BUILDING ON PERMAFROST DURING THE CLIMATE CHANGE CRISIS:

Mitigation and adaptation strategies for the architects

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BUILDING ON PERMAFROST DURING THE CLIMATE CHANGE CRISIS: ***Mitigation and adaptation strategies for the architects***

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Abstract

The thesis aims to define the mitigation and adaptation strategies for the future sustainable development of the territories laid on permafrost that could help to prevent its degradation and provide comfortable living conditions to the locals. The research tends to understand the relationship between permafrost, global warming, and architecture, by analyzing the existing cultural heritage of Yakutsk (Russian Federation), modern research papers, and existing technological solutions of other countries that are facing the same problem.

The thesis will focus on determining the best architectural and urban strategies for permafrost preservation and then will show an example of their application to the chosen site in Yakutsk.

CONTENT

1 INTRODUCTION

Introduction

Climate change is one of the greatest challenges of the 21st century. There are a lot of articles, books, scientific research, and lectures that underline this problem. Moreover, we can observe its pieces of evidence by ourselves. The population is already experiencing the consequences of global warming that are getting worse and worse year by year. Only in recent years, have we experienced a huge number of wildfires all over the world. The EU's Copernicus Atmosphere Monitoring Service (CAMS) concluded that global wildfires in 2021 produced 148% more carbon emissions than all of the fossil fuel emissions in 2020. According to CDP countries like Algeria, Australia, Bulgaria, Croatia, France, Georgia, Greece, Kazakhstan, Morocco, Portugal, Russia, Spain, Turkey, the United Kingdom, US suffered from severe wildfires in 2022. The wildfires are expanding more and more year by year and their effect on the environment and our lives is getting worse and worse. It became common for the territories to experience new fires before recovering from the previous ones.

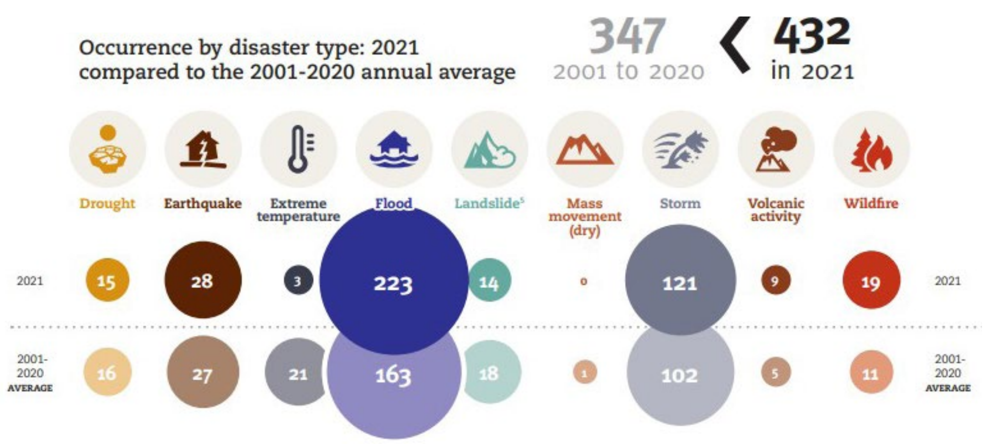


Figure 1. Occurrence by disaster type: 2021 compared to the 2001-2020 annual average. The graph shows the increase in the number of catastrophic events around the world. Predominantly, floods, wildfires, storms, and earthquakes (2021 disasters in numbers EM-DAT report).

In 2021 the EM-DAT (Emergency Event Database) recorded 432 catastrophic events that are way higher than the average in 2001-2020 (average is 347) (see figure 1) (EMDAT report, 2021). Most of them are related to global warming. The research shows that the number of natural disasters such as wildfires, floods, drought, and storms will increase in the following years. We can notice this tendency even now.

In 2022, while some parts of the world were facing heatwaves and following drought (France, Portugal, Spain, Italy, India, China, Brazil), others were experiencing long-lasting rains that led to severe floods (Australia, Pakistan, India, and others) (Counting the cost, 2022). Even the Arctic and Antarctic suffered from the heatwaves. The temperature there was 30°C and 47°C degrees higher than normal. That caused the ice shelf collapse, reduction of the sea ice content, and melt of permafrost (Counting the cost, 2022).

Architecture can be one of the tools to reduce the effect of global warming and maybe even prevent it from future development. Nowadays there are a lot of architectural projects that follow Sustainable development goals and try to reduce the impact on the environment by installing solar panels, using materials with low albedo, inserting green roofs and walls, adding vegetable and rain gardens, and so on.

The majority of the existing projects are made for continental climate zones, where summers are warm or hot and winters are relatively cold but what about the extreme climate conditions, like far north regions? Climate change had a greater effect on these areas (Constable, A.J., et al., 2022). The research shows that Nordic regions suffer from global warming two times more than the rest of the world. The increase in the air temperature provokes permafrost thawing that causes soil instability, floods, wildfires, and many other significant problems that can affect not only locals but everyone around the world. It is important to act now to mitigate the effects of climate change and prevent future disasters. Far North regions can be seen as a good example of what can happen to our planet in some years and also it can be a good opportunity to think about the actions that we can take to avoid future destruction.

Russian Federation is the country that has the biggest area of Far North regions. Moreover, 60% of its territory is covered with permafrost and unlike other countries, these regions are highly urbanized. A high level of urbanization increases man-made emissions into the atmosphere and speeds up global warming (R. Orttung, 2023). These territories could be perfect for the implementation of sustainable strategies since they represent one of the most vulnerable environments under global warming.

Yakutsk is a city in the Far North of Russia. It is the biggest city in the world built on continuous permafrost. Year by year we can see how the city is affected more and more by climate change – wildfires, smog, soil instability that led to the buildings' damage and even their collapse. It is very important to understand what could be done there to mitigate these disasters and improve the situation in the area. However, severe climate conditions make it even more challenging.

So, how can we, as architects make Far North cities more sustainable while at the same time providing comfort and aesthetics for the users? What guidelines do we have to follow?

Methodology

In this thesis, we are going to answer three questions: What type of building to design? Where to design? And the most important – how?

The second chapter is divided into two parts. The first part presents general information about climate change, focusing on the Paris Agreement's goals and actions, and the role of the Russian Federation in this agreement. One of the key aspects of the thesis and particularly this chapter will be permafrost regions in Russia and their vulnerability to global warming. The second part focuses on changes due to global warming in Yakutsk - the biggest city ever built on continuous permafrost. This part is focused on general information about the city. It describes the particularity of daily life of the people in the far north, the monthly challenges that the population is facing, and the results of global warming and its effects.

The following chapters try to define the strategies that can be applied for sustainable building development in Yakutsk and permafrost areas in general. Chapter 3 "Analysis" tries to answer the question of "What

Figure 2: The methodology of the thesis is based on three questions: What? Where? And how?

strategies to use?" by presenting three types of analysis. First of all, we analyse the building heritage of the area. What were the benefits of each type of building? What were their weak points? How the building technologies of the past could protect the permafrost from thawing? And what we can learn from the previous experience? All of these are described in "3.1. Yakutsk building heritage analysis and legacy" where we will follow the building changes in Yakutsk from the nomads' huts to the nowadays architecture.

Secondly, we will focus on norms and regulations in the building field in permafrost areas, where we will compare the norms of designing buildings in Russia and other countries. Building regulation analysis will help to understand the nowadays rules of building construction and how we can preserve permafrost from future degradation.

The last part of the analysis examines the international reports on mitigation and adaptation strategies for buildings and settlements to understand the best modern methods for sustainable development in the building field and which of them we can implement in the permafrost regions.

Based on the previous analysis, chapter 4 presents the set of mitigation and adaptation strategies and explains how they might work in the permafrost regions. The strategies could be applied on both urban and building scales.

To test the theory in practice, we will try to apply all of these strategies to the existing building field in Yakutsk, Russia. Chapter 5, will present an example of the implementation of the strategies both on urban and building scales.

Figure 3: The scheme presents the aspects that should be analyzed to understand what strategies are the best for building in permafrost regions.

The last chapter of the thesis provides a conclusion of the work and a list of the references that were used to write this paper.

This thesis shows the importance of the implementation of mitigation and adaptation strategies in the northern regions and tries to answer the question of how we as architects can protect permafrost from thawing.

2 CLIMATE CHANGE

2. Climate Change: global

Global warming causing significant changes all over the world. It is responsible for intensifying water cycles and changing rainfall patterns, causing floods and droughts in the regions; Global warming provokes sea level rise and changes in the oceans, moreover, climate change amplifies permafrost degradation and provokes the reduction of snow cover.

The study of climate change and sustainable development starts in 1962 with the book “Silent Spring” written by Rachel Carson. In her book, she linked the disappearance of birds in the garden with the use of pesticides, for the first time showing the connection between human actions and their effects on the environment.

Years later the first international conference in 1972 in Stockholm concluded the necessity of environmental protection and presented Stockholm’s declaration with 26 principles of the protection of the environment and some recommendations to follow to preserve nature for future generations (Stockholm Declaration on the Human Environment, 1972). Also, it established United Nations Environmental Program (UNEP) and Earth Watch for monitoring the state of the planet.

In 1987 Intergovernmental Panel on Climate Change was created to study the impacts of human actions on climate change and share the results of the research with the public. Nowadays the IPCC publishes a report each year that contains an analysis of the situation, future risks, and options for mitigation and adaptation.

“Earth Summit” in Rio de Janeiro in 1992 presented the concept of sustainable development and provided “Agenda 21” where they describe international actions on environmental protection. That led to the creation of the Kyoto Protocol in 1997. The protocol obliged industrialized countries and economies in transition to reduce GHG emissions.

In 2015, in Paris (France) the 21st session of the Conference of the Parties took place. As a result of this conference Paris Agreement was signed by 196 parties. Thanks to the Paris Agreement, in recent years we can see an increase in low-carbon solutions or even zero-carbon solutions. According to the article “The Paris Agreement” on the UN website, by 2030, zero–carbon solutions could be competitive in sectors representing over 70% of global emissions.

2.1. PARIS AGREEMENT

The Paris Agreement is a legally binding international treaty on climate change. It was signed by 196 countries at the UN Climate Change Conference (COP21) in Paris in 2015. The main goal of this agreement is to avoid the increase of global average temperature by more than 2°C and try to limit the temperature increase to 1,5°C. Each five years countries, that signed the agreement, have to publish their national plans, also known as nationally determined contributions or NDCs, and report about actions that were made and their results.

Despite the fact that in 2015, the limit the temperature increase was just a suggested recommendation, nowadays more and more countries tend to believe that crossing the threshold of 1.5°C by the end of the 21st century could cause severe changes and put in risk the majority of the population, by causing regular drought, floods, wildfires and so on. The actions on climate change have to be increased to manage to reach the main goal of the Paris Agreement.

2.2. ROLE OF RUSSIA IN THE PARIS AGREEMENT: GOALS AND ACTIONS

Russia was among the countries that signed the Paris Agreement in 2015.

In their NDC Russia set its main goal on the reduction of greenhouse gas emissions and adaptation to climate change, more specifically, it tries to reduce the GHG emission by 2030 to 70% relative to the 1990 level.

According to the data of Russian Nationally determined contribution (NDC) “Since the mid-1970s, the average annual surface air temperature in the Russian Federation has been growing by an average of 0.47°C over 10 years, which is 2.5 times higher than the growth rate of the average global air temperature (0.18°C during 10 years)”. In some regions, it has been growing even faster. The government understands the risks and possible consequences of such a tendency and created a further plan for the reduction of GHG emissions (see figure 4).

Most of the actions of the plan are very abstract and concern mostly the energy sector. For example, NDC mentions actions such as a transition to the best available technologies in the fuel and energy complex, taxation, support of green projects, and request for energy origin certificates based on the fact of the electricity production at carbon-free generating facilities and generating facilities with low greenhouse gas emission.

We can define three actions concerning the building sector, such as gradual change of energy-inefficient residential buildings, use of technologies with low GHG emissions, and control of energy consumption of the buildings. The last action was successfully achieved. Some years ago, the energy consumption of the building was not controlled. People paid a fixed amount of money per person for the use of water, gas, and electricity. By installing the tools for consumption control, Russia managed to achieve a more conscious way to use natural resources.

Improving the energy – efficiency of the buildings is one of the top priorities of the Russian Federation in the Paris Agreement. It will help to reduce the amount of energy spent and therefore the amount of GHG emissions in the atmosphere.

In Yakutsk, one of the coldest cities, located on permafrost, with an annual average temperature of -20,9°C, the energy efficiency of buildings is crucial. Bad insulation causes heat losses and increases the amount of energy spent to maintain the + 20°C inside the building. The research, held

Figure 4 (on the right): The scheme presents the Russian Federation’s goal for the reduction of GHG emissions and its actions according to the published NDC. In pink – ongoing actions that have a relation with the building field. In green – successfully implemented action related to the building sector. In grey – actions that are not related to the building field.

The role of Russian Federation in Paris Agreement

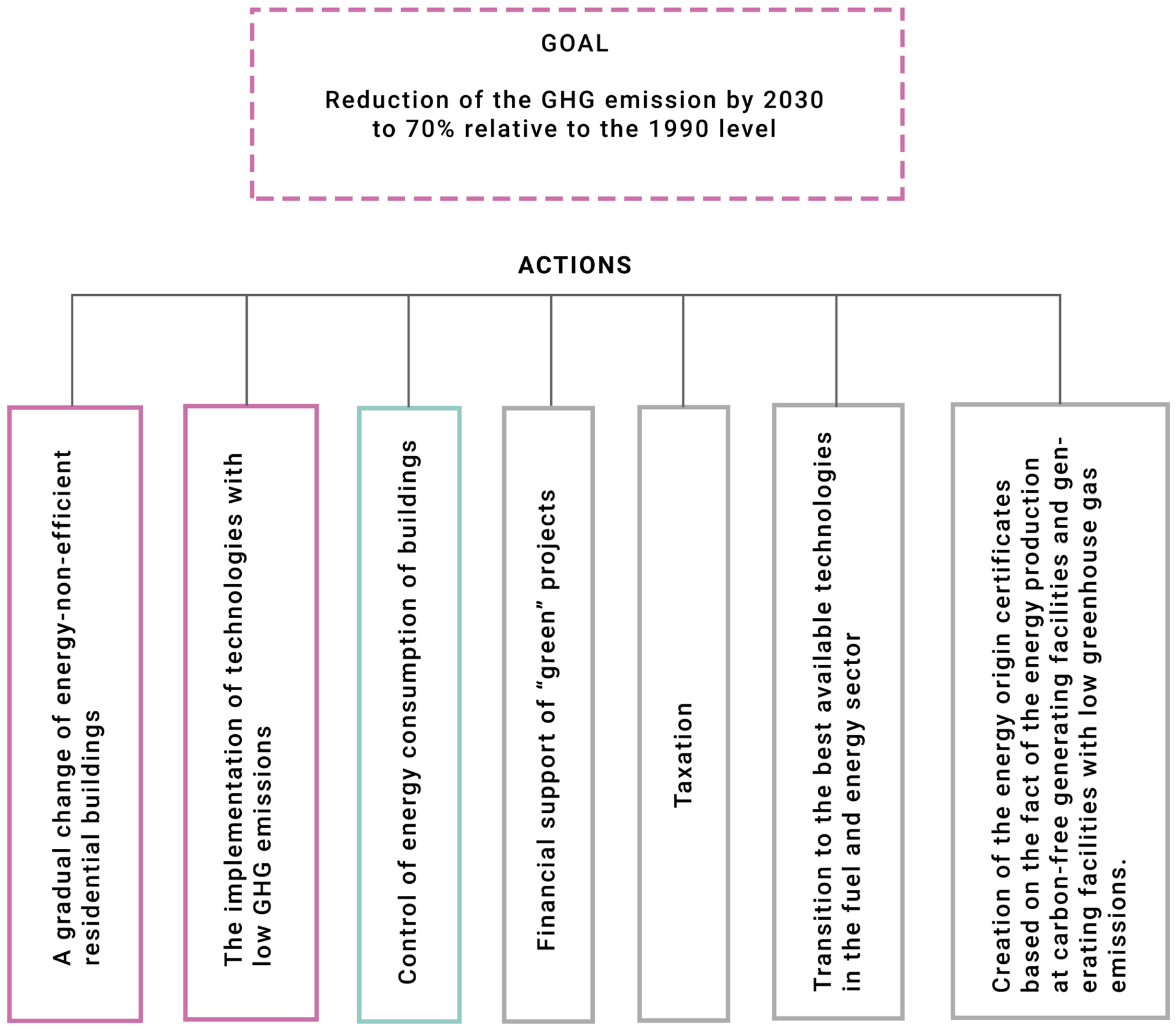
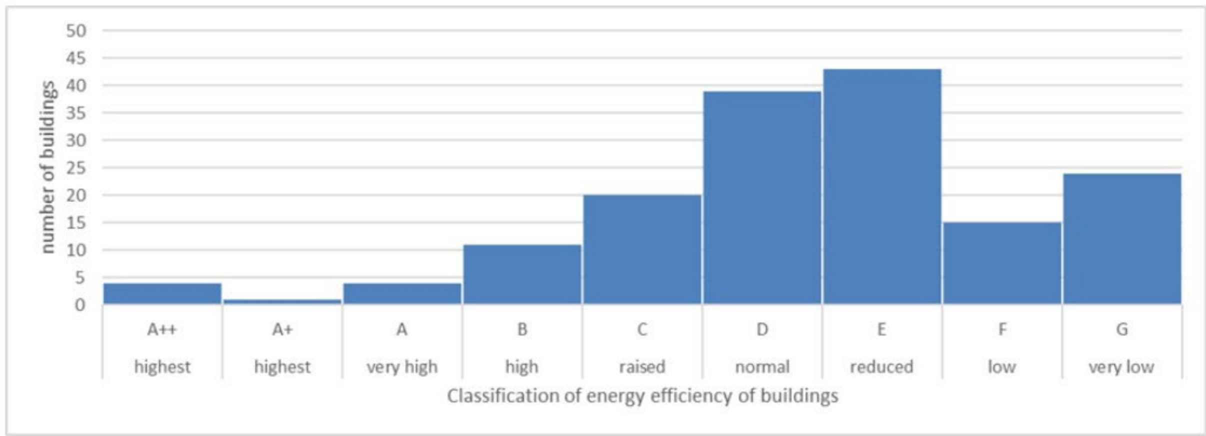


Figure 5 (on the right): Building energy consumption grading in Yakutsk (made by Arkhangelskaya). The graphic shows that most of the buildings in Yakutsk have inefficient building envelope and experience heat losses.



by Arkhangelskaya shows the energy efficiency of the buildings in Yakutsk (figure 5). In her analysis, she is pointing out that the existing buildings of less than 5 – floors are non-energy efficient and belong to class E to G. 65% of the buildings on the 12th floor showed good energy efficiency. However, taller buildings showed extremely poor energy efficiency due to the increase in heat consumption for heating infiltrating air. In winter when the outside temperature drops down to -40°C or even – 50°C, the pressure drop between internal and external air temperature can reach up to 180 -200Pa, in these conditions any defect in the building envelope leads to the cold air penetration and heat losses (Arkhangelskaya, 2022). Moreover, according to the research, declared energy-efficiency class of the building is higher than the reality.

Some of the insufficient buildings are in such dreadful condition that they cannot be fixed or improved. The Russian government has launched a resettlement program that gives new accommodation to families whose recent houses are in an emergency state (Decree of the Government of the Russian Federation of January 28, 2006, N 47 (as amended on September 28, 2022) «On approval of the Regulations on recognizing premises as residential premises, residential premises unfit for habitation, an apartment building as emergency and subject to demolition or reconstruction, a garden house as a residential building and a residential building as a garden home). The building receives the emergency status when 50% of its rooms and bearing load structure are facing extreme deformations and staying inside could be dangerous for the people. If the building received the emergency state, the owners will be resettled in the new accommodation with a value comparable to the one they live or they can receive the money. Their current property will be given to the government and later demolished.

The current resettlement program of Yakutsk is working on the buildings that received emergency state from 1 January 2012 to 1 January 2017. All buildings that are inside this program will be demolished by the end of 2025. The municipality of Yakutsk is planning to resettle and demolish 363 houses with a total surface of 59 981.15 m2 by the end of 2025 (RESOLUTION dated March 1, 2019, N 54p “On approval of the municipal targeted program «Resettlement of citizens from dilapidated housing stock for 2019-2025» in the territory of the urban district «city of Yakutsk»). After the end of this resettlement program, the land of the demolished buildings

will be used for the construction of new housing that will participate in the next governmental program. In this way, the municipality is gradually able to renovate neighborhoods.

His governmental program is an opportunity for the locals to improve their living conditions. One of the problems with these types of buildings is that their condition is so poor that owners cannot resell them to improve their living situation and they cannot afford refurbishment of the house. However, as we can see, it is a long process, considering that the current program is working on buildings that received an emergency state from 2012 to 2017, which means that some of the people have been waiting for resettlement for more than 10 years.

This program could be a solution to improve the energy efficiency of the building, since new houses, built after demolishing inefficient buildings are constructed regarding new norms that provide proper energy efficiency of the building. However, its speed and its efficiency, in most cases caused by lack of finances, could be significantly improved.

Another action, mentioned by the Russian Federation in their NDCs is the implementation of technologies with low GHG emissions. This could play an important role in mitigating climate change, however, there is no data that this action has already been taken or if there are some bonuses that encourage the private sector and companies to use low GHG technologies in building construction and other sectors.

We can conclude that even though the Russian Federation signed the Paris Agreement and declared to take some actions toward a more sustainable future, in reality, these actions are too abstract to be implemented in real-life situations and the one that could be already implemented and could help to reach the set goal are moving too slow due to the financial problems. The “climate action tracker” website points out that “there is little to no action being undertaken” regarding the announced actions. Russia has to rethink its actions and improve the situation to succeed in reaching “net zero GHG emissions by 2060”.

Figure 6: Examples of the buildings that have received the emergency state and after locals will receive new houses and leave the building the structure will be demolished. 1 - the condition of the load-bearing wall; 2 - the house is gradually sinking into the ground due to heat losses, permafrost thawing, and following land subsidence; 3 - due to the land subsidence the house sink into the ground, the ground floor is flooded and with winter time turned into the ice; 4 - the inefficient building envelope creates the condensate on the walls, that turns into the ice and snow; 5 - we can see that the structure of the house is not capable to bear loads, and the ceiling is basically held by the wardrobes.; 6 - the interiors of the house, fallen plaster allows us to see the structure of the wall (Photos source: https://news.ykt.ru/article/120223).

2.3. PERMAFROST REGIONS IN RUSSIA AND THEIR VULNERABILITY DUE TO CLIMATE CHANGE.

Ones of the most sensitive places to global warming in the world are Far North regions like polar regions and the Arctic. According to the IPCC report, polar regions are facing higher damage than other parts of the world due to climate change. The regions in the Northern Hemisphere are experiencing an increase in sea surface temperature of 0.5°C per decade during 1982–2017 in ice-free regions in summer, an increase of atmospheric temperature means higher than the twice global mean (Filippova V., 2020), heat waves and fire weather that provoke regular wildfires, permafrost degradation, regular floods, changes of the ecosystem and many others.

Moreover, the changes due to global warming that scientists are expecting to observe by 2050, are already happening here. So, polar areas can provide a lot of examples of severe consequences of climate change that could happen all over the world in a few decades (Constable, A.J. et al., 2022).

Figure 7 presents a table published by IPCC that shows us all climate hazards and the risks by sector in the polar regions. From there we can see that almost all of the spheres of the polar regions are at risk due to climate change. Heat waves and an increase in the mean air temperature provoke changes in marine and terrestrial ecosystems forcing southern animals and insects to go towards the North. Global warming provokes the expansion of new insects and ticks. That destroys the balance between species, completely changes the existing ecosystem, and brings new diseases to the indigenous people and their cattle. Moreover, the increase in the marine surface temperature causes shifts in marine species, sea ice losses, and changes in ocean salinity. Already now, all these changes, affecting not only the polar regions but everyone else in the world. Nowadays global warming is putting at very high-risk marine transportation, salmon production, and indigenous people's traditions (Constable, A.J. et al., 2022).

