haobo,F., Ke,W. Hindawi. New technology and experimental study on snow-melting heated pavement system in tunnel portal. June 2015. Ejournal. Available at: https://www.researchgate.net/publication/283954961_New_Technology_and_Experimental_Study_on_Snow-Melting_Heated_Pavement_System_in_Tunnel_Portal [Accessed 6 November 2019].

6. Kwesi,M., Jong,Q.C. Journal of Mechanical Science and Technology. Review of technologies for snow melting systems. August 2015, p. 5508-5509. Ejournal. Available at: https://www.researchgate.net/publication/286871845_Review_of_technologies_for_snow_melting_systems [Accessed 7 November 2019].

7. Michael,O. No date. U.S Department of Transportation. Airside use of heated pavement systems. PDF document. Available at: https://www.faa.gov/documentLibrary/media/Advisory_Circular/draft_150_5370_xx_heatpave.pdf [Accessed at 13 October 2019].

8. ASHRAE APPLICATIONS HANDBOOK. USA. 1999. [Accessed 8 November 2019].

9. Matt,H., Taylor,K., Thomas,R., John,C.No date. Heated Driveway Slab. Research studies. Available at:

https://www.slideshare.net/MatthewHilger/snow-melt-system-final-report-52138693 [Accessed 6 November 2019].

10. Hongwei,L., Pooneh.M., Hartmut.M.H. Physics and Chemistry of the Earth, Parts A/B/C. Sensitivity analysis and optimum design of a hydronic snow melting system during snowfall. January 2019. Ejournal. Available at: https://www-sciencedirect-com.ezproxy.xamk.fi/science/article/pii/S1474706518302018 [Accessed 16 October 2019].

11. Raheb,M., Carl-Eric,H., Par,J., Josef,J. Cold Regions Science and Technology. Anti-icing of road surfaces using Hydronic Heating Pavement with low temperature. January 2018. Pages 106-118. Ejournal. Available at: https://www-sciencedirect-com.ezproxy.xamk.fi/science/article/pii/S0165232X17302689 [Accessed 16 October 2019].

12. Xing,J., Xiaosong,Z., Yajun,L., Rongquan,C. Building and Environment. Numerical simulation of radiant floor cooling system: The effects of thermal resistance of pipe and water velocity on the performance. May 2010. Pages 2545-2552. Ejournal. Available at: http://www.uap-seu.com/uploads/201409/540db90489b2b.pdf [Accessed 10 November 2019].

13. Pan,P., Shaopeng,W., Feipeng,X., Ling,P., Yue,X. Journal of Intelligent Material Systems and Structures. Conductive asphalt concrete: A review on structure design, performance, and practical applications. 2015. Ejournal. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.907.4543&rep=rep1&type=pdf [Accessed 19 October 2019].

14. Yuling,G., Sarah P.,C., Sara,P., Linda S.,P. Journal of Environmental Management. Public perception towards river and water conservation practices: Opportunities for implementing urban stormwater management practices. October 2018. Pages 478-488. Ejournal. Available at: https://www.sciencedirect.com/science/article/pii/S0301479718307114 [Accessed 22 October 2019].

15. Hanbae,Y., Edward L.,M., Parwinder S.,G., Warren A.,D. Chemosphere. Dissolved nutrients and atrazine removal by column-scale monophasic and biphasic rain garden model systems. August 2010. Issue 8, page 929-934. Ejournal. Available at: https://www-sciencedirect-com.ezproxy.xamk.fi/science/article/pii/S0045653510005977 [Accessed 30 October 2019].

16. Philadelphia Water Department. No date. Stormwater Retrofit Guidance Manual. PDF document. Available at: https://www.phila.gov/water/PDF/SWRetroManual.pdf [Accessed 1 November 2019].

17. Department of Permitting, Inspections and Enforcement. 2014. Stormwater Managent Design Manual. PDF document. Available at: https://www.princegeorgescountymd.gov/DocumentCenter/View/4627/Design-Manuals-PDF [Accessed 5 November 2019].

18. Yuan,J., Dunnett,N. 2018. Plant selection for rain gardens: response to simulated cyclical flooding of 15 perennial species. The University of Sheffield. Research studies. Available at: http://eprints.whiterose.ac.uk/148725/1/UFUG_2018_57_Revision%201_V0.pdf [Accessed 6 November 2019].

19. Uponor. Uponor Meltaway. Система снеготаяния для установки на открытых площадках. (Uponor. Uponor Meltaway. Sistema snegotayaniya dlya ustanovki na otkrytyh ploshchadkah). PDF document. Available at: https://www.uponor.ru/search-page?q=meltaway&um=0#&downloadcenter=1 [Accessed 5 November 2019].

20. Space Math. No date. Snow Density and Volume. Available at: https://spacemath.gsfc.nasa.gov/earth/89Mod11Prob2.pdf [Accessed 17 October 2019].