Due to global warming, a lot of regions are experiencing wildfires. By themselves, wildfires, are getting more and more dangerous and unpredictable year by year, however, in the case of far north regions, the situation is even worse. Wildfires not only destroy the ecosystem but also melt the permafrost, causing the release of GHG that stay in the atmosphere

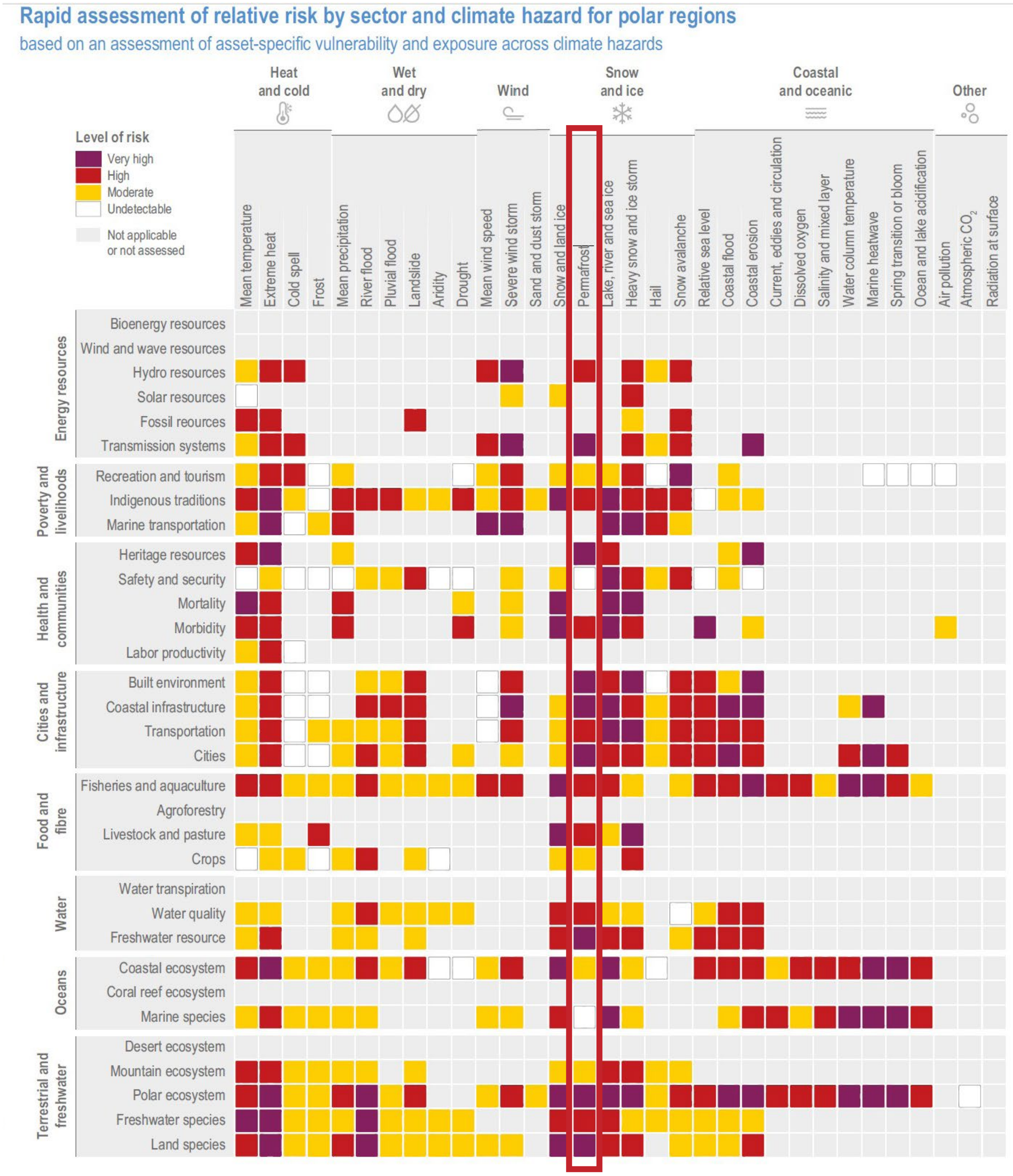


Figure 7 . Rapid assessment for relative risk by sector (y-axis) and climate hazard (x-axis) for polar regions based on the assessment of assets-specific vulnerability and exposure across climate hazards. We can see that the cities and infrastructure are one of the spheres that are at high risk from climate change. Moreover, the permafrost is highly sensitive to temperature changes and that puts at risk not only the soil stability in the Northern regions but also affects almost all spheres all over the world. Permafrost degradation affects water resources and marine ecosystems, causes health problems for the population, changes in the food chains, and many other problems (the scheme is taken from IPCC AR6 WGII CCP6 with further correction of the thesis' author).

and creating even worse wildfires next year.

Furthermore, polar settlements are highly relying on the transportation system. Permafrost thawing, floods, soil instability, and any changes in snow and fog patterns are decreasing the liability and safety of the infrastructure that led to problems with the food supply and healthcare availability. Moreover, from figure 7 we can see that permafrost and its degradation due to climate change put at very high-risk cities and infrastructure. Understanding the relationship between permafrost, climate change, and cities can help us to reduce the impact on the earth and build more sustainable cities.

The permafrost regions are suffering from climate change everywhere around the world, however, the specific Russian Far North region, that made them more vulnerable than anywhere on the Earth, is the high level of urbanization. In other countries the regions with permafrost have a minimum level of urbanization, meanwhile, in Russia, far-north regions have highly urbanized cities. That speeds up the degradation of these areas and creates a lot of problems.

Permafrost is a ground that remains at or below 0°C for two or more years (T.E. Osterkamp, C.R. Burn, 2003). Around a quarter of the Northern Hemisphere is covered by permafrost (Vladimir Frolov, 2016).

In my research essay "Building on Permafrost: adaptation and mitigation strategies for Architects" I describe permafrost, its distribution, its behavior, and its origin in detail. In this thesis, I would like to focus more on the relationship between climate change and permafrost, its vulnerability, and some of the problems that are facing northern regions related to global warming and permafrost thawing.

As we already know, permafrost is highly sensitive to climate change. The increase in the air temperature provokes its thawing. Permafrost is not an isolated phenomenon; it is highly correlated with other parts of the environment and affects almost all spheres of our life. From figure 7 we can see that permafrost is very sensitive to global warming and its thawing puts at risk almost every aspect of life.

The soil instability due to permafrost thaw leads to building and infrastructure instability. The building techniques that are commonly used all over the world, cannot be applied in permafrost regions. The heat of the building transfers to the soil and warms up permafrost, causing its further thawing. The majority of the buildings there are made regarding this problem, providing proper insolation between the building and the ground, however, due to global warming, the instability still exists. The sinkage of the structure is a popular problem in polar regions. Moreover, unequal thaw of permafrost under the building damages the structure and leads to insignificant cracks in the plaster, severe structural damage, or even total collapse of the building.

That could be a serious problem that sometimes could affect not only owners of the house but many other people and even the entire ecosystem if we are talking about building instability of the industrial structures or power plants. For example, in Norilsk in May 2020 thawing of permafrost caused the concrete foundation sinkage and further collapse of the oil storage tank at Norilsk-Taimyr Energy's Thermal Power Plant No. 3. Over 21,000 cubic meters of petroleum products spilled into the ground on an area of 180 000 m2 and into local rivers, causing significant damage to the environment («Diesel fuel spill in Norilsk in Russia's Arctic contained». TASS. Moscow, Russia. 5 June 2020. Retrieved 15.04.2022).

While most of the time, the consequences of the permafrost thawing are ignored by the inhabitants of the cities, indigenous people and local communities of the villages are suffering from its catastrophic impacts. The permafrost regions, like Yakutia, in Russia, were historically populated with nomads that used to live by transhumant horse, husbandry, hunting, and reindeer herding (Filippova V., 2020). The constant change of location allowed them to avoid seasonal floods and feed themselves and their livestock. Due to permafrost thawing landscape is changing: lakes are disappearing, coastlines are changing their shape, landslides happen more often, rivers are changing their paths, and so on. The change in the soil composition due to permafrost thawing provokes the growth of new plants which makes reindeer herding more difficult. The ground turns into swamps that make problematic the seasonal migration. Also, all ecosystems are gradually changing and becoming unpredictable. Fish spawning time has changed, birds and animals have changed, and even polar bears have started to move around (Doloisio N., Vanderlinden J., 2020).

Permafrost thawing affects the health of the population. First, some bacteria and prehistoric viruses are trapped inside the permafrost. Some scientific research shows that these viruses are still alive and that they can be released from the ground due to global warming. An example of this release already happened in 2016, in Yamal, where locals and their cattle were infected with anthrax that had been released from the ground due to the thawing of the permafrost.

Moreover, permafrost melting affects the transportation system which leads to an increase in the morbidity of the population, especially in remote settlements. The healthcare services are facing difficulties in reaching people from the villages and remoted settlements and providing them proper help on time due to the floods and damage to infrastructure caused by permafrost melt (Doloisio N., Vanderlinden J., 2020; Legendre M., Bartoli J., Shmakova L., and al. ,2013).

As we can see permafrost degradation can affect the environment and people on different scales and it is really important to find a way to mitigate global warming's effect on it. In this thesis, we will analyze how we can improve the situation, regarding permafrost degradation from the point of view of architecture. To do so, we will have a closer look at the case study, Yakutsk, to understand what challenges the city faces during the year and how global warming affects the city and its permafrost.

Photo is taken from www.arctic.ru/forumarctica/20190409/845494.html
Author - Igor Ageyenko

CLIMATE CHANGE

YAKUTSK

Photo is taken from www.gazeta.ru/social/news/2021/08/12/n_16376534.shtml
Author - Nina Sleptsova

Photo is taken from www.yakutia-daily.ru/tumany-sohranyatsya-prognoz-pogody-v-yakutii-na-26-yanvarya/
Author - Maria Vasilieva

Cities		
Moscow	6d 18h (direct)	6h 45min.
St. Petersburg	5d 9h (from Neryungri)	12h.
Vladivostok	2d 1h (from Neryungri)	3h 10min.
Kazan	4d 16h (from Neryungri)	13h 50min.
Sochi	6d 10h (from Neryungri)	10h 10min.
Yuzhno-Sakhalinsk	4d 16h (from Neryungri)	9h 10min.

Figure 8: Yakutsk position in Yakutia (marked in orange) and in Russia (marked in blue). The transport connection of the Republic and Yakutsk with the rest of the country. The map shows that the town and the republic have a poor connection with the rest of Russia. It is quicker to reach China, Japan, and Alaska than the centre part of Russia (Moscow, St. Petersburg) (The map is taken from https://masterplan-yakutsk.ru/, further changes is made by Maria Lozitskaya).

2. Climate Change: Yakutsk

2.4 GENERAL INFORMATION

Russian Federation is a transcontinental country, located in the Northern Hemisphere. With a population of 145.5 million inhabitants, it occupies 17,098,246 square kilometers. The country extends across 11 different time zones.

Permafrost occupies 66% of Russian territory (Streletskiy D., Shiklomanov N., 2016). Unlike other countries, Russian polar regions are highly urbanized. According to Colin Reisser Russian arctic region contain 72% of the artic population around the world. Moreover, local towns are highly populated. If in Alaska or Canada, towns of polar regions do not extend more than 10 000 inhabitants, in Russia these numbers can go beyond 100 000 people (Reisser C., 2017).

Exploration of the polar regions in Russia began many centuries ago, however, urbanization of these territories started only during the Soviet period. Since the North, settled by the Soviet government, was strictly planned, we can see 4 main typologies of the settlements. The first type is the large administrative centers like Archangelsk or Yakutsk. With a population of more than 350 000 people, a diversified economy, and cultural centers. The second type of settlement is mono-industrial towns. These towns were built around one, usually extractive, industry, like diamond extraction in Mirny or the mining industry in Norilsk (Fredrich D., 2019). The population is usually no more than 100 000 people and there is a vast majority of seasonal workers. The third type is towns like Devek, Chucotka which were towns with a population of no more than 10 000 people and

were planned mostly as transport nodes, and the last one – are indigenous settlements (Graybill K. J., 2017).

Yakutsk is a town located in the northeast of Russia (see figure 8), on the left side of the river Lena. Being the capital of the Republic Sakha (Yakutia), it plays an important role in the daily life of the entire republic and in Russia in general.

Despite the enormous surface of the Republique (3 084 000 km2), there is a very low density of the population. Less than a million people live in this territory (997 833 people data of 2022). The third of which live in Yakutsk.

Yakutia in general is an isolated area. As you can see from the map (figure 8) there are very few transport connections with the rest of the country and most of them are time-consuming, for example, it takes around 6 hours and 30 mins to go to Moscow by plane or 6 days and 18 hours to reach it by train. Transport connections inside the republic are limited even more. You can reach distant towns and villages by car, boat or in some cases only by plane or helicopter. Mostly, it is due to the severe climate condition and permafrost that cause a lot of problems, for example, in constructing railways.

Originally, Yakutia was inhabited by indigenous people who historically practiced transhumant horse and cattle husbandry. Knowing the particularities of the area and its climate, locals were choosing elevated places to avoid flooding. Cattle breeding required a vast amount of land and created a constant seasonal movement between winter and summer houses (Filippova V., 2020).

In 1632 Yakutsk was founded, however, for a long time, its further development and the growth of population were very limited due to the remoteness from the capital, lack of transport connections, severe climate conditions, and general lack of interest in these territories from the Russian emperor.

The establishment of Soviet power provoked the second "wave" of migration by creating forced labor camps in Siberia, Yakutia, and other remote regions of the USSR and giving special benefits, such as higher salaries, to the citizens.

Nowadays Republic plays an important role in the Russian economy, passing throw a period of change. Large administrative centers experiencing the growth of population and looking for new development plans and strategies. Mono towns are experiencing a hard time and to decline in population due to the lack of diversity in the working field, high prices, and remoteness (Fredrich D., 2019).

Despite severe climate conditions, Yakutsk is a growing city. According to the data of research for competition "masterplan" in all case scenarios, the town's population will continue growing in the following years. Mostly it is due to migration inside the republic, people from small settlements and remote areas moving to Yakutsk to find a job, receive an education, and improve their living conditions.

Nowadays life expectancy in Yakutsk is 74,47 years for women and 65,65 for men, however, there are some cases of extreme longevity, for example, Varvara Semennikova lived 117 years (10(22).05.1890 – 09.03.2008).

The official statistic shows a decline in the amount of population with age more than 90 years old (see figure 10). However, the reliability of the data from the beginning of the 20th century is doubtful. The phenomena of the longevity of the population of Yakutia intrigued scientists at the end of the 19th century, so a special commission was created and information about the age of the population was gathered for the first time. The numbers were inspiring – some people claimed to be 131 and 140 years old. However, further examination showed that the information is not reliable. Low education and the absence of a birth record made it impossible to prove these numbers. The local population was counting their age approximately from a certain age. For example, some people were telling that they must be 100 years old while in reality they were 70. Some were counting one year for two (there is a record about a boy who claimed to be 30 years old. After the request to show how he counts the age he started to count spring, summer, spring, summer, spring, summer etc.), some gave the wrong age on purpose. The last one was especially common during the First and the Second World Wars to avoid going to the battlefield and it was also supported by local government because the remote region needed working

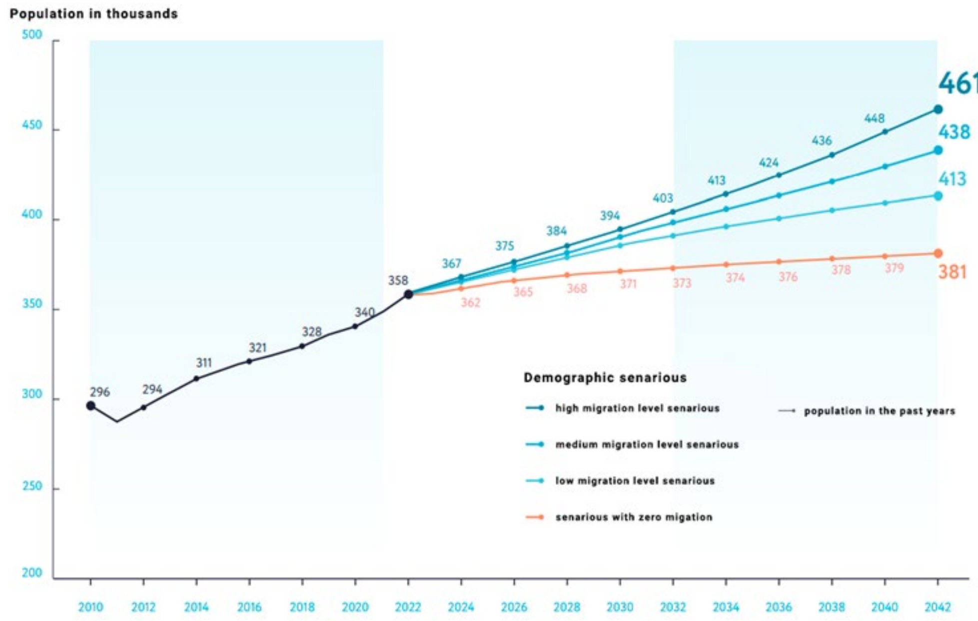


Figure 9: The population prognoses of Yakutsk in several case scenarios. As we can see, even with a zero-migration scenario the population of the town continues to increase (table is taken from the www.masterplan.ru).

power to maintain a difficult process of agriculture. So, the decline of the amount of elderly population can show just the improvement of the birth records but not the degradation of the population.

The lack of reliable data makes it impossible to analyze the effect of the building sector improvement during the century on health and life duration.

	YEAR				
	1926	1950	1970	1989	2010
Amount of people 90 y.o. and older	1248	1023	880	462	316
Including 100 y.o. and older	176	162	100	76	13
Amount of people with longevity on 100 000 of the population	529	454	308	No data	68

Figure 10: The table of comparison of the population with high longevity during the 20th century.

However, considering, the constant growth and density of the population nowadays in Yakutsk and the present problems with construction technologies, the key point in providing a sustainable future is improving the building environment and protecting permafrost.

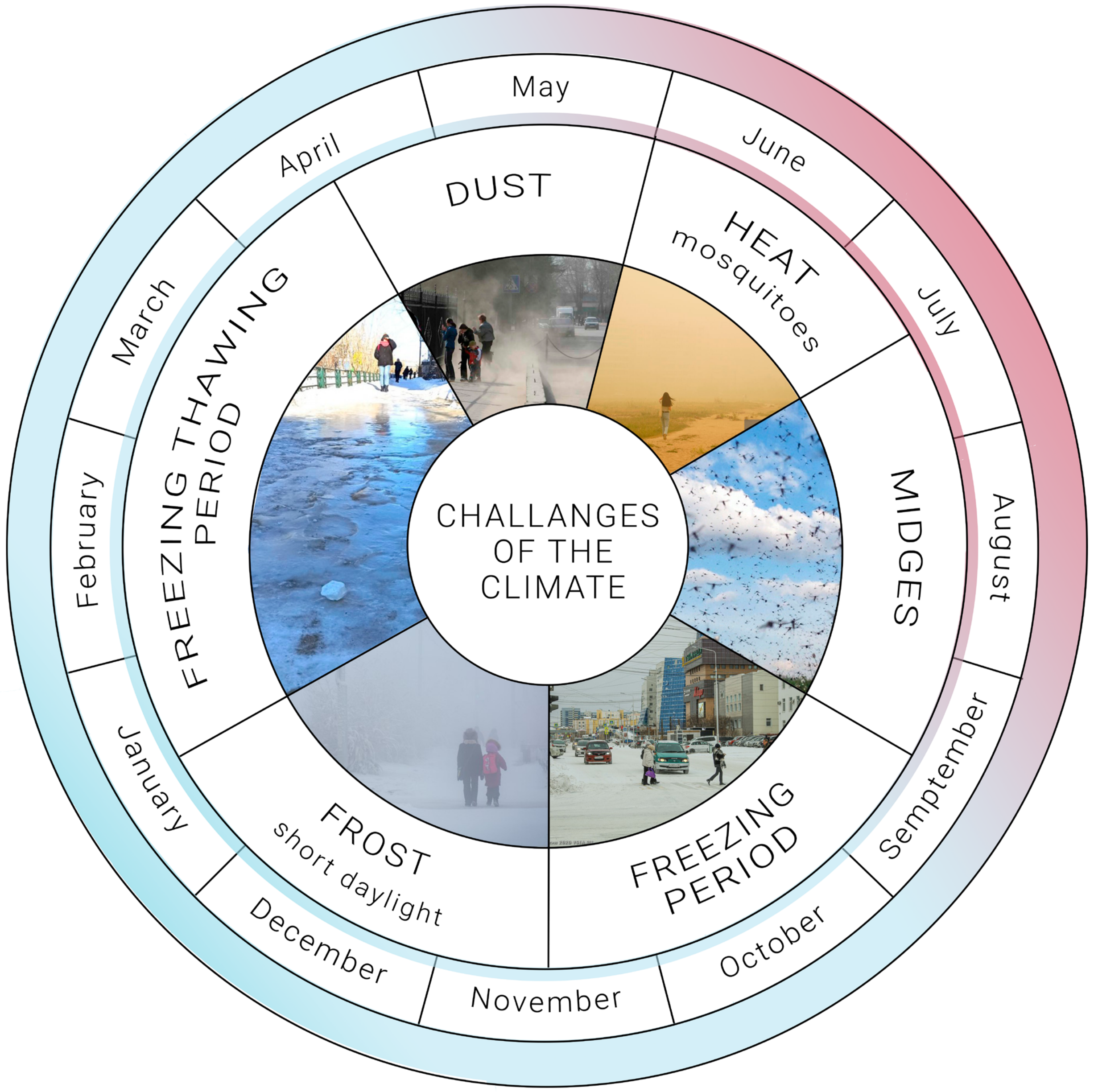


Figure 11: The scheme shows monthly challanges that Yakutsk faces each year.

Figure 12: Fog in winter reduce visibility, increase the risk of car accidents, people loss, and causes respiratory difficulties by lowering oxygen level in the air (photo by Maria Vasilieva available at https://ysia.ru/avtoinspektory-yakutii-rekomenduyut-byt-bditelnymi-pri-poezdke-v-tuman/)

Figure 13: a fish market in Yakutsk. Products are placed without any refrigerator. The extreme cold helps to preserve the freshness of the goods (photo is taken from https://www.inyakutia.ru/sights/rybnyy-rynok/)

2.5 DAILY LIFE AND MONTHLY CHALLENGES

The Yakutsk environment presents a lot of other challenges. Most of them are related to climate change, however, others were present since the city's foundation such as permafrost, severe climate conditions, and remoteness of the area. The "master plan" urban competition that took place in Yakutsk, published a diagram with climate challenges that the town faces month by a month every year (see figure 11). These severe climate conditions that are gradually getting worse due to climate change create a lot of problems for locals and for the future development of the city. Starting with early winter that comes in October (the average air temperature in October is -10°C) and lasts till the end of April (the average air temperature in April is - 5°C), going down below – 50°C in December and January (-64°C is the minimum air temperature).

In the wintertime when the temperature goes below -40°C dense fog appears in the streets, reducing the visibility up to 20 - 30 meters and causing respiratory difficulties (fog lowers the oxygen lever in the air) (see figure 12). The wind blows predominantly from the north and the daytime is very short. These create difficulties in daily life, however, also give some benefits. Due to the extreme cold, most of the population uses balconies as a freezer and it allows to create unique places like the famous fish market (see figure 13), where all products are placed outside without any special tools to preserve freshness.

The soil of that area has very high volatility and turns into dust that flies everywhere in the town as soon as it unfreezes. The summertime is short but very hot. The temperature in July can reach +35°C. The daylight lasts up to 20 hours during the summertime. Moreover, there are wildfires that happen regularly due to global warming and create a lot of area pollution.

Summertime in Yakutsk is a period of insects, particularly, mosquitoes in June and July, and then biting midges later, in August, terrorize locals both in forests and in the town. It is impossible to go outside without any spray protection (see figure 15).

Figure 14: A pedestrian way covered with dust due to the high volatility of the soil (photo is taken from https://yakutia.info/article/206174).