21. Строительная Климатология СНИП 23-01-99*.(Stroitel'naya Klimatologiya SNIP 23-01-99*). 2018.

22. GISMETEO weather forecast. Weather diary. WWW document. Available at: https://www.gismeteo.ru/diary/4079/ [Accessed 6 November 2019].

23. ASHRAE HANDBOOK. Heating, Ventilation and Air-Conditioning APPLICATIONS. USA. 2015.

24. Xiaobing,L., Simon J.,R., Jeffrey D.,S. Applied Thermal Engineering. Modeling snow melting on heated pavement surfaces. Part I: Model development. June 2006. Pages 1115-1124. Ejournal. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.408.6578&rep=rep1&type=pdf [Accessed 22 October 2019].

25. Martii,V., Jarmo, T. Heating systems. Part 2: Hydronic heating Water based central heating, main parts. Mikkeli University of Applied Sciences. [Accessed 15 November 2019].

26. Properties of mixture Water/Glycol. Table 8-3-1. WWW document. Available at: https://detector-cooling.web.cern.ch/Detector-Cooling/data/Table%208-3-1.htm [Accessed 6 November 2019].

27. Uponor. 2007. Uponor Handbook for snow melting system design. PDF document. Available at: https://docplayer.fi/32945114-Lu-m-e-n-s-u-l-at-u-s-ja-r-j-e-s-t-e-l-m-a-k-a-s-i-k-i-r-j-a-kasikirja-uponor-lumensulatusjarjestelma.html [Accessed 5 November 2019].

28. VIESSMANN. 2019. Technical Data Manual. Vitodens 200-W. PDF document. https://www.viessmann-us.com/en/residential/gas-boilers/condensing-boilers/vitodens-200-w.html [Accessed 19 November 2019].

29. Martii,V., Jarmo, T. 2016. Heating systems. Part 10: Expansion and safety. Mikkeli University of Applied Sciences. [Accessed 15 November 2019].

30. Flamco. 2017. Expension Vessels. PDF document. https://flamcogroup.com/media/files/documentation/EXP17_PSTEST_LR_v09022017_Chapter_1.pdf [Accessed 19 November 2019].

31. Giacomini. R140R Предохранительный клапан компактный. (R140R Predohranitel'nyj klapan kompaktnyj). WWW document. Available at: https://ru.giacomini.com/prodotti/r140r [Accessed 19 November 2019].

32. Flexcon. Vessel Calculations for Central Heating Systems. PDF document. Available at: https://lafipa.lv/files/uploads/000/000/025/original/ins_exp_flexcon_calculation.pdf?1433233311 [Accessed 19 November 2019].

33. Grundfos Product Center. WWW document. Available at: https://product-selection.grundfos.com/product-detail.product-detail.html?from_suid=1574178045619046298984466863&pumpsystemid=713134184&qcid=713141058 [Accessed 19 November 2019].

34. Газпром. Комитет по тарифам Санкт-Петербурга. Распоряжение от 24.12.2018 N281-р (Gazprom. Komitet po tarifam Sankt-Peterburga. Rasporyazhenie ot 24.12.2018 N281-r). WWW document. Available at: http://www.peterburgregiongaz.ru/informatsiya-dlya-naseleniya/sankt-peterburg/tseny-i-normativy/roznichnye-tseny/20194 [Accessed 19 November 2019].

35. Interstate standard. 5542-2014. Interstate Council for Standardization, Metrology and Certification. 2014.

36. Петербургская Сбытовая Компания. Свободные цены. (Peterburgskaya Sbytovaya Kompaniya. Svobodnye ceny). WWW document. Available at: https://www.pesc.ru/for_clients/disclosure_of_information/St_Petersburg/free-of-control_prices/2019/ [Accessed 19 November 2019].

37. Uponor. Прайс-лист. (Price List). 2015. PDF document. Available at: http://www.glavteplotorg.ru/dload/price_list_uponor_2016.pdf [Accessed 21 November 2019].

38. VIESSMANN. Прайс-лист. (Price List). 2020. PDF document. Available at: file:///C:/Users/%D0%9C%D0%B0%D0%BA%D1%81%D0%B8%D0%BC/Downloads/Preis-list-polnaya-versiya.pdf [Accessed 21 November 2019].

39. Lunda. R140R Предохранительный клапан компактный, Giacomini.(Lunda R140R Predohranitel'nyj klapan kompaktnyj, Giacomini). WWW document. Available at: https://lunda.ru/catalog/category/c805/product/klapan-r140r-giacomini_18471.html [Accessed 21 November 2019].

40. WOLSELEY. Flamco Flexcon expansion vessel 12 ltr. WWW document. Available at: https://www.wolseley.co.uk/product/flamco-flexcon-expansion-vessel-12-ltr/ [Accessed 21 November 2019].

41. Римос. Насос Grundfos CM15-3 A-R-A-E-AVBE. (Nasos Grundfos CM15-3 A-R-A-E-AVBE). WWW document. Available at: http://www.rimos.ru/catalog/pump/22957 [Accessed 21 November 2019].

42. Центральный банк Российской Федерации. Официальные курсы валют на заданную дату, устанавливаемые ежедневно. (Central'nyj bank Rossijskoj Federacii. Oficial'nye kursy valyut na zadannuyu datu, ustanavlivaemye ezhednevno). WWW document. Available at: http://www.cbr.ru/currency_base/daily/?date_req=21.11.2019 [Accessed 21 November 2019].

43. WIRSBO. Snow and Ice Melting Design Manual. PDF document. Available at: https://www.uponorpro.com/~/media/Extranet/Files/manuals/SIMeltMan2003.aspx?sc_lang=en [Accessed 21 November 2019].

44. Top house. Арматурная сетка. (Top house. Armaturnaya setka). WWW document. Available at: https://www.tophouse.ru/price/31115/?gclid=Cj0KCQiAiNnuBRD3ARIsAM8KmlsRjkKaG5T9fsrP0SnHBPL1Q8G_5kItVrd9__u5wk27n-KWtCRsiSQaAqaTEALw_wcB [Accessed 21 November 2019].

45. Министерство Строительства Российской Федерации. Документы. О рекомендуемой величине индексов. (Ministry of Construction, Housing and Utilities of the Russian Federation. Documents. About recommended increase indices). WWW document. Available at: http://www.minstroyrf.ru/docs/ [Accessed 22 November 2019].

46. ФЕР 81-02-11-2001 Полы. Таблица ФЕР 11-01-016. Федеральные единичные расценки на строительные и специальные строительные работы. (FER 81-02-11-2001. Poly. Tablica FER 11-01-016.. Federal'nye edinichnye rascenki na stroitel'nye i special'nye stroitel'nye raboty).

47. ФЕР 81-02-16-2001 Часть 16. Трубопроводы внутренние. Таблица ФЕР 16-04-003-01. Федеральные единичные расценки на строительные и специальные строительные работы. (FER 81-02-16-2001 Chast' 16.

Truboprovody vnutrennie. Tablica FER 16-04-003-01. Federal'nye edinichnye rascenki na stroitel'nye i special'nye stroitel'nye raboty). Moscow 2008.

48. ФЕР 81-02-18-2001 Часть 18. Отопление - внутренние устройства. Федеральные единичные расценки на строительные и специальные строительные работы. (FER 81-02-18-2001 Chast' 18. Otoplenie - vnutrennie ustrojstva. Federal'nye edinichnye rascenki na stroitel'nye i special'nye stroitel'nye raboty). Moscow. 2014.

49. ФЕР 81-05-02-2001 Часть 2. Таблица ФЕРп 02-01-001. Автоматизированные системы управления. Федеральные единичные расценки на строительные и специальные строительные работы. (FER 81-05-02-2001 Chast' 2. Tablica FERp 02-01-001. Avtomatizirovannye sistemy upravleniya. Federal'nye edinichnye rascenki na stroitel'nye i special'nye stroitel'nye raboty). Saint-Petersburg. 2015.

50. ФЕР 81-05-07-2001 Часть 7. Теплоэнергетическое оборудование. Федеральные единичные расценки на строительные и специальные строительные работы. (FER 81-05-07-2001 Chast' 7. Teploenergeticheskoe oborudovanie. Federal'nye edinichnye rascenki na stroitel'nye i special'nye stroitel'nye raboty).

51. ММР-4.8-16. Глава 4. Сборник 4.8. Методика определения стоимости проектных работ в зависимости от стоимости строительства. (MMR-4.8-16. Glava 4. Sbornik 4.8. Metodika opredeleniya stoimosti proektnyh rabot v zavisimosti ot stoimosti stroitel'stva). Moscow. 2016.

52. Инфляция в России. Таблица инфляции. (Inflyaciya v Rossii. Tablica inflyacii). WWW document. Available at: https://xn----ctbjnaatncev9av3a8f8b.xn--p1ai/%D1%82%D0%B0%D0%B1%D0%BB%D0%B8%D1%86%D1%8B-%D0%B8%D0%BD%D1%84%D0%BB%D1%8F%D1%86%D0%B8%D0%B8 [Accessed 24 November 2019].

53. DEVI. Ground application.Ice and Snow Meltingand. Application manual. PDF document. Available at: https://devi.danfoss.com/media/1768/devi_am_ground_vglug102.pdf [Accessed 23 November 2019].