Figure 15: A cloud of midges in August (Photo is taken from http:// old.sakhaparliament.ru/obchestvo/2017/08/sezon-moshkaryi/)

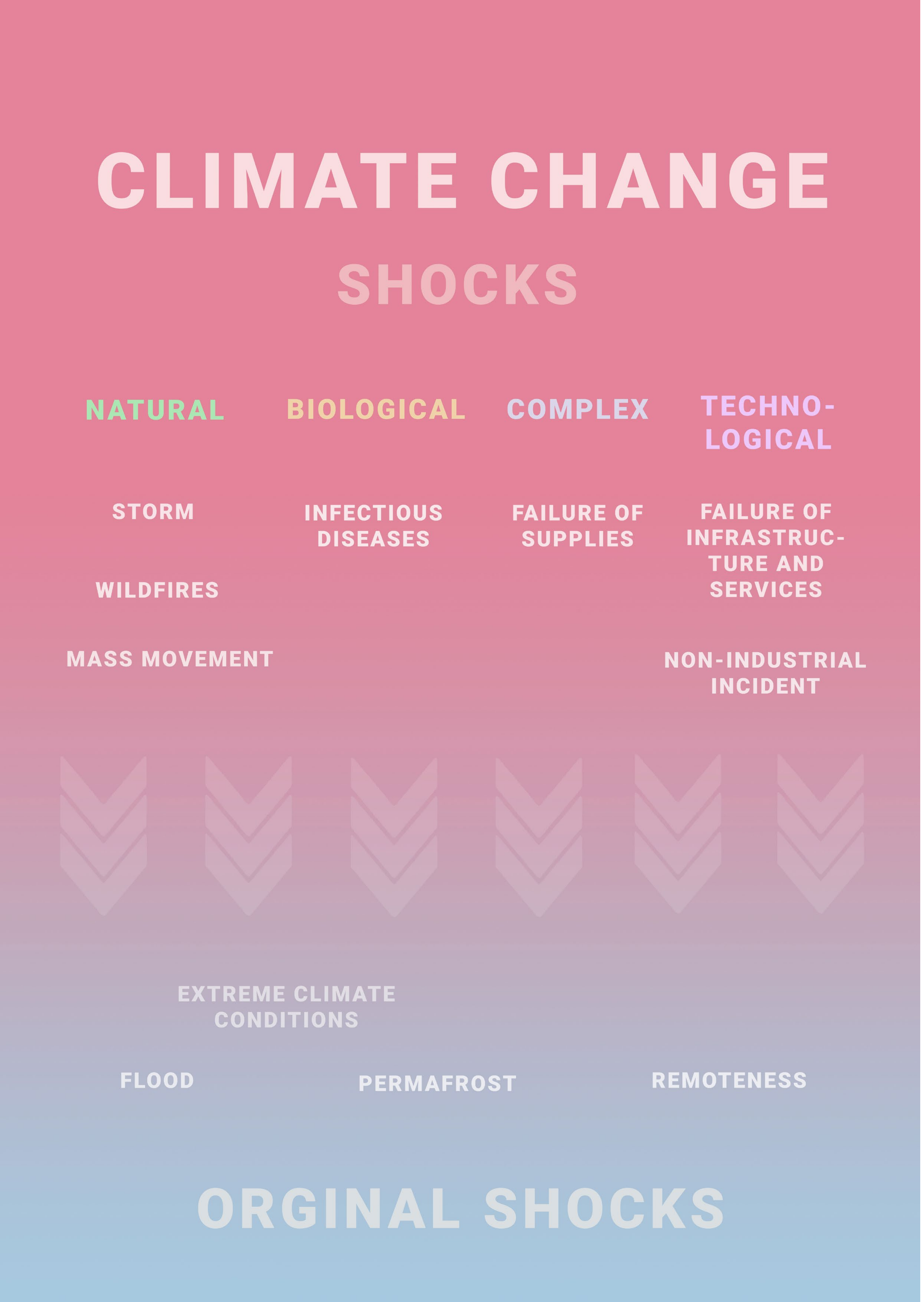


Figure 16 (on the left): Climate change shocks that Yakutsk will face in the following years (the scheme is made by Maria Lozitskaya based on the CRPT 2020)

2.6 THE RISKS OF GLOBAL WARMING TO THE CITY

40% of Yakutia is in the arctic circle which makes it very sensitive to climate change. Yakutsk is located 450 km south of the arctic circle; however, it is the biggest city in the world built on continuous permafrost. This fact and the density of the population make it highly sensitive to climate change. Depending on the scenario, various prognoses show an increase in the temperature in Yakutsk from 4°C to 8°C by the end of the 21st century (Yakutsk: Recommendation). Since the town is built on continuous permafrost, this increase can be dreadful for both locals (due to the soil instability) and people all over the world (permafrost contains GHG that will be released due to its degradation).

The CRPT identified the shocks that the city has to face in the next decade such as wildfires, fog, cold waves, extreme winter conditions, mass movement, floods, storms, infectious diseases, and food crises. Unfortunately, most of them are already happening now and moreover became normal for the locals.

All shocks that Yakutsk will face in the following years can be divided into 4 groups (figure 16). The first and biggest group of shocks is natural disasters: such as storms, floods, mass movements, wildfires, and extreme meteorological conditions.

Yakutsk was at risk of flood since its foundation (see the risk map figure 18), due to the presence of the Lena River. The territories around Yakutsk face seasonal flooding each spring (see figure 17). Ice break-up on the river provokes ice jamming in the river's lower parts, which usually reduces the flow and causes upstream flooding. Usually, there is no flood in the town itself, however, in May 2020 the river went too close to the town. The water level in the Lena River in the Yakutsk region has reached 841 centimetres, although the mark of 827 is considered dangerous (Vasiliev A., Krasikov A., 2020) (see figure 18).

Global warming can provoke more dangerous floods. Moreover, during seasonal floods, vast territories stay waterlogged for a certain amount of time, and that speeds up permafrost degradation and causes the release of GHG into the atmosphere.

Figure 17: The scheme shows zones of risk of floods and wildfires around Yakutsk. As we can see, the town is located between two risk zones (source CRPT 2020).

Figure 18: waterlogged village in Yakutia after a seasonal flood in 2018 (photo is taken from https://ysia.ru/n-fakty-i-mify-o-vesennem-polovode-v-yakutii/).

Figure 19: The river Lena went too close to the town due to the ice break and following ice jamming in its lower part. (photo is taken from)

Wildfires are common in Yakutia due to the dry climate during the summer, low precipitation levels (under 200mm per year), and huge amounts of forests that mainly consist of highly flammable Siberian larch trees. According to the research, 90% of the fires within 90km of the town are man-made accidents, outside this area only 40% of fires are caused by people, and others are caused by dry thunderstorms. Usually, wildfires happen in May and June, however in recent years due to climate change, heat waves and drought appeared and provoked wildfires also in July and August bringing the disaster on a national scale. For example, in 2021 wildfires in Yakutia spread on 4.2 million hectares, releasing 505 megatonnes of carbon dioxide equivalent (data according to EU's Copernicus Atmosphere Monitoring Service (CAM)), and beating the previous years' records (Balmforth T., 2021).

Wildfires cause the release of GHG into the atmosphere, biodiversity loss, permafrost degradation, and air pollution. Climate change puts Yakutsk in Yakutia at high risk for wildfires.

Even though Yakutia has the coldest city in the world (Oymyakon) and Yakutsk is usually considered a northern city with a quite short summer period, it still suffers from extra-tropical storms that can reach up to 18-19 m/s within the urban area, and up to 24m/s within Yakutsk Gorod. These storms can cause basic infrastructure and public services breakdown. For example, after one of these storms, more than 50 000 people in Yakutsk were left without electricity because of the local system breakdown

Mass movement in Yakutia is present by ground subsidence due to permafrost degradation. This problem is present in different scales in the cities and outside. If outside the town we can observe mass movements, river bank erosions, and wavy roads without significant damage to the locals, inside the city ground subsidence can be a serious problem and even dangerous one. Moreover, because of the higher density population, permafrost degradation and following land movements are more often inside the city.

Yakutsk is constantly facing difficulties regarding construction and building maintenance due to the permafrost and its degradation. It is common to have roads (fig. 20.1, 20.2, 20.3) and building deformation,

Figure 20: Some exaples of the deformations caused by permafrost. 1- the deformation of the pedestrian path due to the subsidence of ground because of permafrost thawing. 2 - the deformation of the pedestrian path made from asphalt due to the formation of the frost lenses and further ground uplift. 3 - the cracks on the road 4 -the crack in the building. According to the authorities, the crack has been examined and prevention measures were taken, so it does not put inhabitants of this building in danger (https://www.yakutia.kp.ru/daily/27426/4626332/). 5 - The damage to the residence building caused by the subsidence of the ground due to permafrost thawing. According to locals the crack appeared suddenly and got bigger in a few minutes. People quickly left the building and called local services to close the gas supply and avoid a bigger disaster. This situation shows that some of the buildings are in a state of emergency and need to be regularly examined and fixed. Also, permafrost degradation is a serious issue that can cause significant damage to the population (https://news.ykt.ru/article/102837). 6 - The damage to the engineering facilities due to soil instability caused leakage of hot water. In Yakutsk due to permafrost, almost all communications are located above the ground. Sometimes due to land subsidence or extreme cold, pipes got damaged, and leakage of compounds happened. In the photo, we can see the hot water leakage that has already got frozen due to the cold weather condition. These accidents speed up further permafrost degradation and cause basic infrastructure breakdown.

cracks in facades, and even the collapse of some parts of the building and engineering facilities(fig.20).

The last shock also creates some technological shocks like a failure of infrastructure and services. Permafrost and severe climate conditions, especially cold winters reduce the lifecycle of the infrastructure and increase the risk of breakdown. For example, in January 2013, a rupture of heating pipes in the Straitelmy district put around 3 000 people at risk of being left without heating under -50°C. In 2017, an incident involving the Yakutsk power plant left Yakutsk and nearby areas without an energy supply. Around 476 000 people were affected by this accident.

Yakutsk is famous for its extreme meteorological conditions, however, because of global warming it is getting worse and worse year by year. Each year Yakutsk faces cold waves, extreme winter conditions, and dense fog. Severe weather conditions also create a biological shock, increasing the risk of seasonal infection and viruses.

Also, the poor transport system and remoteness of the region sometimes create failure of supplies and further crises, like the food crisis in 2013, when transportation of goods was blocked due to the low water in the river (it was the cheapest way to deliver goods). This caused panic in the city and raise the prices.

3 ANALYSIS

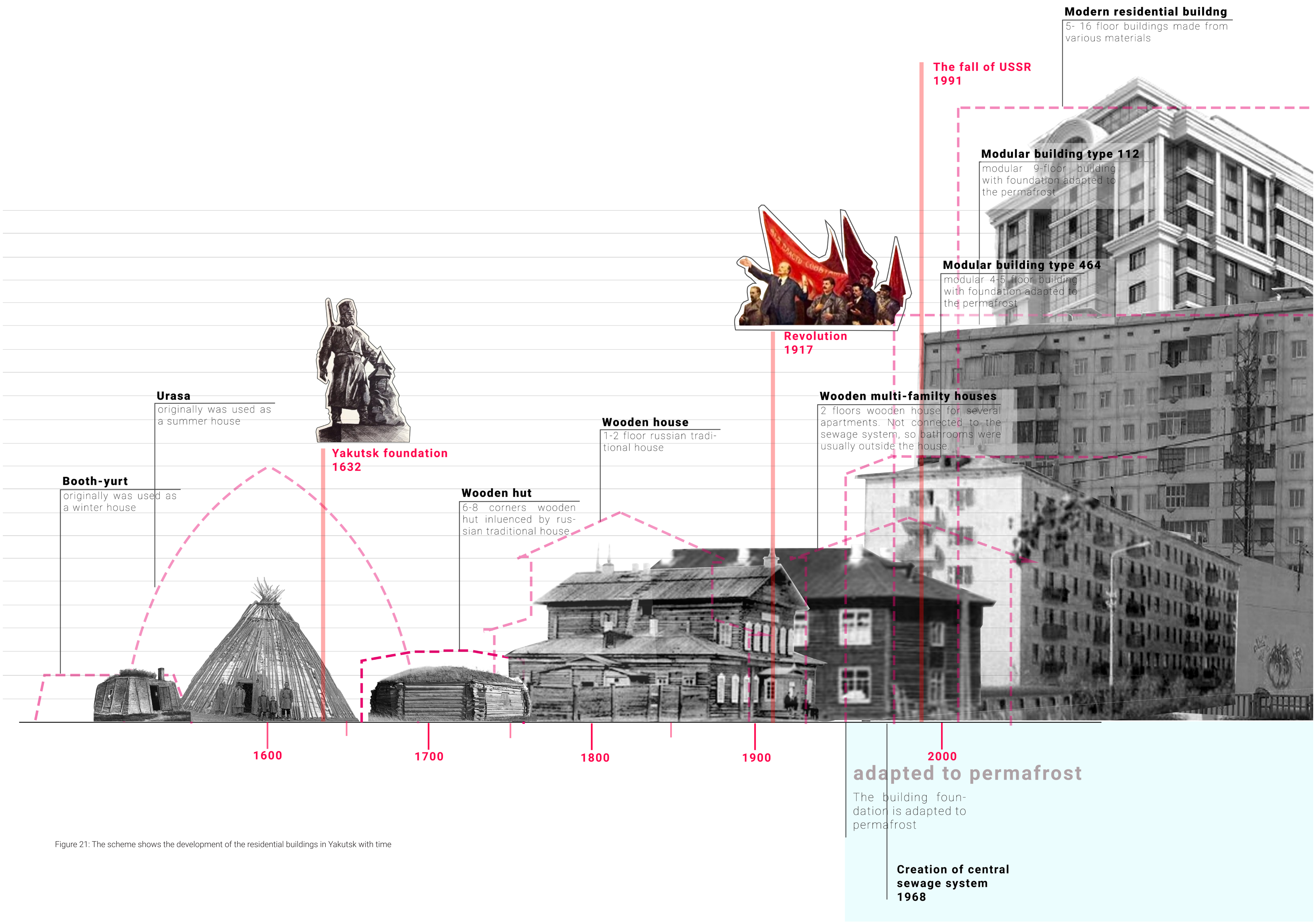


Figure 21: The scheme shows the development of the residential buildings in Yakutsk with time

3. Analysis

3.1. YAKUTSK BUILDING HERITAGE ANALYSIS AND LEGACY

Analyzing the history of building construction in Yakutsk can help us to determine good and bad strategies for permafrost preservation. By looking back to the past we can understand which building technologies worked in favor of protecting permafrost and which instead provoked its degradation. These analyses could help us to define some strategies that we can apply to nowadays constructions.

All of the residential buildings in Yakutsk can be divided into several categories, depending on the period in which they were built and the materials that were used in the construction. Most of the buildings were made during the Soviet period of "fast construction", when all the details were prefabricated at the factory and then quickly assembled on the construction field. It was so successful regarding the speed and permafrost protection that nowadays some of the modern buildings are still using the technologies of the Soviet epoque. However, not everything was built in this period. Yakutsk building heritage takes place from the traditional housing of the indigenous people that gradually got mixed with Russian traditional wooden huts. Some of these buildings are still preserved, and some are left only in drawings and schemes. With the help of written sources and photos, we can evaluate how some technological solutions could affect permafrost and how they could help survive locals in such severe climate conditions.

In this Chapter we will analyse the construction of the local residential buildings such as Booth-yurt and ***Urasa***, then we will move to the wooden hut and its local version and then we will enter the Soviet wooden and concrete buildings, and finally, examine nowadays construction.

First of all, it is important to mention that Yakutsk is quite young as a city. It is still developing and growing. It was founded by Cossacks in 1632. Before that and even after the town's foundation, the local population used to live by seasonal movement. For their buildings, they used local materials. Hard to tell if this way of buildings' construction was better for permafrost preservation. More likely the constant change of location and low density of population helped to keep it frozen. Originally, locals had two types of houses – winter, known as booth-yurt, and summer, known as *urasa*.

3.1.1 BOOTH - YURT

This typology of residential building was common in XV – XVI centuries, however, it was still used till the beginning of the XX century. The winter house, urta or balagan, or booth–yurt (the name varies depending on the source), can be built within a week. The house usually had 4, 6, 8, or sometimes even 12 structural pillars around 0,5 meters in diameter and about 1,2- 1,4 meters tall, placed into the ground at 5–8-meter distance from each other. The number of pillars depends on the family size. Then 4 structural beams were placed, the first two parallel beams and then the other two above them, to connect all beams and pillars, the beams were cut in a specific way to allow the connection without nails. In the centre of

Figure 22 (on the bottom): the booth-yurt with birch frame windows (photo is taken from https://varandej.livejournal.com/1139336.html) the structure, from north to south, the main - roof beam was placed. This was the structural part of the house (see figure 26).

The walls were made by covering the structure with vertically raised logs. These logs were placed with a small inclination towards the centre of the building that was made to allow sunlight to warm the walls. The house had 2-3 small windows on the walls, the north wall was left untouched. The windows were covered by different materials to keep the transparency such as ice blocks, oiled paper, swim bladder, mica, or even have them completely unfilled in a warm period of time. The material for the window depends on the time of the year and the availability of the materials. Later, with the influence of Russian culture, locals started to create birch cork frames and sew pieces of glass in them with horsehair (see figure 22, 25).

The door was made in the centre of the east wall and was also inclined as all walls of the building. The door was made from leather stretched over the wooden frame.

The roof was made in a similar way, logs were laid on the center beam of the roof, creating a pitched roof. After creating the structure of the future building the roof was covered with a 60-70 cm layer of pressed ground. The walls were covered with 10 - 15 cm of clay, mixed with straw, and sometimes manure. Usually, the floor was just pressed ground, however, sometimes to keep the house warmer it was covered with straw.

Figure 23 (on the left): The traditional winter house (the photo is taken from the official website of the museum "Druzhba" www.museumdruzba.ru/?p=3216)

Figure 24 (on the left): The interior of the traditional winter house (the photo is taken from the official website of the museum "Druzhba" www.museumdruzba.ru/?p=3216)

Figure 25 (on the right): The birch frame of the traditional winter house (the photo is taken by Nina Frolova from https://archi.ru/russia/image_large.html ?id=163842)

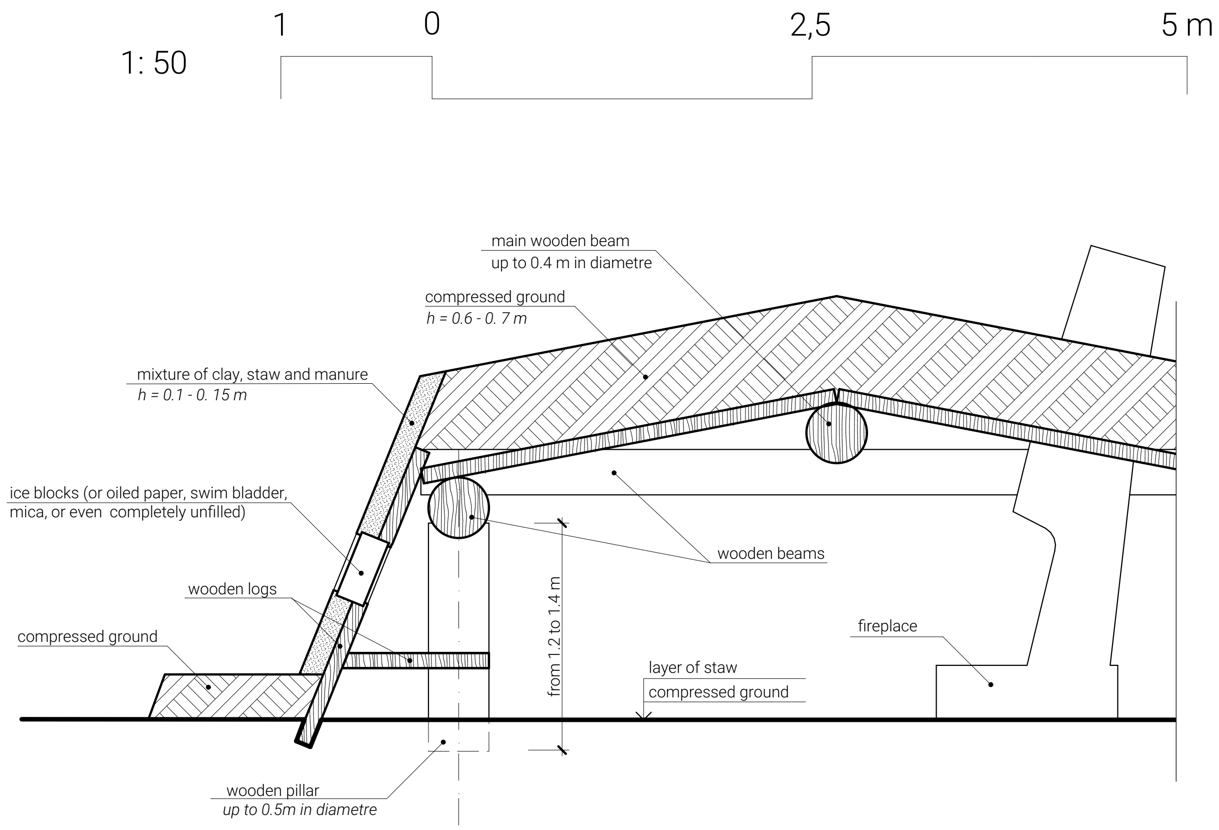
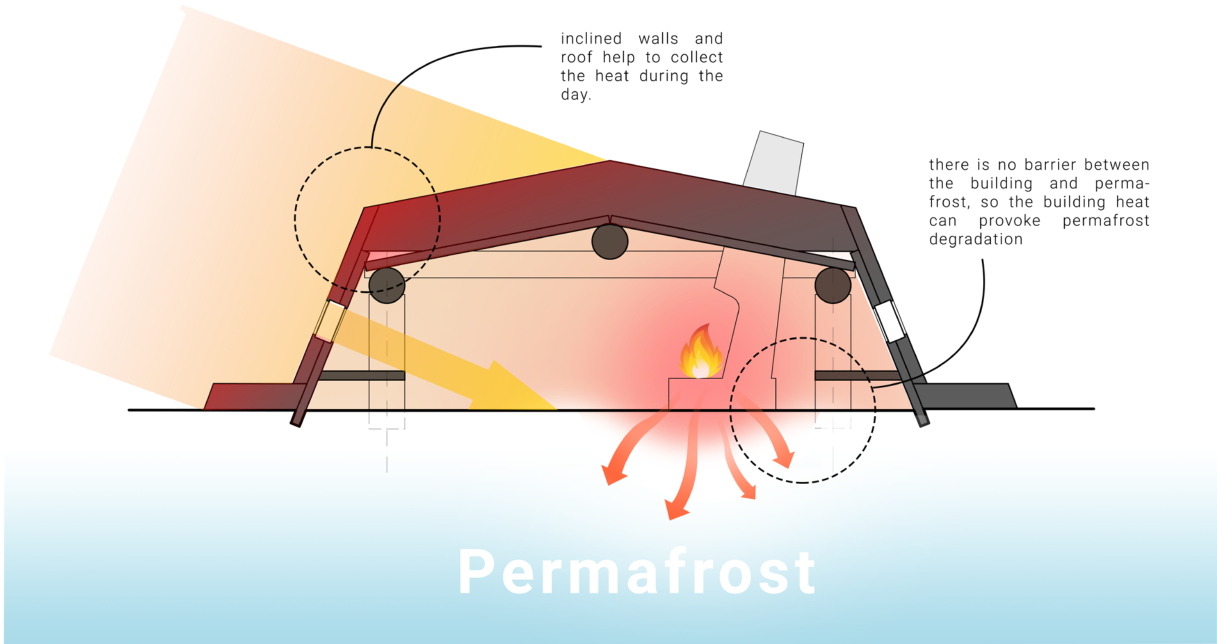


Figure 26 (above): Section of the construction of the booth-yurt on scale 1:50. The drawing is made based on written sources and photos by Maria Lozitskaya

Figure 27 (on the bottom): the scheme of the balagan that shows how inclined walls and roof help to preserve the heat of the building and how the building heat provokes permafrost degradation.



In the beginning, the fireplace was in the centre of the building, however, with time it was moved into the corner that is closer to the entrance. The fireplace is made from clay and capable of fast warming the house. However, as soon as the fire is gone, it gets cold inside the structure.

To have extra insulation the pressed ground was placed around the house. Also, in some cases, an additional structure for animals was built from the north part of the building.

This type of residential building has several good aspects. First of all, the speed of construction and use of local materials, made it easy to assemble the house in a short period of time and almost everywhere. The building envelope was made regarding the climate conditions. The walls were inclined to let the sun warm them during the day and a high percentage of the opaque building envelope helped to preserve the heat inside. However, this type of residential building was built regardless of permafrost. The house stays directly on the ground so the heat of the building melts the permafrost beneath it (see figure 27). However, due to the small scale of the house and constant seasonal movement, this probably wouldn't cause any serious problems.