54. DEVI. Нагревательный кабель DEVIsnow DTCE-30 380V B-190 m. (DEVI. Nagrevatel'nyj kabel' DEVIsnow DTCE-30 380V B-190 m). WWW document. Available at: http://devi.market/obogrev-krovli-i-vodostokov/deviflex-dtce-30/deviflex-dtce-30-190-m [Accessed 23 November 2019].

55. DEVI. Эдектронный терморегулятор Devireg 610. (DEVI. Edektronnyj termoregulyator Devireg 610). WWW document. Available at: http://devi.market/termoregulyatory-dlya-ulichnyh-sistem/devireg-610-t-ot-10-do-50-c [Accessed 23 November 2019].

56. DEVI. Датчик температуры на проводе NTC, 15 kΩ/25°C. (DEVI. Datchik temperatury na provode NTC, 15 kΩ/25°C). WWW document. Available at: http://devi.market/termoregulyatory-devi-dlya-teplogo-pola/datchik-temperatury-na-provode-ntc-15-kom-25-s [Accessed 23 November 2019].

57. DEVI. Оцинкованная стальная монтажная лента DEVIfast для крепления кабеля. (DEVI. Ocinkovannaya stal'naya montazhnaya lenta DEVIfast dlya krepleniya kabelya). WWW document. Available at: http://devi.market/dopolnitelnoe-oborudovanie-devi/montajnye-elementy/otsinkovannaya-stalnaya-montajnaya-lenta-devIfast-dlya-krepleniya-kabelya-1up-5-m [Accessed 23 November 2019].

58. Песок в Санкт-Петербурге. Карьерный песок. (Pesok v Sankt-Peterburge. Kar'ernyj pesok). WWW document. Available at: https://algoritm-nerud.ru/pesok/[Accessed 23 November 2019].

59. ФЕР 81-02-11-2001. Полы. Федеральные единичные расценки на строительные и специальные строительные работы. (FER 81-02-11-2001. Floors. Federal'nye edinichnye rascenki na stroitel'nye i special'nye stroitel'nye raboty).

60. ЭСН. 11-01-046. Устройство электрических систем отопления “теплый пол” типа “DEVI”. (ESN. 11-01-046. Ustrojstvo elektricheskih sistem otopleniya “teplyj pol” tipa “DEVI”). Moscow. 2004.

61. ТЕРп-2001 Часть 1. Электротехнические устройства. Территориальные единичные расценки на пусконаладочные работы. (TERp-2001 CHast' 1. Elektrotekhnicheskie ustrojstva. Territorial'nye edinichnye rascenki na puskonaladochnye raboty). Saint-petersburg. 2015.

62. JCB. 4CX ECO Backhoe Loader. WWW document. Available at: https://www.jcb.com/en-gb/products/backhoe-loaders/4cx-eco [Accessed 24 November 2019].

63. Маск Групп. Аренда Экскаватора-Погрузчика JCB 4CX. (Mask Grupp. Arenda Ekskavatora-Pogruzchika JCB 4CX). WWW document. Available at: https://mack-group.ru/arenda-ekskavatora-pogruzchika-jcb-4cx/ [Accessed 24 November 2019].

64. Volvo Trucks. FMX 520 10X4. Technical specifications. WWW document. Available at: https://www.volvotrucks.in/en-in/trucks/mining-construction-haulage/volvo-fmx-10x4-tag-ob.html [Accessed 24 November 2019].

65. Резерв. Самосвал Volvo FMX. (Rezerv. Samosval Volvo FMX). WWW document. Available at: https://rezervooo.ru/avtopark/samosvaly/Samosval-Volvo-FMx/ [Accessed 24 November 2019].

66. ТЕР 1.01. Ручная уборка улично-дорожной сети. Территориальные сметные нормы и территориальные единичные расценки на работы по содержанию улично-дорожной сети Санкт-Петербурга. (TER 1.01. Ruchnaya uborka ulichno-dorozhnoj seti. Territorial'nye smetnye normy i territorial'nye edinichnye rascenki na raboty po soderzhaniyu ulichno-dorozhnoj seti Sankt-Peterburga). Saint-petersburg. 2008.

67. Green Stormwater Infrastructure partners™. The economic impact of Green City, Clean Waters: The First Five Years. 2016. PDF document. Available at: https://gsipartners.sbnphiladelphia.org/wp-content/uploads/2016/07/Local-Economic-Impact-GCCW-Report_packaged.pdf [Accessed 25 November 2019].

68. United States Environmental Protection Agency. Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. 2007. PDF document. Available at: https://www.nrc.gov/docs/ML1102/ML110270042.pdf [Accessed 25 November 2019].

69. Washington State Department of Transportation. Low Impact Development BMPs. No year. PDF document. Available at: ftp://ftp.odot.state.or.us/techserv/Geo-Environmental/SCOE/William_Fletcher_lid_scoe_18jun.pdf [Accessed 25 November 2019].