3.1.2 URASA

The summer type of house, urasa, was a house with a diameter of 10 meters and a height of about 11-12 meters, was made with logs and birch cork that were previously soaked and cooked till it turns soft and elastic.

Figure 28 (on the right): An example of traditional summer house – urasa, made in our days (photo is taken from https://usksuntar. ru/ objects/37-stroitelstvo-obekta -berestjanaja-urasa-balagana-i-otsypka-territorii-v-pkio-s-suntar. html)

The building construction started with the structural part. In this case, the house had a circle in the plan. It was made from several pillars with a maximum height of 2 meters. Usually, there were 12 pillars that create the base of the house. They were joined together with 2-3 poles in the circle on top.

To make the walls thin and flexible poles were placed around, connecting by horsehair with the structural part of the house and with the upper ring on top that was made the same way that the middle pole ring but smaller, and with the bigger pole ring on the bottom of the building. In this way, the structure had a dome shape with a hole on top.

Then the structure was covered with birch cork that was previously soaked in the water. The pieces of cork were placed starting from the bottom of the structure in the way like nowadays the tiles are placed: the upper layer was placed in a way to cover a bit the lower layer, to avoid leakage during the rain. When the first layer of cork was placed, the structure was covered again with vertical poles. The poles were placed in between the first pole structure. And the last layer was birch cork again, placed exactly like the first layer.

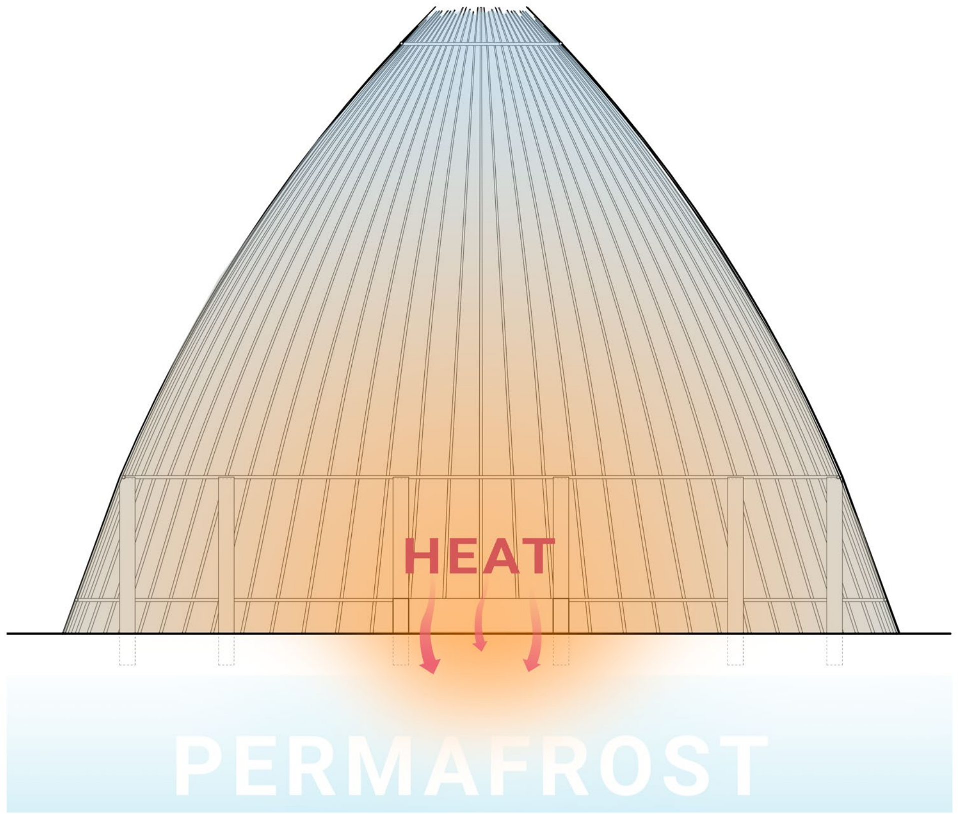


Figure 29 (on the left): the scheme shows the effect of the urasa on permafrost

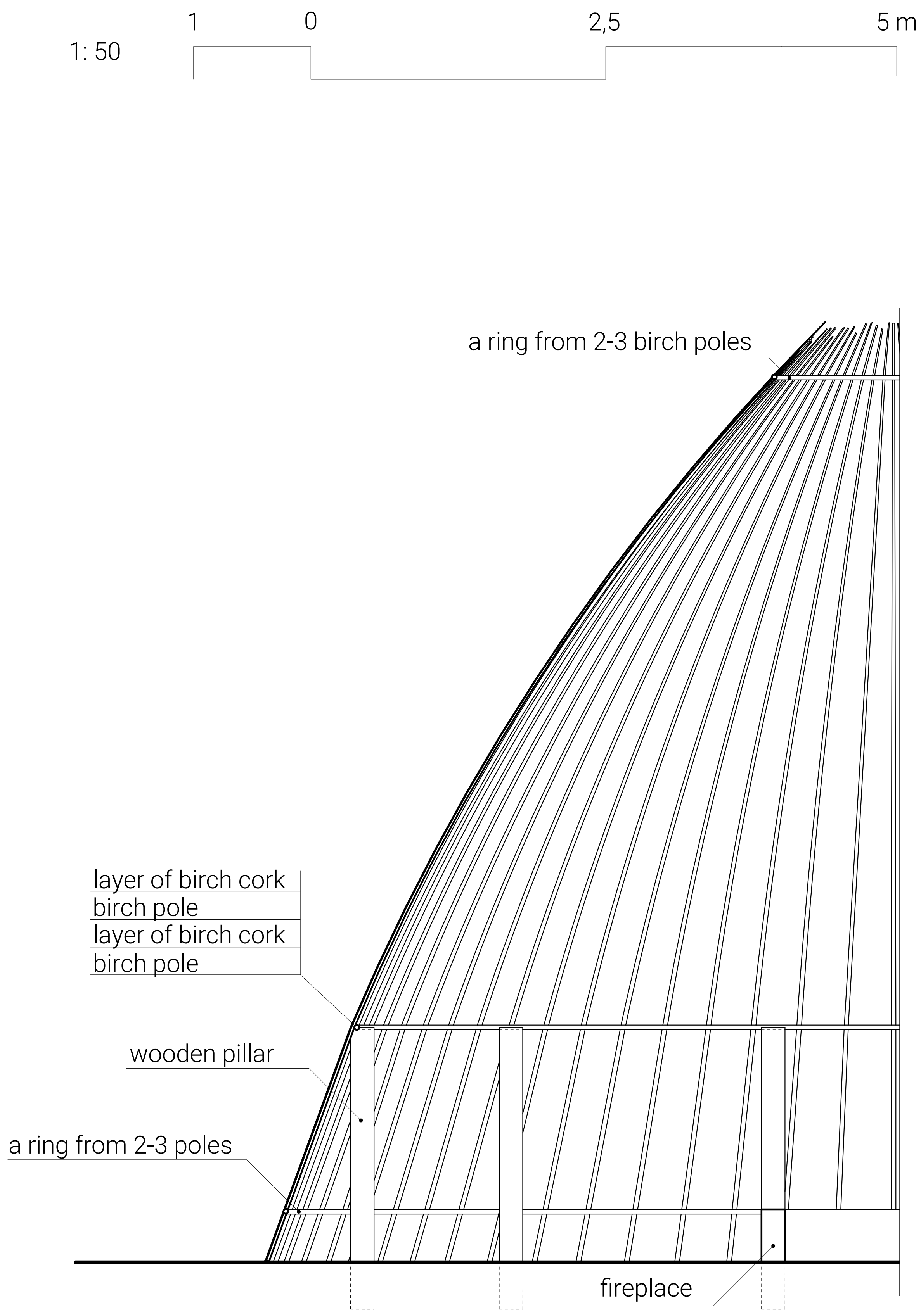


Figure 30: the section of the urasa on scale 1:50 made by Maria Lozitskaya based on the building description.

The door usually was cut on the west part of the building. The fireplace was placed in the centre and usually was 2 meters in diameter. The base of it was made from wood and then it was covered with clay. The hole on the top of the building worked as a chimney by letting smog from the fireplace go away and also gave fresh air to the inhabitants.

The structure was around 10-12 metres tall and allowed up to 100 people stayed inside. However, the building process was quite long and urasa gradually disappeared from daily life. Later it was built mostly in rich families as an extra structure of the household as a simbol of the wealth. For the actual summer house, locals started to use the same structure as that booth-yurt but a lighter version (without covering it in clay).

The urasa's strong points were the use of local materials, fully opaque building envelope that helped to keep the structure cool in the summer time and the mobility of the structure. The building could be disassembled, moved to a new place, and then assembled again. It had the same disadvantages as the previous type of building – balagan. Since the building was placed in the ground without any basement or floor that could isolate the heat of the fireplace from the ground, the permafrost beneath the structure was suffering from the heat from the fireplace. However, it was not as severe as in the case of balagan, since urasa was used as a summer house and did not require heating. The fireplace was used just for cooking.

Urasa stayed in the local culture as a traditional and sacred shape of the building and we can see how its shape is still used as a symbol in the modern architecture of Yakutsk (Aleksandrova). For example, figure 31 shows how conic shape of the traditional sakha building was used as the entrances shape in the local stadium (see figure 31).

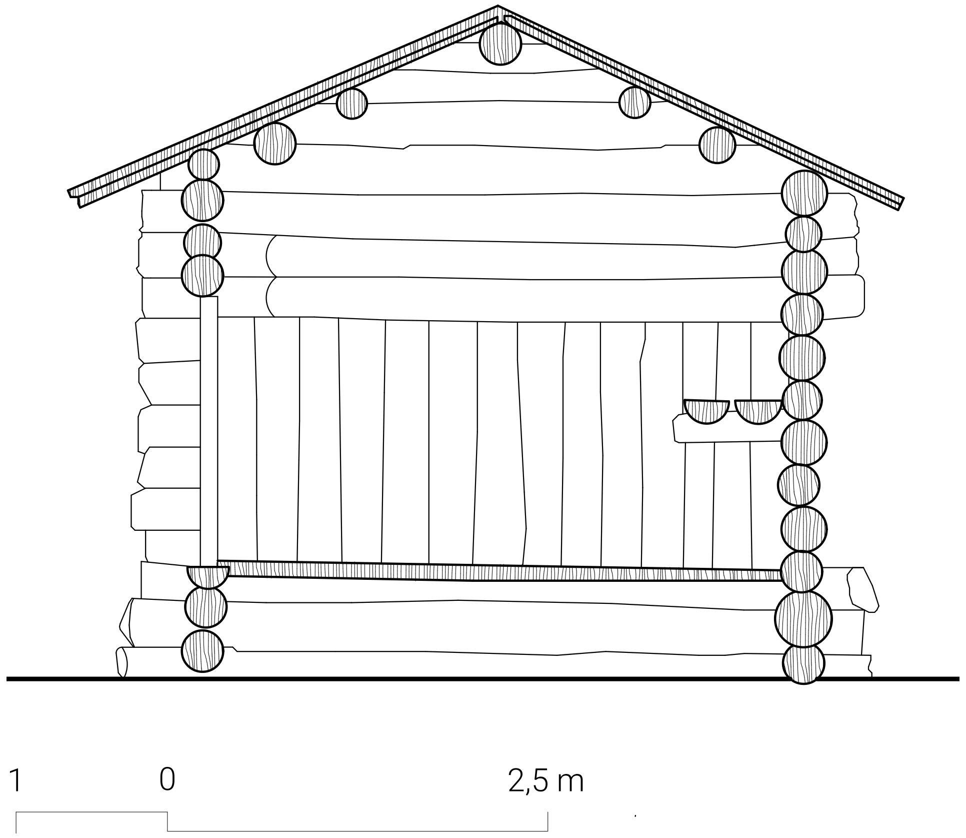
3.1.3 WOODEN HUT

The conquest of these territories by Russians and the foundation of the first town there in 1632 brought a new typology of the residential buildings – "Izba" or wooden hut (figure 32). The most common type was a five-wall wooden hut – square in the plan with a fifth wall inside to divide the space into two rooms. These cabins were built with logs (usually 20 – 30 cm in diameter) laying horizontally and connecting with each other by cog joints without the use of any nails. The most common joint in the North of Russia is presented in figure 33. The buildings were not adapted to permafrost; however, this type of house had a basement that lifted the "warm" part of the house from the ground and provided passive protection to permafrost (figure 34, 35). From time to time the buildings still were suffering from ground subsidence due to the permafrost thawing but not as much as if the building had been located directly on the ground without a basement.

Gradually, locals, influenced by Russians, changed the appearance of their traditional residence houses, creating a mix of Russian traditional hut and their own urasa (figure 36). For their new dwellings, the local population

Figure 31 (on the left): An example of the use of urasa shape in the modern stadium. The entrances to the stadium are made in semi-cone shape that should remind about traditional heritage (photo is taken from https://www.modernglass.ru/projects/sportivnyy-kompleks-triumf/).

Figure 32 (on the right): A house of Molchanov. An example of the hut. (photo is taken from https://yakutia-daily.ru/chto-tayat-v-sebe-starye-zdaniya/).



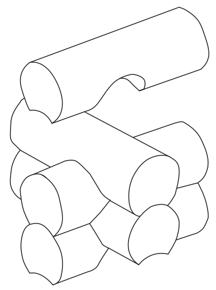


Figure 33 (above): The scheme of the cog joint for the traditional hut(https://hometi.ru/the-construction-of-the-walls/the-technology-of-cutting-the-frame-into-a-bowl-of-marking-video-preparation-of-logs.html)

Figure 34: A section of a traditional five-wall hut. As we can see the structure is completely built by logs of 20 – 30 cm in diameter.

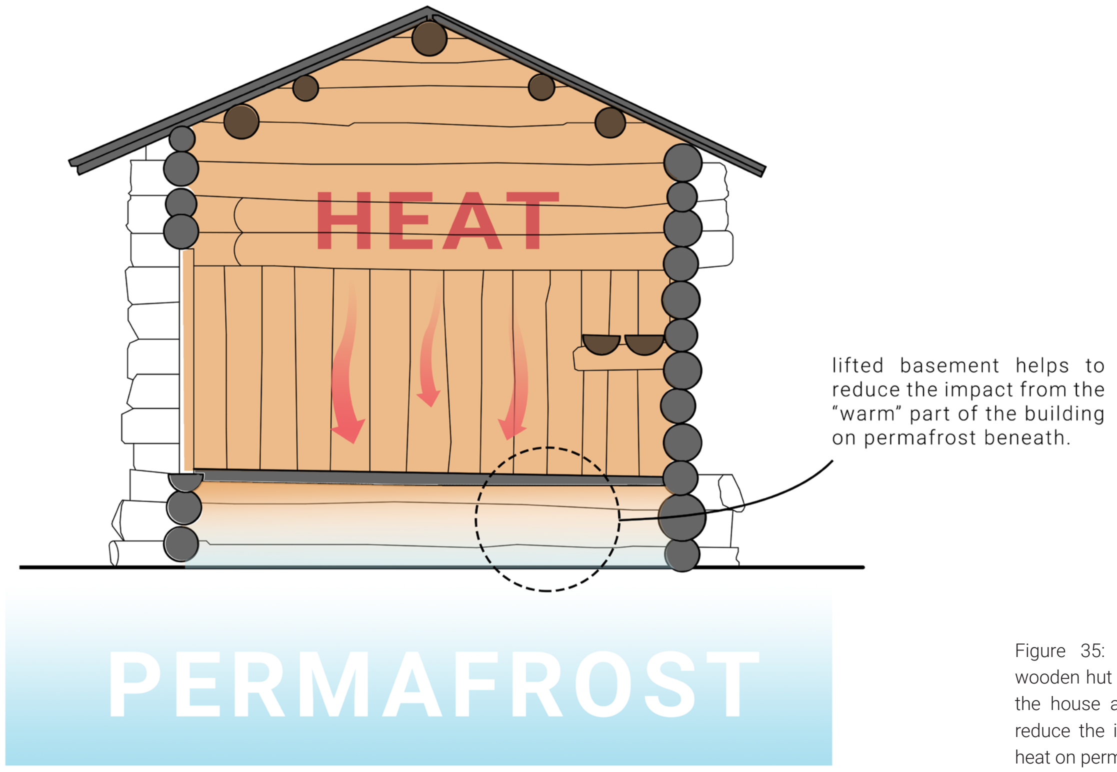
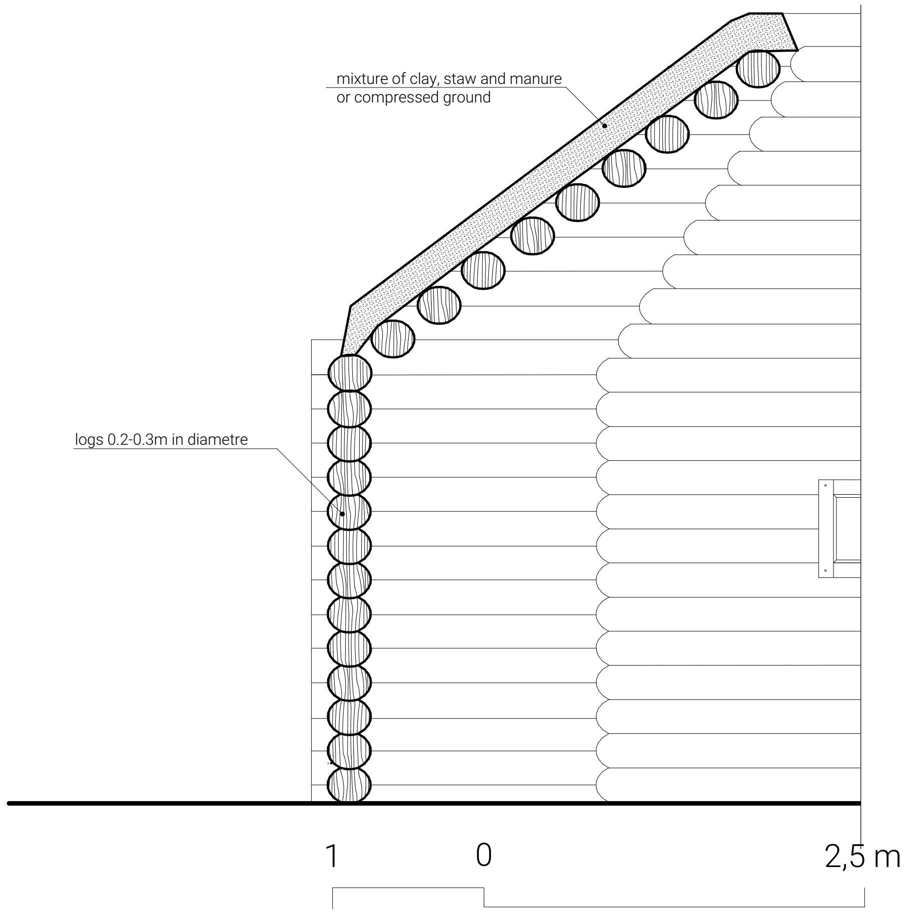


Figure 35: The scheme of the wooden hut that shows how lifting the house above the ground can reduce the impact of the building heat on permafrost.

Figure 36: a section of a "wooden urasa". Locals combine together two typical residential buildings: urasa and traditional Russian house. The dwelling has a similar to the Russian wooden hut construction method where logs were connected by cog joint, however, the house does not have a basement and the roof is following the shape of the traditional summer house of the local population – urasa with layer of the pressed ground for extra insulation.



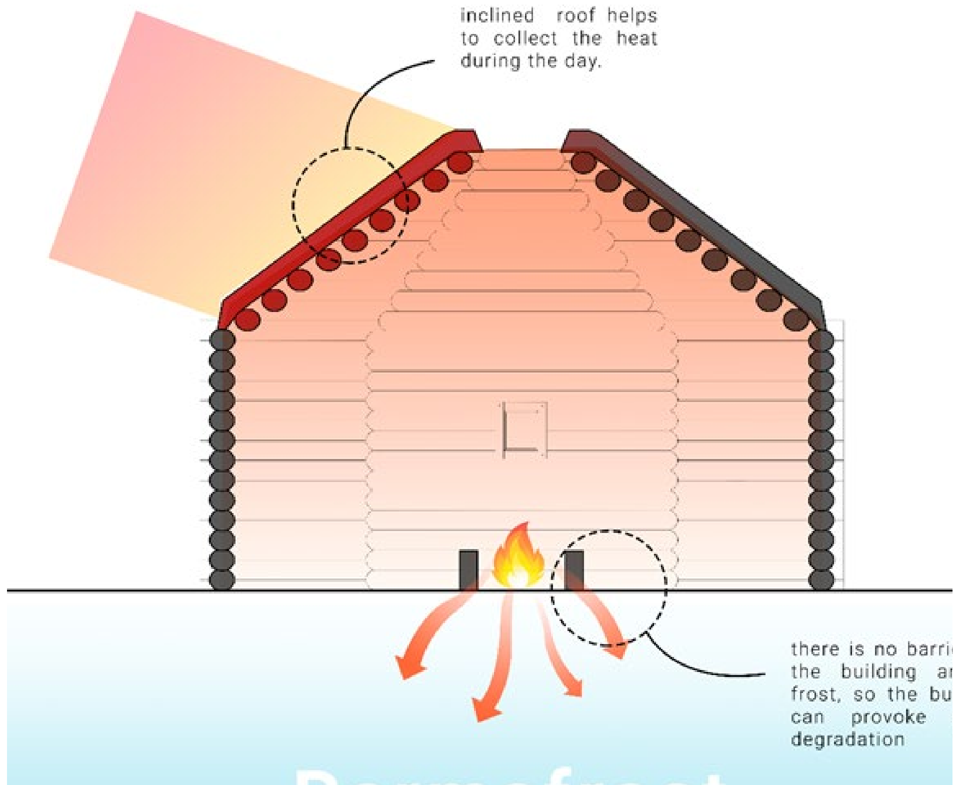


Figure 37: The scheme shows the negative and positive aspects of the new dwelling. The inclined roof with compressed ground keeps the building warm, however, due to the lack of foundation the heat from the building and from the fireplace is directly transferred to the ground and causes permafrost degradation.

Figure 38 (on the left): an example of the "wooden urasa", a dwelling of locals (photo is taken from https://nazaccent.ru/content/25155-kogda-udar-molnii-blago.html).

Figure 39 (on the left): An example of Sakha house built in 1881 (photo from https://kartarf.ru/dostoprimechatelnosti/226177 - shestigrannyy-derevyannyy-dom-roda-sosinyh).

used not 4 or 8 corners building structure but 6 (see figure 36, 38, 39). The house was a maximum of five meters tall and had one door 90 per 110 cm and one or two windows 35 per 40 cm. The reduction of the window's size, compared to the Russian traditional hut allowed to keep the precious heat inside during the winter.

The roof of the house sometimes was covered with clay and pressed ground to provide better insulation.

Unfortunately, their version of the wooden hut was worse for permafrost, since they did not use any foundation, and the new type of dwelling was placed directly on the ground as its predecessors (figure 37). Since the house was used all the year, the heat of the fireplace eventually melted the permafrost beneath.

These three types of buildings seem to be long – gone past, however, they were still used at the beginning of the XX century. There were 1114 buildings in Yakutsk by the end of the XIX century, 128 of which were traditional winter houses of the locals, 961 of them were built from wood and only 25 buildings were made of bricks (Opolovnikov A. V., Opolovnikova E, 1983).

3.1.4 TWO – FLOOR WOODEN BUILDINGS

The establishment of the Soviet Union and its industrialization provoked the growth of the population in the towns. To face the increased demand of the population for the housing, Soviet Union changes the housing - building policy. From now on, architects work all together on designing houses and other types of buildings for mass production all over the country. This sort of centralization helped to provide in very short time affordable dwellings for the population.

The lack of materials pushed architects to focus on wooden housing since the wood was relatively cheap and, moreover, available in every region, including Siberia and the Far North where transportation was especially complicated due to the lack of infrastructure, weather conditions, and remoteness of the territories.

Generally speaking, a traditional wooden hut, which usually hosted one family, was developed and transformed into a several-flat-building. Architects continue to experiment with the plan and construction methods to achieve the best results in terms of speed of the construction, house capacity, and availability of the materials.

The first series of the building were constructed in the same technique as their “ancestor” – a wooden hut, with timber logs and cod joints. Some mineral wool was placed between the timber logs to avoid heat losses. Sometimes facades were covered with wooden slabs for flat surfaces. The houses continued using the stove heating and did not have any sewage and water supply. Usually, these facilities were shared and located outside of the house in the common yard. Moreover, Yakutsk by itself, did not have a sewage system till 1968, due to the permafrost. So, it was common for the locals to use cesspools and water tanks outside the houses for their needs.

Adaptation of buildings to the permafrost and its preservation from the heat were not a goal of these mass constructions. However, the fact that the building was raised 60-80 cm above the ground (as a traditional wooden hut), could help to keep the permafrost frozen (see figure 42) but in reality, the lack of insulation of the houses led to overuse of the heating system and as a result, provoked permafrost thawing underneath of the buildings, land subsidence and buildings’ collapse. The residential houses of that time are famous for their sinkage. Nowadays, the entrances to these houses are located lower than the ground level, even if all of them have raised foundation.

The foundation of these buildings could be done in two ways. As it was said, it was made from wooden logs (treated or not) and could reach 60-80 cm (see figure 43). While in the traditional wooden hut, it was kept empty, here it was fully or partially filled with a mixture of sawdust and ashes. Ashes were used to keep mice away from the structure.

Also, there was an additional structure around the perimeter of the house constructed from wooden bars and filled with sawdust. It was supposed to keep cold winds away and protect the building from moisture. However, despite all the measures, this type of foundation was not good enough for these climate conditions and the foundation’s logs often went rotten and

Figure 40 (on the right): An example two-floor wooden building (photo is taken from https://trinixy.ru/143466-ekskursiya-po-17-kvartalu-yakutska-85-foto.html).

Figure 41 (on the right): An example two-floor wooden building (photo is taken from https://news.ykt.ru/article/91316).

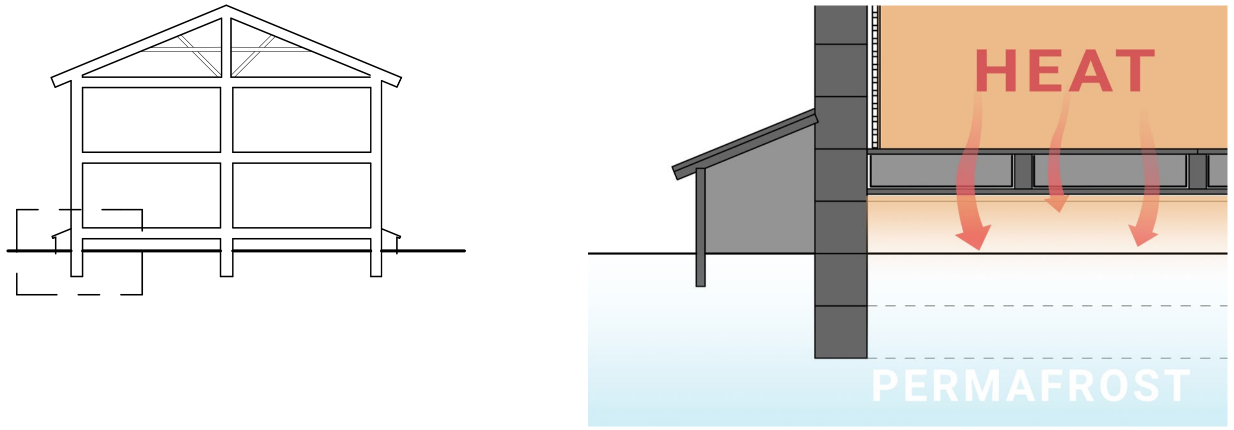


Figure 42 (on the left): A scheme shows the positive effected of raised foundation. The air gap works as barrier for the building heat, protecting permafrost from thawing. In real conditions, however, due to the overuse of heating system, this air gar was not enough to prevent permafrost degradation .

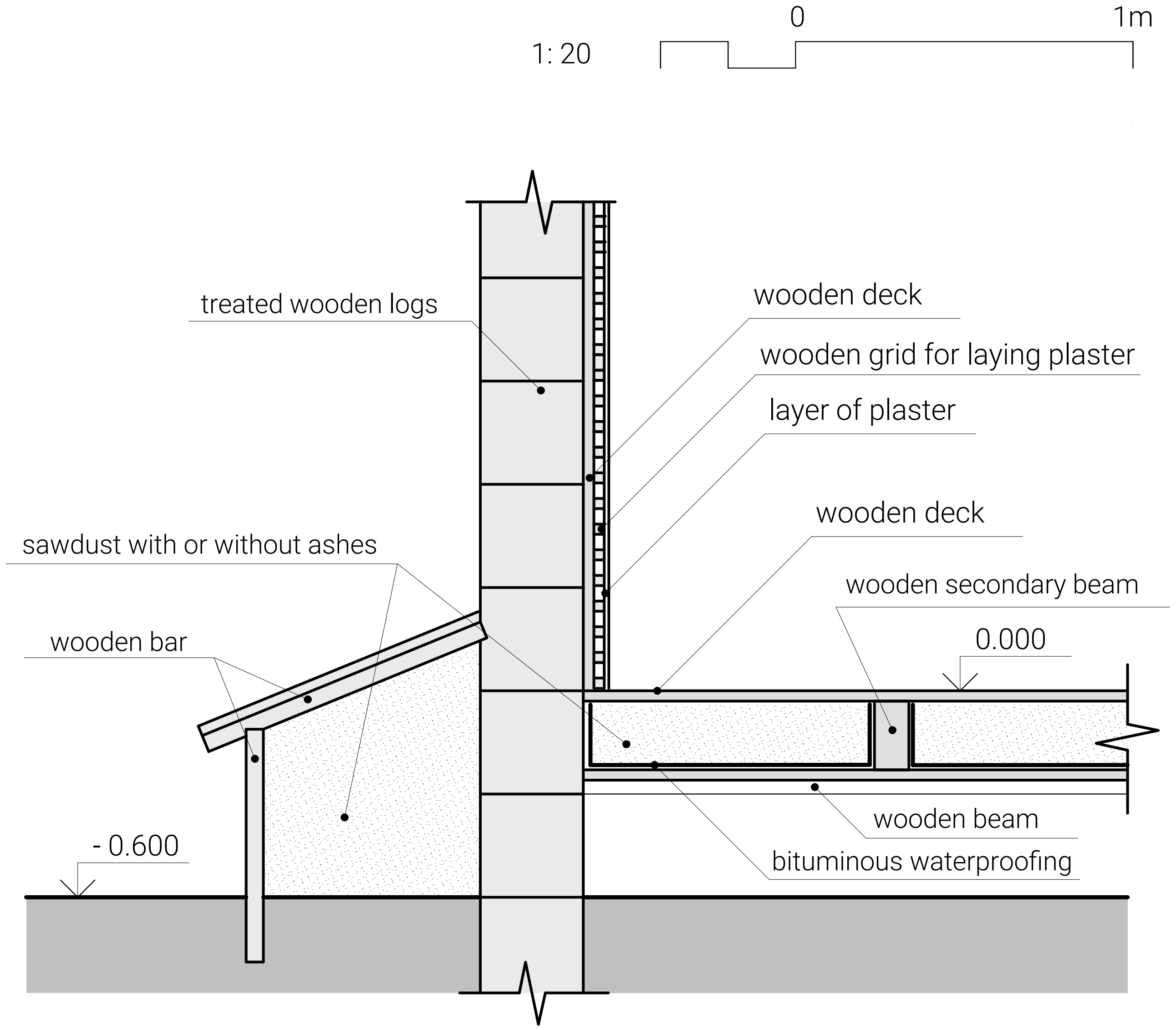


Figure 43: An example of foundation of the wooden house, where the basement is partially filled with sawdust and ashes. Section is made by author, based on written sourses and photos

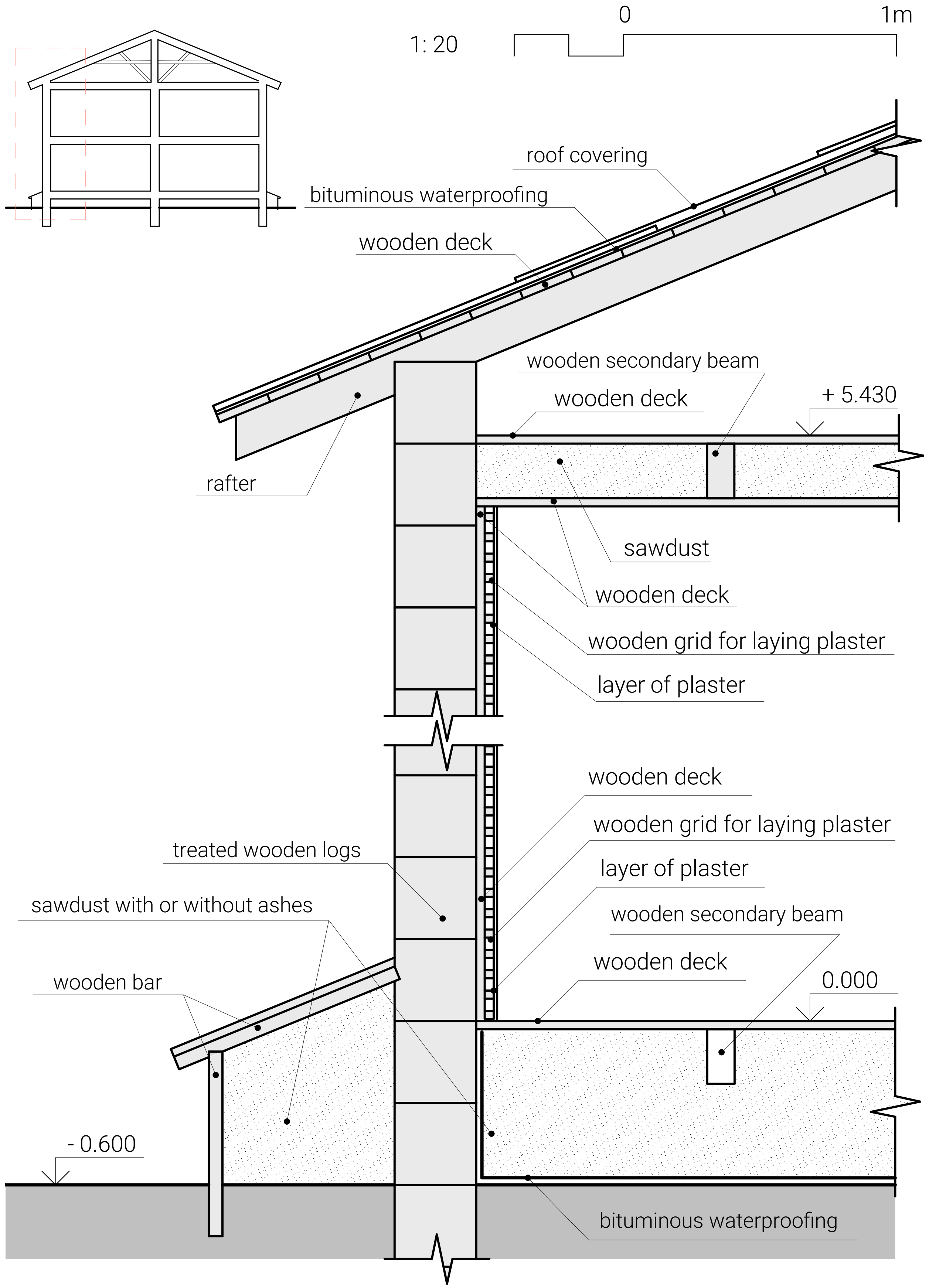


Figure 44: A section of the two 'floor wooden house construction (made by Maria Lozitskaya based on written sources and drawings)

required change each year. To do that the building was uplifted, rotten parts were removed and new ones were placed.

With the development of the nearby factories wooden logs started to be treated and now could be with a square section 30 per 30 cm. That simplified the construction process. You can see the wall structure in the figure 43.

Also, to reduce the price of the buildings even more, sometimes the walls were built just with wooden slabs, that created outside and inside surfaces of the wall, and the space in between was filled with compacted sawdust. In this way, the height of the wall was growing gradually to make the process of sawdust compression easier for the workers.

The floor and the ceiling were built as in the figure 44 wooden deck laid on the secondary wooden beams and the space in between was filled with sawdust. The buildings had a double-pitched cold roof, without any insulation.

With time houses were involved as did the city, so the next series of buildings had a water supply, central heating, and later sewage. These buildings managed to solve the issue of lack of housing and provided apartments to the population in a short time, however, in the context of the permafrost, this type of dwellings was negative. Lack of insulation, overuse of heating, and contact with the ground, all of that had provoked the permafrost thawing and led to new issues both in construction and environmental fields.

3.1.5 MODULAR MULTI-STORY BUILDINGS OF SOVIET EPOQUE

Lack of finances, industrialization, and a high demand from the population for new dwellings provoked the mass production of modular buildings. At first, it started as an attempt to have unified staircases and façade panels just to simplify and speed up the building process, but then, with time it grew into a fully industrialized process with the Central Committee of the CPSU, planning institutions, factories, and workers. Architects and engineers were designing different types of buildings, trying to create the best option for both the government, budget, and people.

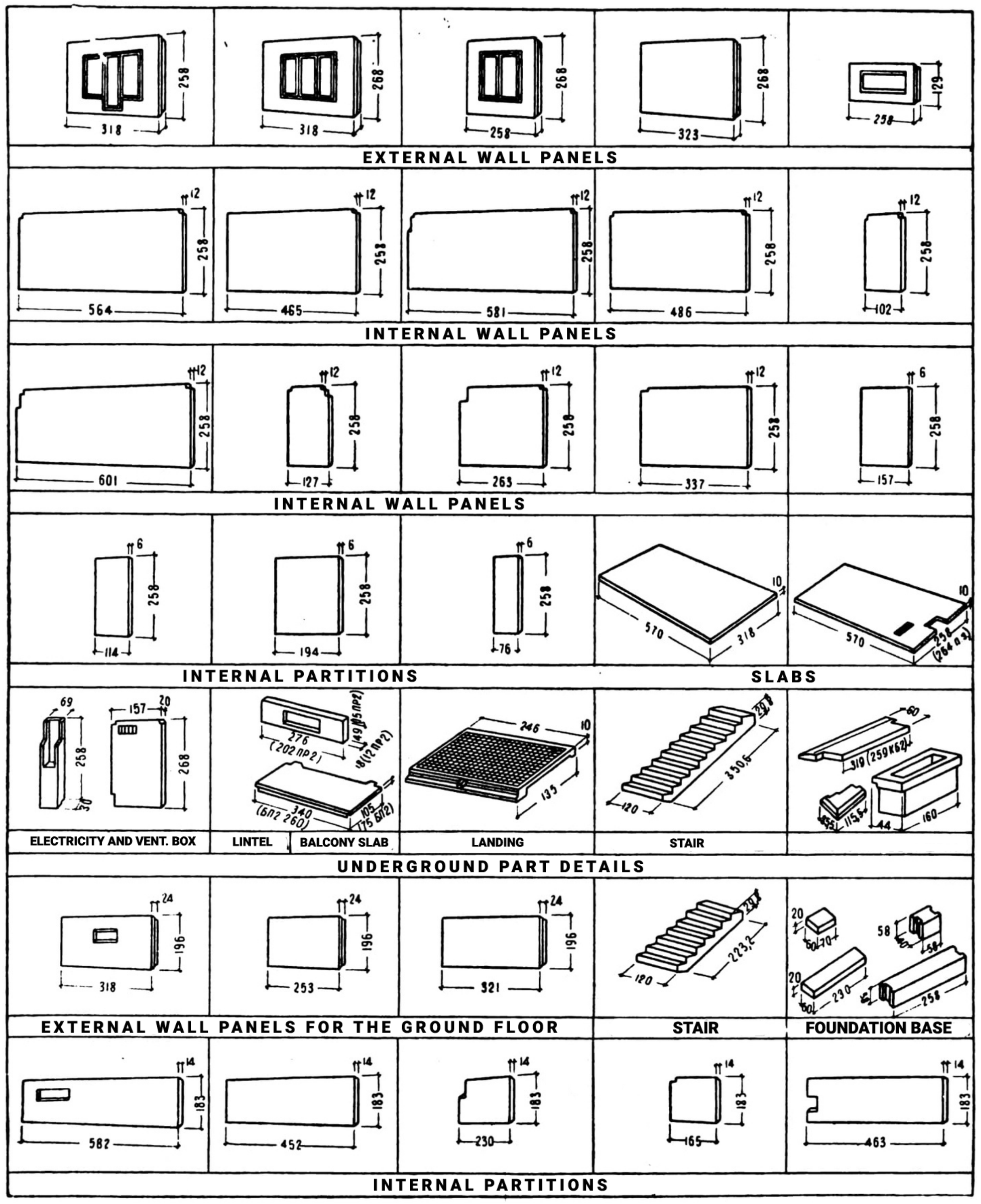


Figure 45: A catalogue of building details for the residential house type 1-464. All of these details were prefabricated. Workers just had to assemble them on building site. (figure is taken from Moiser, 2015)

All details for construction were pre-fabricated and workers needed just to assemble them in the construction field. The process was so well organized that to receive a building permit, all you had to do was to show how the future house would be connected to the city communications such as sewage system, water supply, electricity, and so on. Right after that you would receive all necessary drawings and needed details to assemble the building.

The speed of construction, its simplicity, and low cost started a boom in mass production in the USSR. The ability of the buildings to adapt to different climatic zones, family situations, or even typologies, created a boom in the construction of these buildings.

The series 1-464 received its popularity all over the Soviet Union, including Yakutsk. The simplicity of the construction's details, reasonable use of the materials, and similar weight of the building's elements allowed to speed up the building process and make it relatively cheap.

Figure 46 (on the right): A photo shows a modular building type I-464-BM (BM stands for «permafrost» or «вечная мерзлота» in russian) in Yakutsk (the photo is taken from https://vk.com/photo-1618109_457343095)

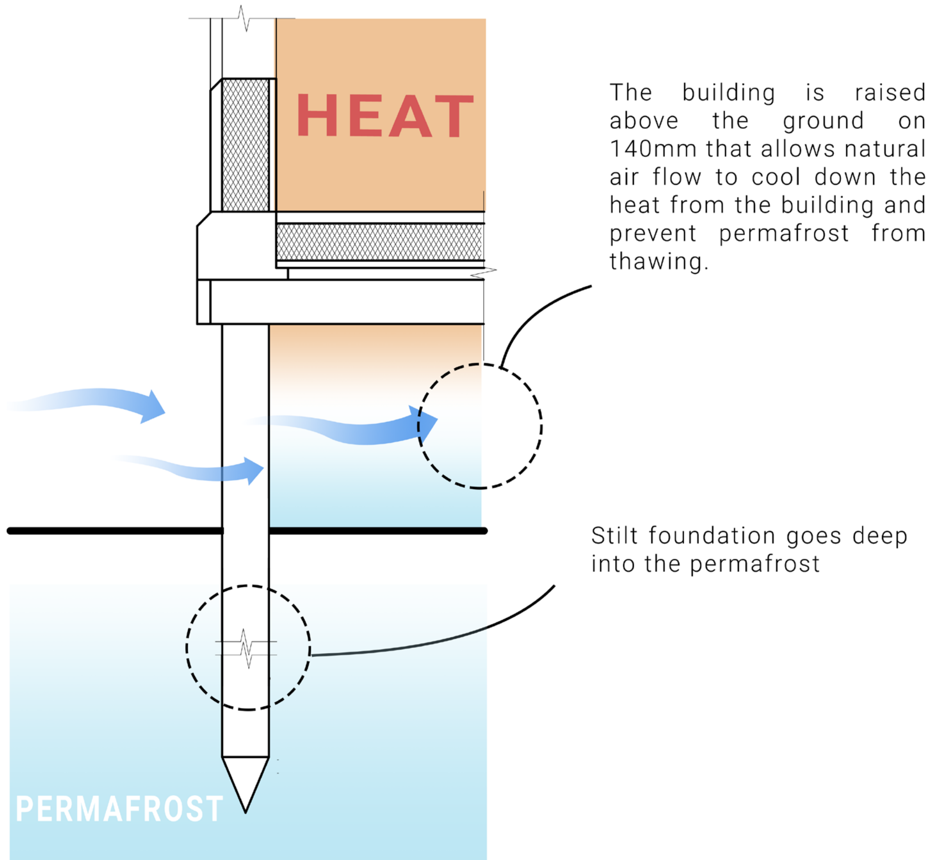


Figure 47 (on the left): A scheme of the stilt foundation. The gap between the ground and the buildidng allows natural air flow to cool down the heat from the building. Stilt foundation usually lay directly on permafrost. In this case it is very important to keep permafrost frozen, else it can affect not only the environment, but also the safety of the building.

Figure 48 (on the right): A photo shows a modular building type 112 (photo is taken from https://vk.com/album-1618109_117055616)

Moreover, for the first time, mass-production buildings were adjusted to the climate conditions. A modified version of the series 1- 464, was 1-464-BM (BM stands for «Вечная Мерзлота» which means permafrost in Russian). The original version of the building was put on a stilt foundation that allowed isolation of the heated part of the building from permafrost and natural ventilation that could reduce the heat transfer to the ground. Knowing the importance of protecting permafrost from heat, soviet architects added extra insulation on the floor slab of the first floor to prevent heat transfer into the ground.

Buildings type 1-464-BM were firstly 4 floors and lately 5-floor-tall. The stilt foundation, laid of permafrost, created an uplift of the building by 1,44 meters for natural airflow. It formed a grid of 2,6 per 3,2 meters. Almost all the walls in the building were bearing loads and the floor slabs were laying on all of the 4 walls that formed a room. The first floor was not a residential one. It was used to shelter all engineering communications since they could not be put underground.

Knowing the nature of permafrost and its sensitivity to temperature changes, soviet engineers decided to divide the building into several separated thermal blocks each 9 – 12 meters. That means that the house had several completely structurally independent parts. You can see expansion joints on scheme 49, that divide the building into three parts. Since the structure is fully independent, the building has a doubled stilt foundation at these points.

The buildings have 3-6 entrances and could be formed from several blocks with 4 types of apartments from different family compositions (1,2,3 and

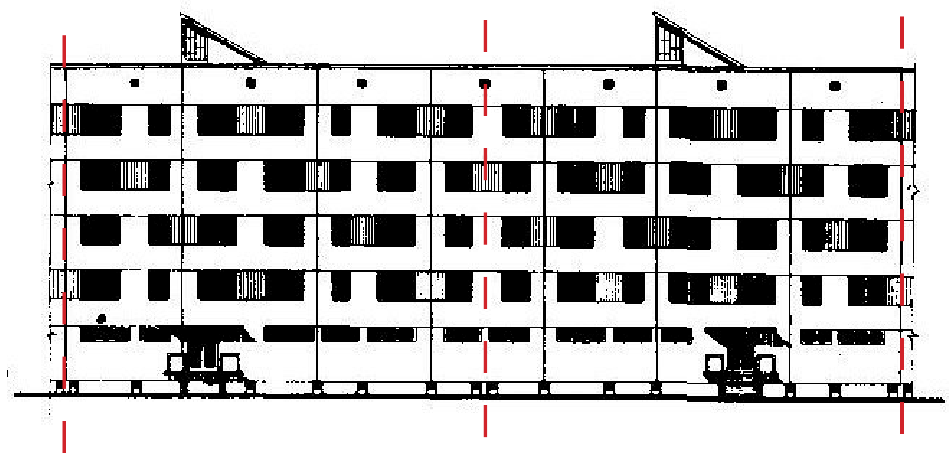


Figure 49 (on the right): A scheme shows the location of expantion joints in the building.(photo is taken from https://vk.com/album-1618109_117055616 with further editing by Maria Lozitskaya)

4-room apartments + kitchen). The centre blocks of the building usually had a combination of apartments 2-2-3-3 and the border blocks had 1-1-4-4 room apartments. The walls were made from sandwich panels that consisted of reinforced concrete, insulation material, and concrete again. In Yakutsk, it was popular to use expanded polystyrene of 250 mm for insulation. The space in between the wall panels also was insulated with expanded polystyrene.

Most of the heat losses were in the window areas. To improve the situation, specific windows were installed (see Figure 54). The window had two window frames. Outside window frame with single glass and inside doubled window frame.

With the development of the design institutions, a new series of residential buildings were created and, at this time, they were designed specifically for the severe climate conditions. Series 112 was one of them. Architects supposed that the people of the North USSR regions spent most of their time inside the building, so it had to become bigger – the floor height was increased up to 3,0m and the surface of the flats was generally enlarged

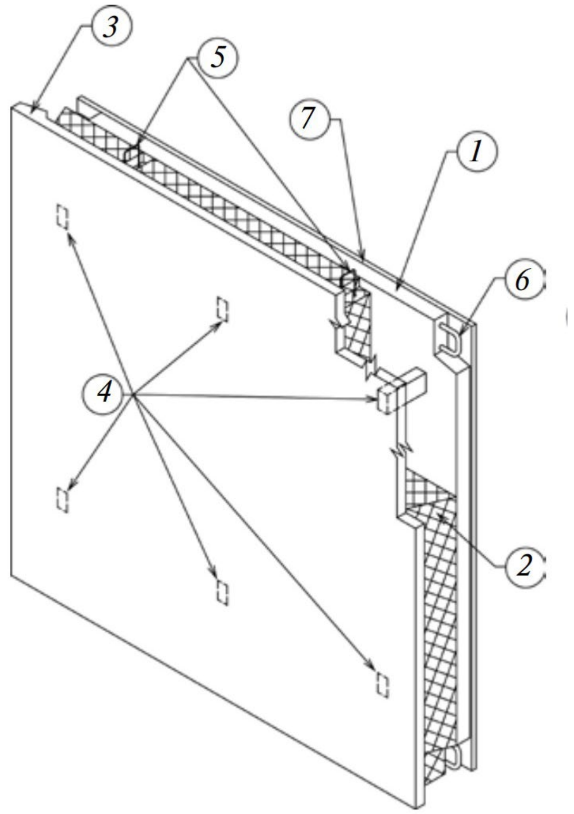


Figure 50 (on the left): the typical wall of the building type 112: 1 – inner reinforced concrete panel, 2 - polystyrene foam insulation, 3 – outside reinforced concrete panel, 4 – connections from reinforced concrete; 5 – metal loops; 6 – metal connectors.

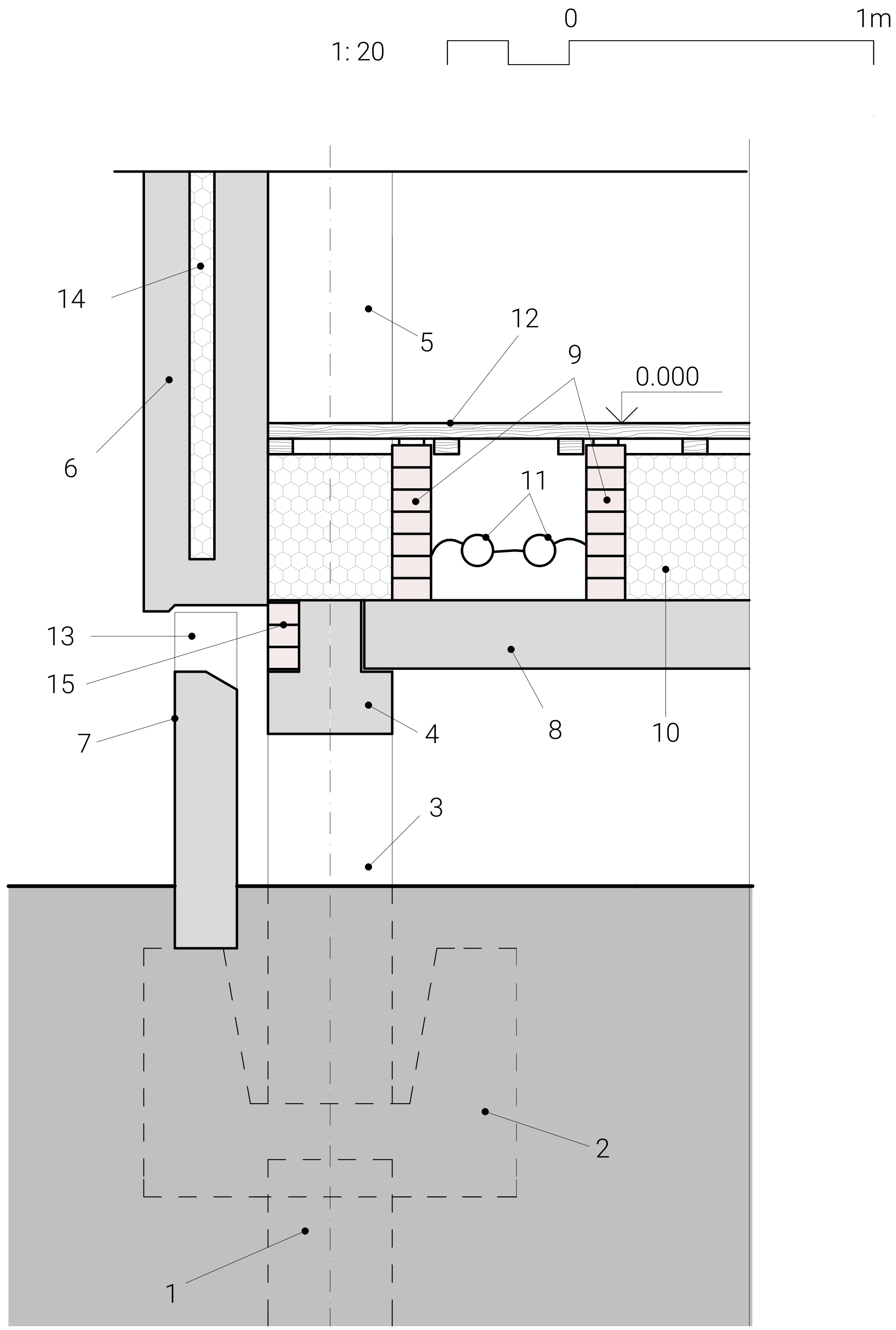


Figure 51: A detail of the stilt foundation: 1- stilt, 2- grillage, 3 - colunm sill, 4 - header, 5 - column, 6 - wall panel, 7 - basement screen, 8 - slab, 9 - brick wall, 10 - foam glass insulation, 11 - pipes, 12 - wooden floor, 13 - ventilation, 14 - polestyrene foam slab, 15 - bricks (Vaskovskij A. P. Shkliarov N. D. 1979)

by 10%. They also reduced the size of the windows to reduce heat losses.

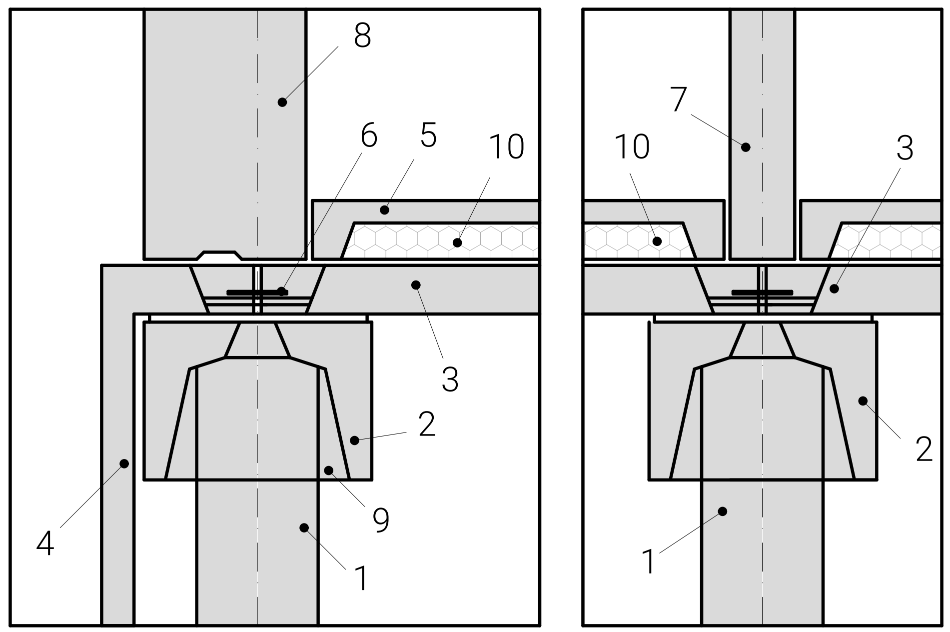
The stilt foundation also had some changes. On schemes 51 and 52 you can see how the structure is involved. These changes allowed the reduction of the materials used for the foundation and also to speed up the building process.

Moreover, the development of technologies allowed the wide steps of the stilt foundation grid. From now the foundation columns have to be with steps of 2,4m; 3,0m; 3,6 m in one direction and 3,0; 5,1; 6,6 meters in another in 4 -floor building and with steps of 3,0; 3,6m in one direction and 6,0; 7,2m in other direction for 9 – floor buildings. That allowed a wider range of design options. Moreover, the height of the building changed as well and now could host more people (9-floor building).

Walls also were made as sandwich panels with a layer of reinforced concrete, a layer of polystyrene foam, and another layer of reinforced concrete. A building could be 4 or 9 floors in height.

Modular residential houses, built in the Soviet epoque, managed quickly to solve the situation with a lack of buildings, by proving cheap and highly adaptable projects. As we can see all the design solutions were developing in the direction of cost reduction and an increase in the construction speed.

Figure 52 (on the right): A detail of the stilt foundation: 1- stilt, 2- pile head, 3 - slab, 4 - basement screen, 5 - ribbed floor slab, 6 - connection joints, 7 - inner wall panel, 8 - external wall panel, 9 - concrete, 10 - mineral wool (Vaskovskij A. P. Shkliarov N. D. 1979)



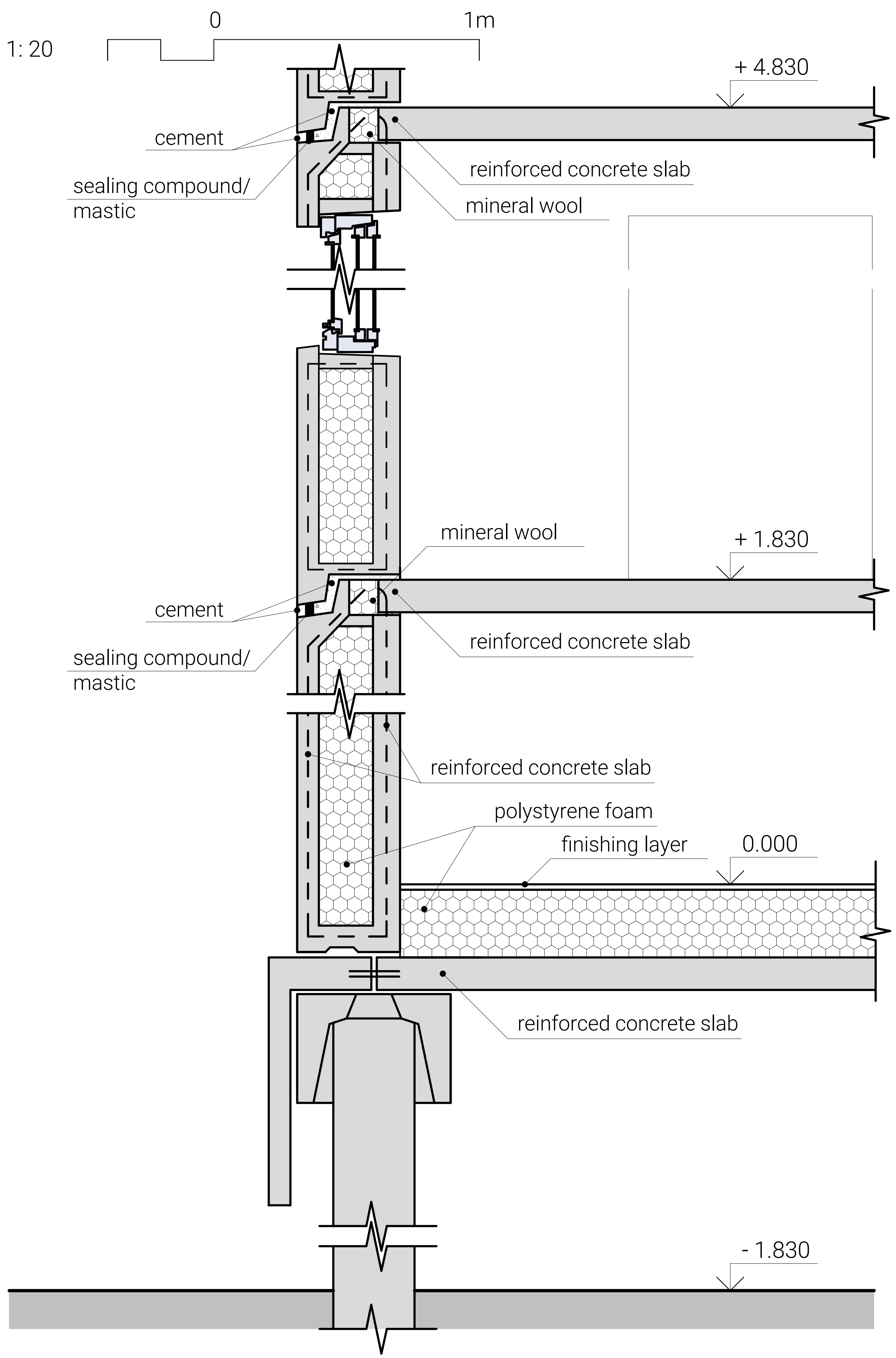


Figure 54 (on the left): a section of the mass production residential builbding type 1- 464BM. (The section is made by Maria Lozitskaya based on written sources and available drawings).

However, this time, the buildings were adjusted to the existing climate conditions: stilt foundation, natural ventilation, and an efficient building envelope to prevent heat transfer.

Nowadays, despite the Soviet architects' and engineers' efforts, these buildings are not good enough for the existing situation: global warming, poor maintenance of the structure and time did their job and now we can observe cracks in the walls and foundation, building subsidence, linkage of the hot water from the pipes and so on.

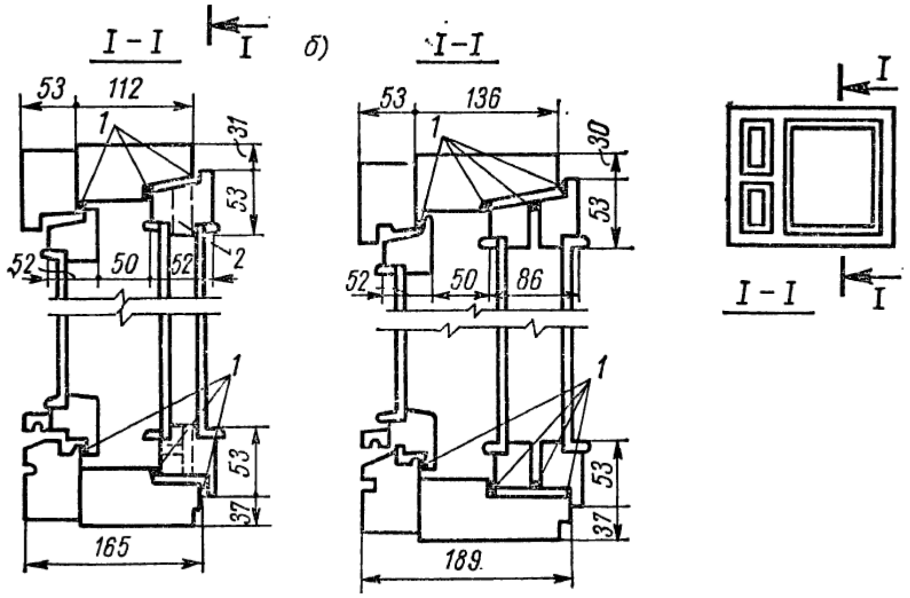


Figure 53 (on the left): windows construction. A window usually had two window frames, outside one had a sigle glass and inside - double. Extra space between the frames helped to reduce heat losses: 1- foam rubber seals, 2 - ventilation gap (Vaskovskij A. P. Shkliarov N. D. 1979)

3.1.6 NOWADAYS CONSTRUCTION

Modern architects have already started to search for a new path for the Yakutsk, trying to add some colors to the soviet buildings and revive the almost-lost identity. Nowadays we can find a lot of traditional ornaments and shapes in the local architecture (see figure 55). A lot of buildings are covered with coloured glass that represents ice and diamonds (Yakutia is the largest diamond producer in Russia).

New planning decisions can help both prevent permafrost from thawing and provide comfort to the population. Nowadays we can notice two tendencies in new constructions. The first one – continue experimenting with uplifting the building higher and higher above the ground. Sometimes it is done just by increasing height of the stilt foundation, sometimes by adding extra non- residential floors.

For example, the building, presented on the figure 56 has a triple-level platform to protect permafrost from heat transfer from the building. The first level is pillars to provide natural ventilation, the same level as we used to see in most buildings. The second level is heated parking. A heated parking is very important for this area, since the car could not be turned on in winter if it stays outside without any protection for too much time. The third level is non-residential buildings like offices and shops. And residential floors go after. This distribution of the functions allows a gradual reduction of heating power from the residential floor to the parking, to have less heat transferred to the ventilated floor and later to the permafrost.

One of the common ways to build a house in permafrost is to combine brick walls with reinforced concrete pillars and beams cast-in place.

Another trend is, otherwise, reducing the height of the building and coming back to 5-floor buildings and use of natural materials in the facades (see figure 59).

There is a new residential district in Yakutsk that used another planning decision to improve accessibility. As we know, buildings in Yakutsk are

Figure 55 (on the left): a photo presents decoration of the building by use of coloured glass and traditional ornaments (a photo is taken from https://sakhalife.ru/wp-content/uploads/2020/07/img_8242-2.jpg).

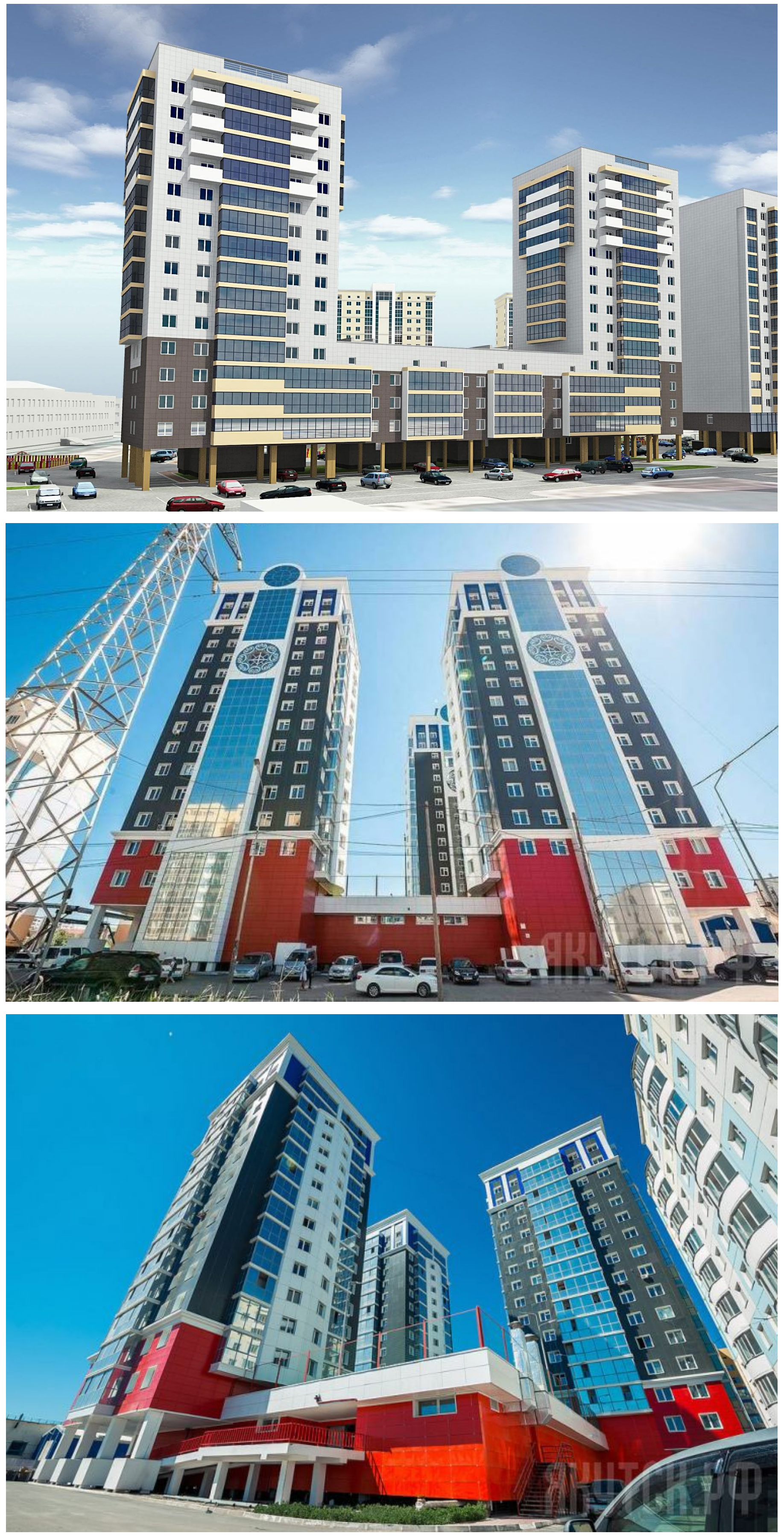


Figure 56 (on the right): photos show the modern residential building built on triple-level platform to avoid heat transfer to the ground (photos are taken from https://aartyk.ru/kiin-kuorat/gorodskaya-sreda-yakutsk-v-poiske-novyh-arhitekturnyh-reshenij/).

Figure 57: nowadays situation of the construction field of new district. The entrances are made from the ground level allow to make this district accessible for the disabled part of population (photo from https://ysia.ru/pode zdy-bez-lestnits-chistovaya-otdelka-i-ozelenenie-kakim-budet-mikrorajon-zvezdnyj-v-yakutske/)

Figure 58: perspective view from the project(photo fromhttps://ysia.ru/podezdy-bez-lestnits-chistovaya-otdelka-i-ozelenenie-kakim-budet-mikrorajon-zvezdnyj-v-yakutske/)

made on stilt foundation. That is a good strategy to prevent permafrost from thawing, however, this has a bad side – the city is completely inaccessible for disabled groups of population. The new district plan to solve this issue by creating a platform from gravel that will allow people to enter to the building without stairs directly from the ground level. The buildings of the district have stilt foundation as well; however, the gravel platform allows to raise the ground level.

Nowadays residential building construction is still an important topic for the Yakutsk and its surroundings. The population is constantly growing and the buildings that were built during the soviet period are gradually degrading. Architects are trying to find a solution for permafrost preservation, on the one hand, and the comfort and affordability of the buildings, on the other hand.

Reduction of the height of the buildings, of course, reduces the capacity of the dwellings, however, it has a positive effect on the locals and moreover, it makes it easier to protect the permafrost from thawing. Smaller buildings could be more adjustable for severe climate conditions. However, its real effect on the permafrost we could find out only in some years

Figure 59 (on the right): a vista of the residential house. Project is made by EYGEArchitects

3.2. BUILDING REGULATION ANALYSIS FOR PERMAFROST REGIONS

In this chapter building regulations of the permafrost regions will be analysed and compared to understand what is already done in different countries to protect the permafrost and what new could be implemented.

3.2.1. RUSSIAN REGULATION

Russian Regulation СП 25.13330.2020 "Soil bases and foundations on permafrost soils" demands that every restauration and new building construction should be supported with deep research about soil and its specific characteristics.

This regulation allows two ways of construction depending of the results of the analysis. The first one, is more sustainable and more common, uses permafrost as a foundation for the future building and intend to keep it frozen during the all period of construction and maintenance.

"...principle I - permafrost foundation soils are used in a frozen state, maintained during the construction process and throughout the entire period of operation of the structure, or with the assumption of their freezing during construction and operation;"

The second one is more used in the south of the Republic, in the areas where a layer of permafrost is not that thick and presented as sporadic and isolated patches. The thawing of permafrost before the construction allows to reach rock foundations and build a more stable building.

"principle II - permafrost soils of the base are used in a thawed or thawing state (with their preliminary thawing to the estimated depth before the start of the construction of the structure or with the assumption of their thawing during the operation of the structure)"

Here, attention will be focused on principle I, when the permafrost by itself is used as a foundation for the future building. In this case, Russian regulation demand to use of ventilated floor to obtain natural ventilation that helps to preserve permafrost from thawing.

"... 6.3.1 When permafrost soils are used as foundations for structures according to the principle I, in order to preserve the frozen state of the foundation soils and ensure their design thermal regime, the designs of foundations and foundations must provide for: on the basis of the construction of ventilated pipes, channels or the use of ventilated foundations (6.3.3), the installation of seasonally operating cooling devices of liquid or vapor-liquid types - SOU (6.3.4), as well as the implementation of other measures (heat shields, etc.) to eliminate or reduce thermal effects structures on frozen foundation soils."

The height of the ventilated floor or ventilated foundation has to be minimum 1,2meters if there is no need of the location of the engineering facilities and a minimum 1,4 meters if there is a need for them.

The ventilated floor can be left open, closed, or with an artificial ventilation to provide better permafrost preservation.

The ground below the building has to be covered with hard material and has to have a slop outside the building perimeter to provide good water drainage to avoid waterlogged surface and permafrost degradation.

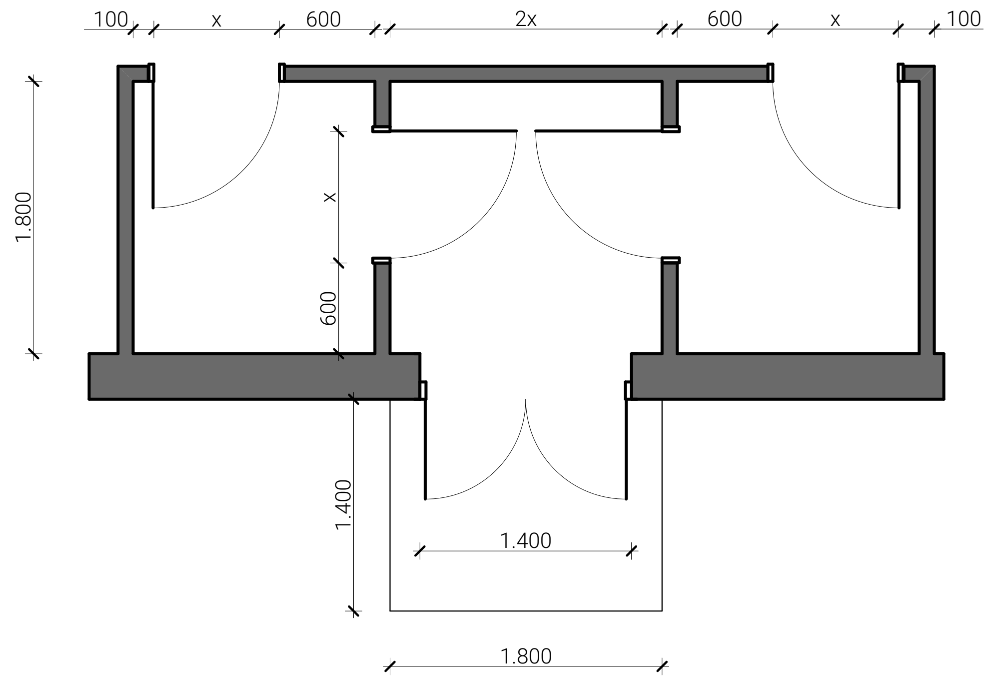


Figure 60 (on the right): an example of double vestibule. Usually, this scheme is used in public buildings

All engineering heat-generating communications, located in a ventilated ground floor must be thermally insulated to avoid the permafrost thawing. As we can see the main focus of the Russian building regulation in permafrost areas is providing proper ventilated floor and good insulation between building and the ground. There are few other specific characteristics of the residential buildings in Yakutsk, like dividing the building of thermal blocks with maximum length of 15 meters that allows to provide building stability in case of permafrost thawing (adaptation strategy).

Concerning building design, it is necessary to provide a double vestibule to avoid cooling down the building in the wintertime. Figure 60 and 61 show the example of double vestibules.

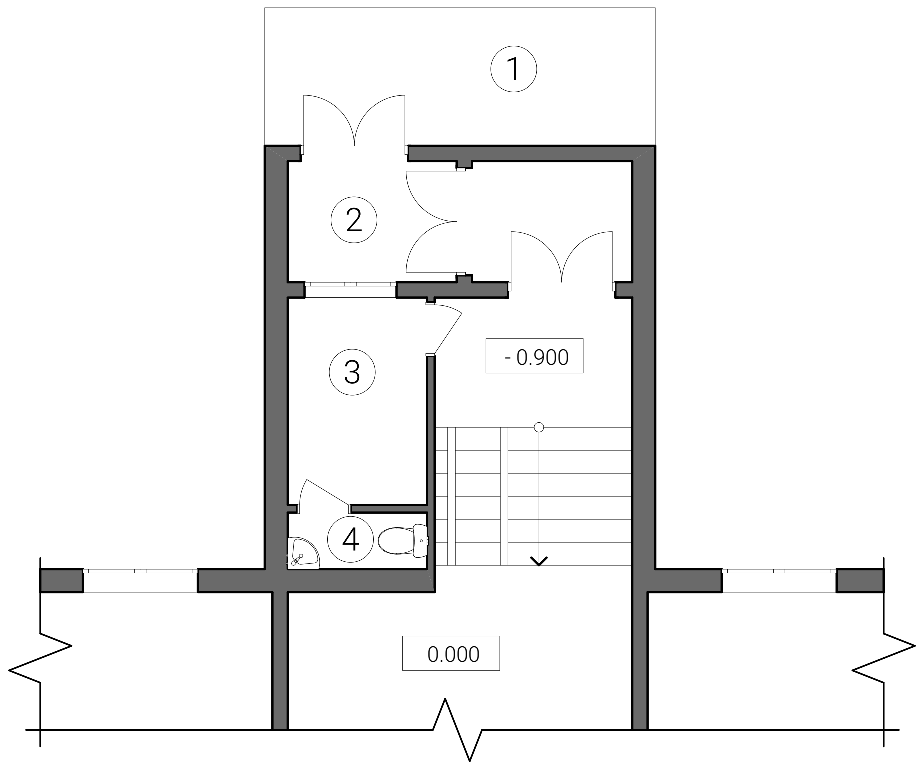


Figure 61 (on the left): an example of implementation of double vestibules into residential buildings. 1 – entrance, 2 – double vestibule, 3- staircase, 4 – concierge room, 5 – WC for a concierge (scheme is based on the drawing from https://pandia.ru/text/78/553/26185.php)

3.2.2. OTHER COUNTRIES' REGULATION

Most of the countries present also keep the main focus on building foundation and naturally and artificially ventilated floor. In case of Canada, the height of ventilated floor is lower than in Russia and has to be minimum 0.6 meters (comparing with 1,2 meters in Russia) However, they also provide extra strategies for permafrost preservation.

There are two main directions. The first one, mitigation, attempts to reduce the impact of climate change and tries to prevent it from further development. The second one, adaptation, deals with the consequences of global warming and tries to adapt our buildings and lives for nowadays reality. In case of permafrost sometimes strategies are working simultaneously in both directions, so they protect as much as they can permafrost and in the same time protect the building in case of perma-frost thawing and land subsidence.

Here is a list of adaptation and mitigation strategies that other countries apply in their permafrost regions:

- Extra shading of the ground provides a decent mitigation effect and slows down permafrost degradation. Especially, if it is placed in the south part of the building. The shading can be natural or artificial, however, it should not block the airflow of the ground floor.

- Any water accumulation around and beneath the building speed up permafrost degradation. The water temperature is way higher than permafrost, going deep into the ground, water melts it, causing soil instability, the release of GHG, and other catastrophic effects. To solve this issue, some standards, like Canadian CAN (CSA-S501-14), require to provide rapid drainage from the building of around 4 meters. Some research papers insist on using im-permeable materials around houses and in permafrost areas in general, to avoid water pen-etration and further degradation of permafrost.

- Another mitigation strategy is ground insulation; however, it has two sides. On one hand, it provides great insulation, prevents heat transfer, and protects permafrost from penetration of any hot compounds. On another hand, it also protects permafrost from cold during the winter time which has a negative effect on its preservation.

- Mechanized refrigeration or thermosyphons is the most effective technique to prevent per-mafrost from thawing. It allows freezing ground even more during the winter period

- One of the adaptation strategies is foundation adjustment and releveling. That will not pre-vent permafrost from further degradation, however, will protect the building from defor-mation due to uneven ground subsidence. This strategy requires seasonal maintenance and creates difficulties in designing entrances and stairs. Moreover, this technology cannot be applied in multi-story buildings.

The last two recommendations are not connected with architecture but yet play an important role in the preservation of permafrost. Water and snow management help to freeze ground during the win-ter time and protect permafrost from melting during the summertime. There are researches that provide data that snow works as a good thermal insulative material during the winter time, so its accumulation can prevent permafrost from further freezing during the winter time. During the spring season, its melt warms the ground and provokes further degradation.

3.3. INTERNATIONAL RESEARCH ON ADAPTATION AND MITIGATION STRATEGIES FOR THE BUILDING AND URBAN SETTLEMENTS

International Report on Climate Change 2022 underlines the problem of permafrost regions and the importance of implementation of adaptation and mitigation strategies in these areas. However, it does not suggest any precise strategies regarding the building field. Most of their recommendations for the North regions are focused on the use of local production, policymaking, and creation programs for the local communities and indigenous population.

So, what about building construction? What could be done in the architecture field for the northern regions that could help us protect permafrost?

To answer these questions, we have to check the mitigation and adaptation strategies for the buildings that are recommended by the IPCC report and analyze which of them could be implemented in permafrost areas and which are not suitable for extreme climate conditions.

SER strategy

For the building scale IPCC report proposes to use the SER framework as an efficient mitigation strategy. SER stands for Sufficiency, Efficiency, and the Renewables.

Sufficiency

According to the IPCC report the first principle, sufficiency, could be applied to the building in different ways, for example, by optimizing the use of the building and repurposing unused areas, giving priorities to multi-family homes over individual buildings, and adjusting the size of buildings to the evolving needs of households by reducing the size of the dwellings. The implementation of these strategies could help to reduce the demand for materials during the construction phase and energy demands during the life cycle of the building. Smaller rooms with smaller windows demand less heating during the cold season and less cooling during the summertime. Shared areas between multiple families (such as laundry, or offices) could optimize the space that stays empty half of the time.

Efficiency

Efficiency is focused on the energy efficiency of the building and tends to avoid unnecessary use of heating, lighting, and cooling during the year. For example, the use of proper insulating materials could help to reduce heating demands during the winter and avoid the use of air conditioning during the summer.

Renewables

The third principle, "renewables" is meant to help buildings minimize the impact on the environment even after their lifespan by using recyclable materials or by using materials or structures that could be dismantled and turned into something new.

Could this SER strategy be implemented in the permafrost areas and how it could help us to protect the permafrost from thawing? SER strategy could perfectly complement our previous research. We already know that it is important to protect permafrost from the potential heat transfer from the building and providing an energy-efficient building envelope could be one of the options.

Could this SER strategy be implemented in the permafrost areas and how it could help us to protect the permafrost from thawing?

SER strategy could perfectly complement our previous research. We already know that it is important to protect permafrost from the potential heat transfer from the building and providing an energy-efficient building envelope could be one of the options.

Foundation

We already know that an efficient building envelope and stilt foundation prevent heat transfer from the building to the soil. However, this structure creates a problem that was not taken into consideration before. Since the foundation piles lay directly in permafrost, during the summer they are also exposed to the heat of the environment (air temperature in summer in Yakutsk could go up to +36°C). In this way in the summertime, natural ventilation gives us a negative effect. The stilt foundation, warmed up by the environment and hot air brought by natural ventilation, transfers the heat directly into the permafrost and provokes further degradation.

Some of the variations of the common stilt foundation could keep a cooling effect of the natural ventilation during the wintertime and at the same time reduce the exposed surface of the stilt foundation during the summertime to protect permafrost from thawing. For example, a transformation of the foundation columns into arches could reduce the exposed surface of the foundation during the warm period time and at the same time provide a cooling effect through natural ventilation during the wintertime (Plotnikov A.A., Guryanov G.R., 2021).

Another option, according to the survey, is the use of insulating materials (see figure 62). Insulation placed on the ground beneath the building could protect permafrost from overheating during the summertime. However, in this way, it will also protect permafrost from cooling during the winter and gradually that could lead to permafrost degradation.

The solution to this problem could be to place a seasonal insulation (see figure 62). The layer of insulation placed beneath the building could protect permafrost from thawing during the summer and will allow it to freeze more during the winter. However, it will require extra maintenance during the lifespan of the building. In this case, natural-based solutions could help us to avoid seasonal maintenance. Some of the natural materials like moss or timber scabs could be used as insulation. In the wintertime, exposed to

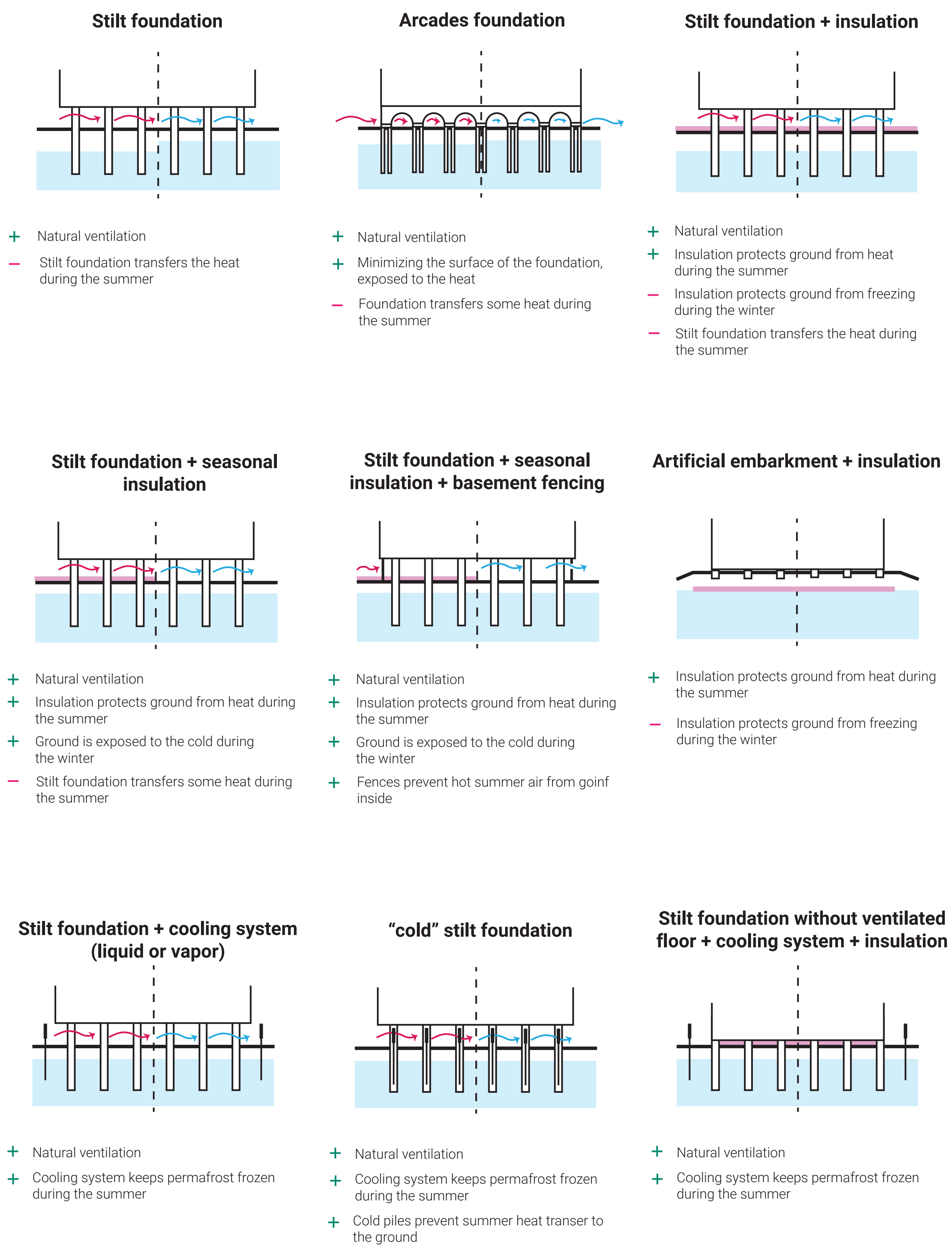


Figure 62: Scheme shows different solutions of the foundation for the buildings for the permafrost regions and its advantages and disadvantages

moisture, they freeze and lose their thermal insulation properties, permitting permafrost to freeze more. However, in the summertime, these materials get dry and take back their thermal insulative characteristics, protecting permafrost from thawing. Even though these solutions help to protect permafrost from thawing, there still will be some heat that transfer to the permafrost via the piles (Plotnikov A.A., Makarov V.I., 2020).

Implementation of a protective screen, with some holes that could be opened and closed, on the perimeter of the building (see figure 62) could help to control airflow during the year by keeping the screen's "windows" closed during the summer to prevent hot air from going inside and heating the foundation piles, and keep the "windows" open during the winter to provide an extra cooling effect and prevent heat transfer from the building to the ground (Plotnikov A.A., Guryanov G.R., 2021).

Another solution could be installation of the cooling devices like thermosyphons around the building to cool down the ground beneath during the summer. Nowadays, it is the most efficient technology to keep permafrost frozen. There are two types of thermosyphons: the one that works with cooling liquid, such as kerosene, and the one that works with gases, like freon (Plotnikov A.A., Guryanov G.R., 2021). Both of them have their pluses and minuses. Cooling devices with cooling liquid inside are more secure. The leakage of kerosene is very unlikely. That lengthens the lifespan of the device. However, the manufacturing process is complicated and requires more materials than thermosyphons that work on gases, which as a consequence, increases the cost of the device. Thermosyphons that work on gases have a simpler structure that makes them cheaper but they are more unstable. They require constant pressure inside them to keep the cooling properties of the device. Unfortunately, it is not that easy to maintain, hence, it is common to have a failure of the system and freon leakage (Plotnikov A.A., Guryanov G.R., 2021). That is why it is recommended to use gas-based thermosyphons as a short-term solution, for example, for freezing taliks - unfrozen parts of the ground in permafrost zones, and liquid-based thermosyphons for the long-term solutions, like keeping the permafrost frozen (Plotnikov A.A., Makarov V.I., 2020).

Schemes 63 and 64 show the structure of the thermosyphons – a pipe with cooling liquid or gas is placed in the ground. In the wintertime, when the

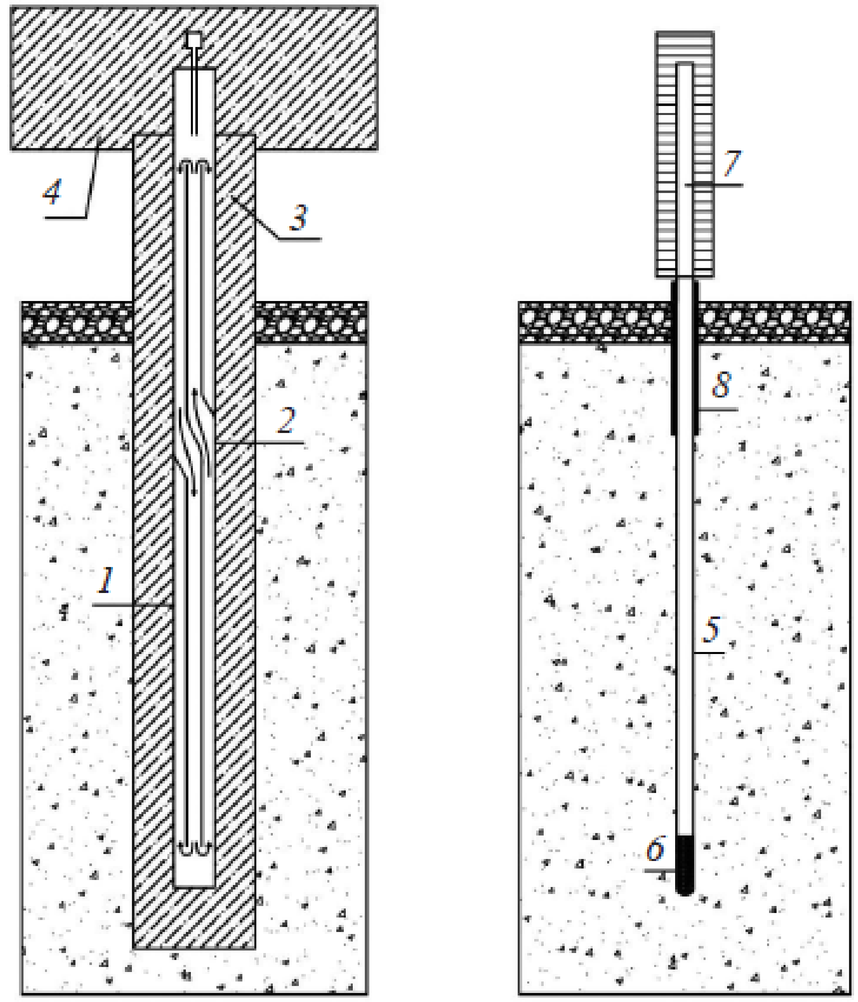


Figure 63: Construction of SCD (Seasonal Cooling Devices). On the left - «cold» stilt foundation, on the right - an example of thermosyphon that could be placed around the building. 1 — metal pipe 120 mm; 2 — stream directing device; 3 — reinforced concrete pile; 4 — grillage; 5 — pipe 50 mm; 6 — liquid heat transfer agent; 7 — condenser; 8 — thermal insulation (the scheme is taken from the Aleksandr A. Plotnikov, 2021)

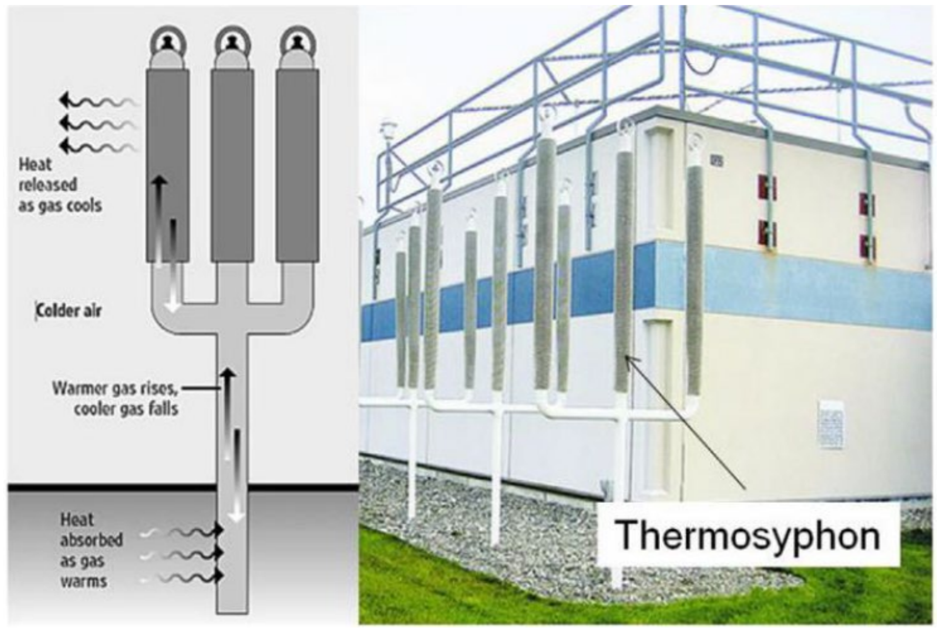


Figure 64: The scheme shows the working principle of thermosyphons: During the wintertime, when the permafrost is warmer than outside air temperature, its heat warms the working fluid inside the thermosyphons pipes. The warmer gas rises and release the heat, meanwhile the cold gas falls and cool down the permafrost (the scheme and photo are taken from Jim Carlton/The Wall Street Journal).

permafrost is warmer than the air temperature outside, permafrost warms the working fluid (or liquid) inside pipes and this gas rises, and releases the heat. Meanwhile, the cooler gas (or liquid) falls and freezing permafrost even more.

A further step in the development of the stilt foundation and thermosyphons is a "cold" stilt foundation. It is a stilt foundation with a cooling device inside the piles (see figure 63). This technology helps to keep foundation piles cold during the year and prevent any heat transfer into the ground. The benefits of this construction are the stability and safety of the structure. Kept inside the stilt foundation cooling devices are secure from breakdown and leakage. The first multi-stored residential building was built in Mirnij, in 1970 and showed good results in terms of stabilizing permafrost beneath the building (Plotnikov A.A., Guryanov G.R., 2021).

Nowadays, more and more researchers are pointing out that the best way to not only stabilize the permafrost but also increase its thickness is to merge two strategies – cooling devices with thermal insulation. Some research papers claim that with proper insulation and cooling devices, the building could be placed directly on the ground without a stilt foundation. In this way, we protect permafrost from thawing and avoid piles overheating

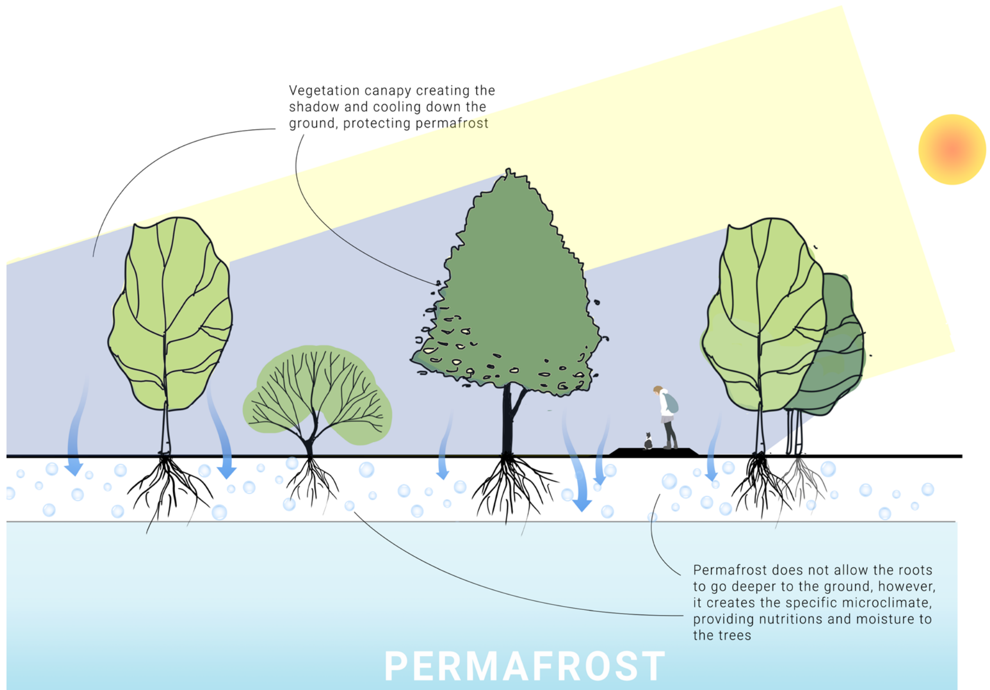


Figure 65 (on the left): a scheme that shows the relationship between vegetation and permafrost. Trees create vegetation canopy that protects permafrost from thawing meanwhile permafrost prevents roots to go deeper into the ground, forcing them to stay in the active layer. There permafrost creates a specific microclimate that provides vegetation with nutrients and moisture.

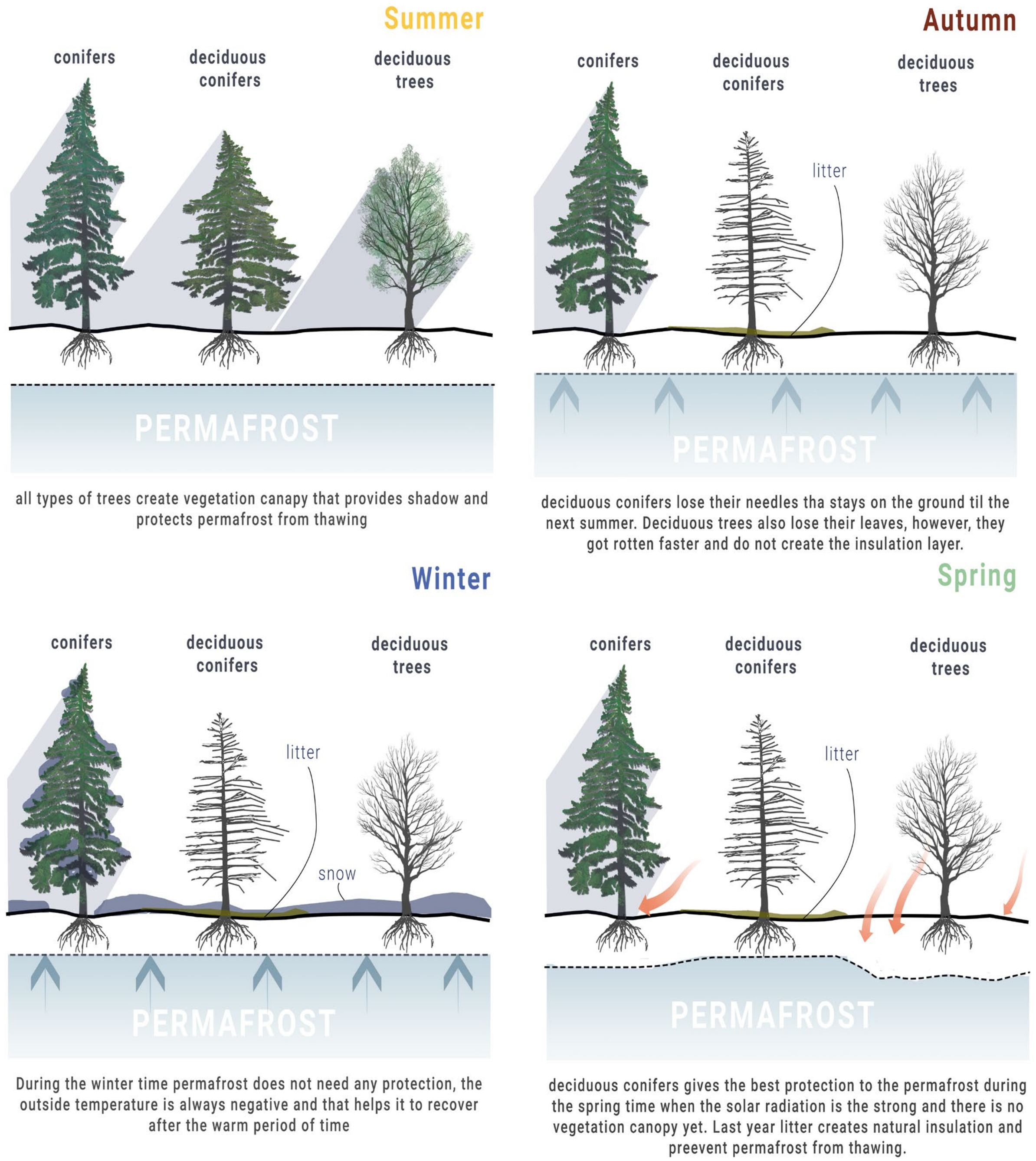


Figure 66: a scheme that shows how different types of trees protect permafrost during the year. In summertime, each of them has a vegetation canopy that create the shadow and protect the ground from overheating. In autumn, the outdoor temperature starts to be negative and the ground starts to freeze even more, raising the permafrost level. The deciduous trees and deciduous conifers are losing their canopy. Fallen leaves starts to rot, meanwhile litter creates the insulation level. In winter, permafrost is protected. The snow creates insulation to protect ground from freezing, however, in Yakutia this insulation is unsignificant and still allows to freeze the ground. During the spring the snow melts and the vegetation canopy is absent, so the litter protection is the only way to prevent permafrost from thawing. Conifers that still have vegetation canopy also protects the ground from solar radiation, however, according to the research, in this case, the litter insulation works better.

(Plotnikov A.A., Guryanov G.R., 2021, Plotnikov A.A., Makarov V.I., 2020). Moreover, this solution makes buildings accessible for the population with low mobility. The research shows that the insulation layer of 24 cm beneath the 12-meter-wide building and cooling devices around it could stabilize the ground beneath the building and also increase the permafrost thickness (Plotnikov A.A., Guryanov G.R., 2021).

Another way to provide a safe foundation to the permafrost foundation could be an artificial embarkment with an insulation layer. The research shows that an insulation layer made from granular foam class could prevent heat transfer, even without a stilt foundation. However, it is possible only for 1-2 floor buildings.

Other strategies

Since permafrost is not an isolated phenomenon and could be found everywhere in the city and not only below the buildings, it is important to understand, which strategies could be implemented on the urban scale.

Most of the IPCC report urban strategies aim to reduce CO2 emission. It could be useful for permafrost protection on a global scale since permafrost degradation is progressing due to human activity and global warming. An increase in air temperature provokes permafrost thawing. So, the implementation of some of the strategies could mitigate the negative effect on permafrost as well.

The report proposes to make cities more compact and walkable to reduce the use of cars, hence emissions into the atmosphere. Cars and roads, indeed, provoke the thawing of permafrost. The road's material tends to accumulate the heat and transfer it to the ground which leads to the permafrost thawing. The change of material or a reduction of the number of roads could indeed potentially improve the situation. For example, the placement of extra insulation layers beneath the roads could help to cool down the permafrost beneath the urban infrastructure. Implementation of this strategy in Alaska improved the stability of the road and helped to minimize the damage from uplifting soils due to the permafrost degradation beneath the roads (Currey. J., 2020).

Light-colored road materials or materials with high albedo also could be used to reduce the amount of heat absorbed by a pavement to limit the permafrost degradation under the roads (Simon Dumais, Guy Doré, 2016). White-coated asphalted show a positive cooling effect in permafrost regions (Zhilang You and al., 2021).

The research also underlines the importance of urban green and blue infrastructures for reducing the total warming in urban areas due to its local cooling effect. These infrastructures could be presented in different ways, for example, as urban forests, greenways, vegetable gardens, green walls and roofs, and blue spaces such as lakes, channels, etc. The report also notes that forests could be more efficient in cooling cities than designed green areas.

Natural-based solutions work everywhere, including permafrost regions. There is a strong interdependent relationship between permafrost, active layer thickness, and vegetation (JIN, X.-Y., et al., 2020). The permafrost works as a barrier that does not allow the roots of the plants to grow deeper, forcing them to stay in the active layer, however, it plays a crucial role in supplying soil moisture and nutrients to plant growth, sustaining stable microclimate and ecosystem balance (JIN, X.-Y., et al., 2020). On another side, the trees create a vegetation canopy that protects soil from solar radiation and overheating, helping to protect permafrost from thawing.

At first sight, it seems that conifers are the best type of trees. They can protect from the sun during the year. However, there is one type of tree that can work even more efficiently. The most dangerous period for the permafrost is spring when the soil is exposed to solar radiation and there is no protection in the face of snow or tree canopy (for deciduous trees). In this way, some types of trees, like larches are the best type of trees to prevent permafrost degradation (Weichao Guo, 2018). The larches are conifers that lose their needles before winter, creating litter insulation on the ground that protects the permafrost from thawing in the spring and summertime (Weichao Guo, 2018). Planting green corridors of larches in the neighbourhood can protect permafrost from solar radiation both in summer – by shadowing and in spring – by insulating layer of litter.

Vegetation could also be implemented on a smaller scale as a green roof and walls in the building. That could have a great cooling effect and provide extra insulation to the building, leading to a more efficient building envelope. That is important for permafrost preservation and could help to avoid heat transfer to the ground. Moreover, the proper design of the green roof could help in water management and water collection which is important in terms of permafrost protection since water provokes its degradation.

We can conclude that the strategies that are focused on cooling down the surfaces of the building or the city could be implemented to protect permafrost from thawing. Natural-based solutions could help with that but all plants should be chosen according to the climate conditions. Some types of greenery, like larches and moss, could give extra benefits to the area and directly protect permafrost from thawing.

4 STRATEGIES

4.1. STRATEGIES FOR BUILDING ON PERMAFROST

Previous research shows us that the permafrost degradation is a serious problem that has to be studied and resolved. Analysing building heritage of Yakutsk, building regulation of different countries and different researches helped to form strategies that we could apply in architecture to adapt buildings to the nowadays climate conditions and moreover, to protect permafrost.

It is obvious, that for better results the adaptation and mitigation strategies have to be applied in three different scale in building scale, district scale and in urban scale.

4.1.1. Uplifting the building

The residential buildings of the past show us a gradual development toward permafrost preservation. The first locals' dwellings were located directly on the ground and the heat of the fireplace was eventually melting permafrost beneath the building. Then, with time, the houses gradually started to be lifted higher and higher above the ground, like in the traditional Russian hut where the building was placed on the log basement or like later in the Soviet period when the multi-story buildings were settled on the stilt foundation. That allowed to reduce the heat transfer from the "warm" part of the building to the ground and mitigate the building's impact on permafrost.

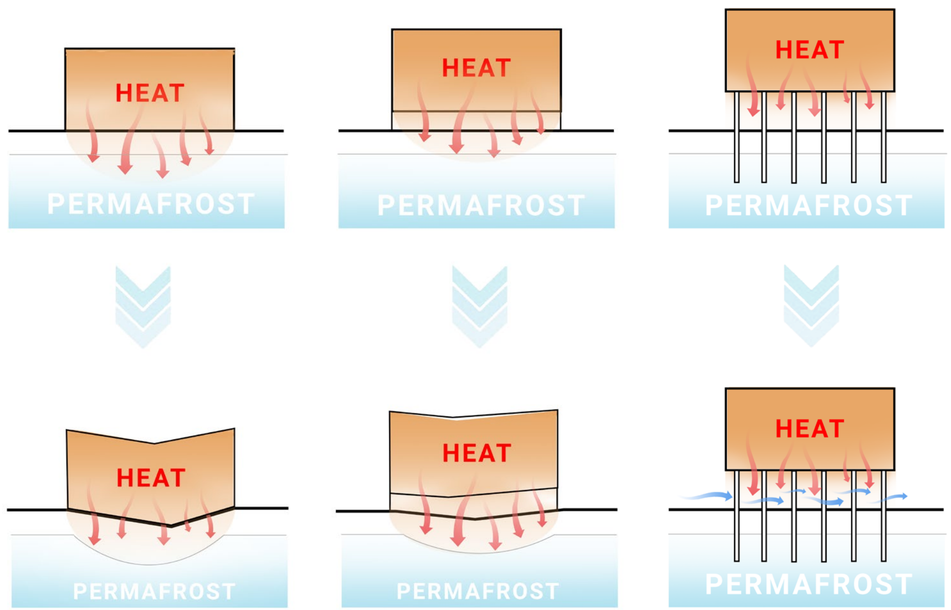


Figure 67: a scheme shows how it is possible to reduce the effect of the building on permafrost by lifting it above the ground. As bigger the distance between the warm part of the house and the ground as less heat will be transferred to permafrost. In the third example, where the building is placed on the stilt foundation, additional cooling appears. The wind circulation between stilts provides natural ventilation that reduces the heat transfer to the ground and helps to avoid permafrost degradation.

Permafrost preservation was not a conscious action against global warming. It was more a necessity for building stability and an attempt to avoid constant seasonal refurbishment of the structure. The heat of the building was causing thawing of the permafrost with further land subsidence, structural damage, and even collapse of the building.

From the scheme, we can see that further from the ground is placed the heated part of the house is better for the permafrost preservation and building stability as follows. Putting the building on a stilt foundation creates an additional cooling effect because of the wind circulation. Natural ventilation helps to minimize heat transfer and protects permafrost from further degradation.

4.1.2. Reduction of the temperature from the building to the ground

Based on building heritage analysis in Yakutia, we can assume that one of the key strategies of building on permafrost could be the reduction of the temperature from the building to the ground. This can be done by lifting the main part of the building from the ground as far as possible. The effect can be increased even more by efficient planning solutions of the

Figure 68 (on the right): a scheme shows how it is possible to reduce the effect of the building on permafrost by design. Placing the different functions of the building according to their temperature requirements. The hottest areas, like residential blocks, should be placed on top, as further as possible from the ground. The coldest, like storage rooms and parking, have to be placed close to the permafrost. In this way, the hottest areas will transfer heat not to the ground but to the storage area and parking, so in the end permafrost will receive less heat than if the building was fully residential

building. Different functions needed different temperature regime inside: living rooms has to be warmer than the storage rooms, or parking. The mix-uses building with residential floors, offices, storage and parking can help to reduce the building's impact on permafrost.

4.1.3. Creating an efficient building envelope

To improve the situation in building scale, we should work on the building envelope. In Yakutsk severe weather conditions with annual average temperature of – 20°C demands continuous heating season of 252 days and together with low energy efficiency of the buildings (Arkhangelskaya E. A. 2022), it creates a huge amount of heat transfer from the building to the ground, warming up the permafrost and causing its thawing. It is important to not only using the stilt foundation, benefits of which are described in the chapter 4, but also providing the energy - efficient building envelope that can keep the heat inside and reduce the heat losses.

The permafrost in Yakutsk is not presented as an isolated patch, it is a continuous mass. Providing efficient building envelope and putting building on a stilt foundation helps for its preservation, however, only beneath the

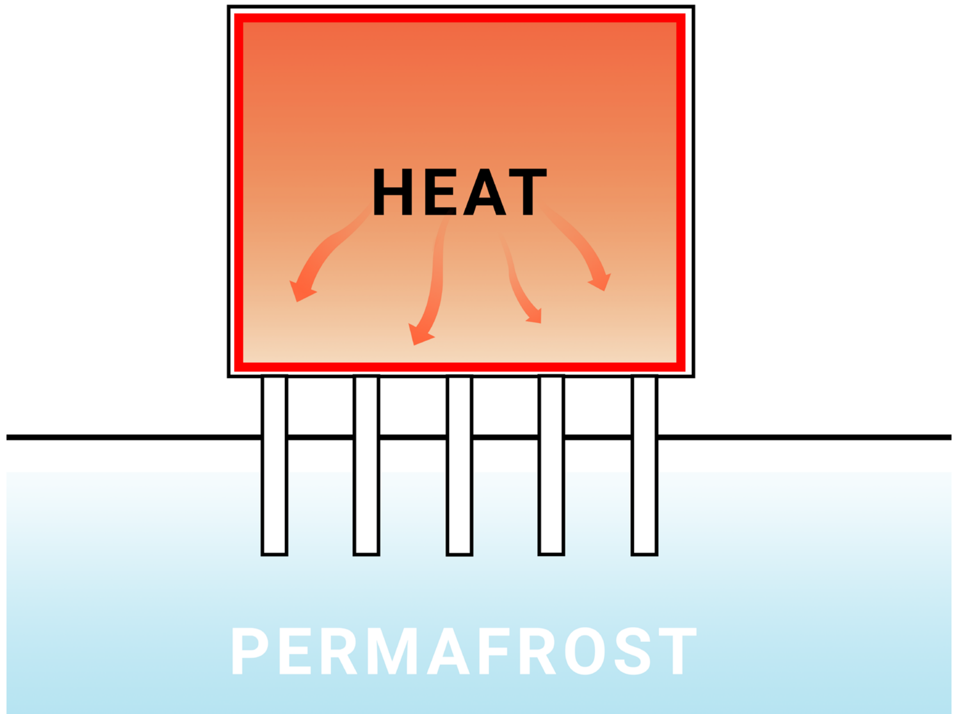


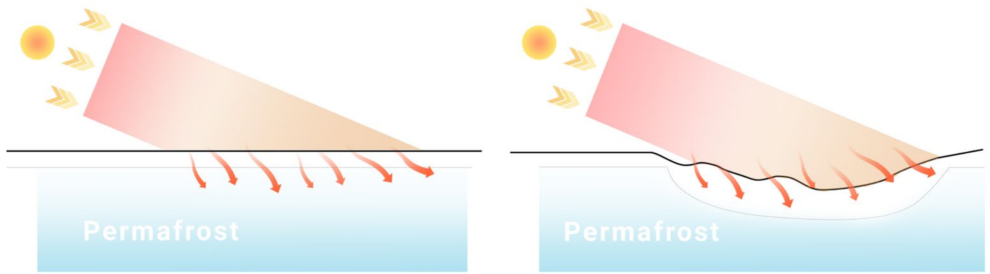
Figure 69 (on the left): a scheme shows that the energy efficiency of the building can be the main action that we can apply on buildings, especially in permafrost regions. In combination with a stilt foundation, it can create the best result for permafrost preservation. The heat of the building is kept inside due to the efficient insulation, ventilated ground floor, helps to accelerate the effect.

building. To mitigate the climate change effect on permafrost everywhere it is necessary to apply strategies in neighborhood and urban scales.

4.1.4. Ground insulation

The ground exposed to solar radiation warms up and provokes permafrost thawing that leads to the land subsidence (see figure 70) that affects both environment and people. Land subsidence creates building and infrastructure instability causes their damage and even collapse. Therefore, it is important to protect the soil from sun heat and not just beneath the buildings. It could be done in various ways.

Figure 70 (on the right): a scheme shows the effect on permafrost of solar radiation. The ground, exposed to the solar radiation warms the soil and provoke permafrost degradation and land subsidence



First of all, it can be done simply by putting a layer of insulation. Usually, this method is applied in road construction in Alaska. For insulation they use expanded polystyrene or extruded polystyrene foam boards.

Figure 71 (on the left): a photo shows the road construction with the use of foam boards to preserve permafrost (photo is taken from https://dot.alaska.gov/traveltopics/building-in-permafrost.shtml)

Figure 72 (on the right): a section of the road with the use of insulative foam boards.

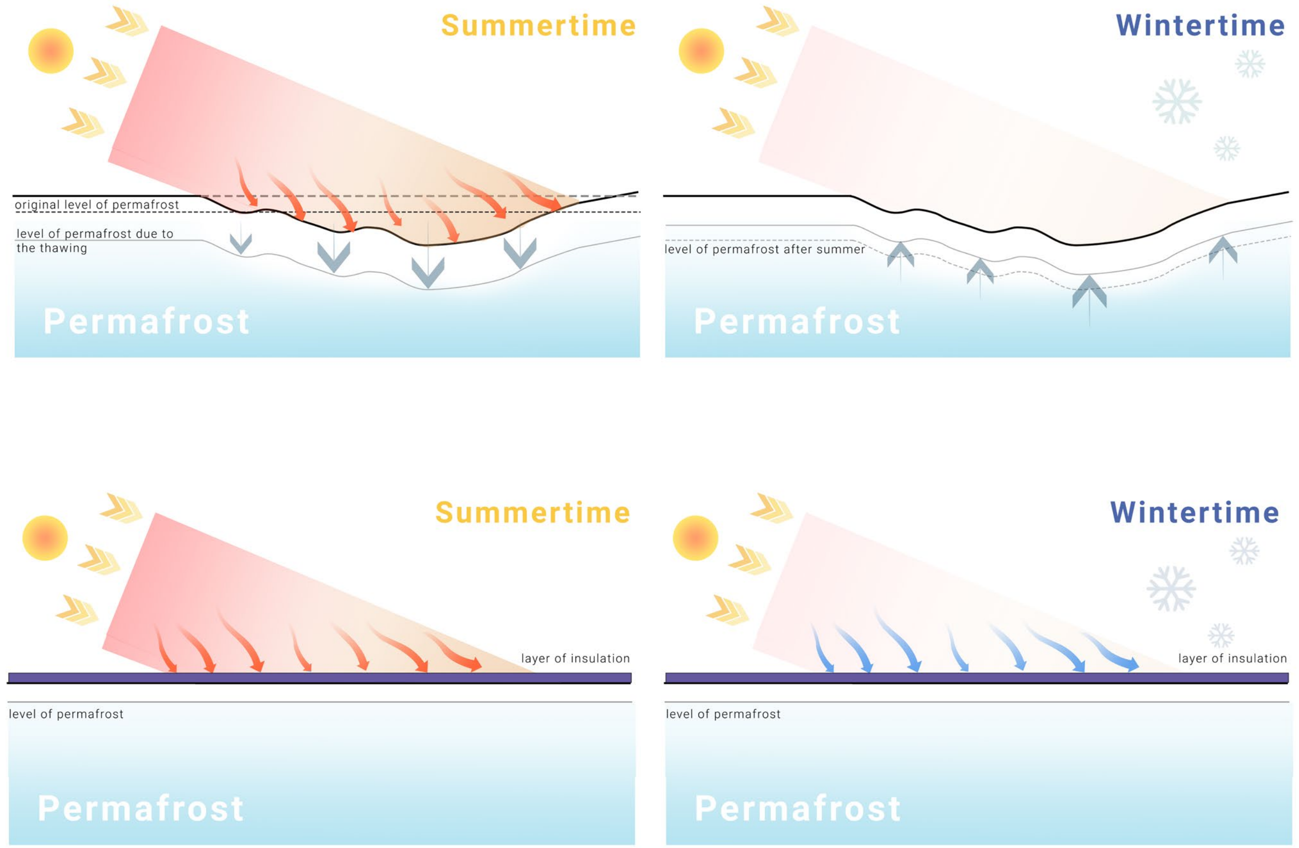


Figure 73: the schemes show the impact of insulation layer on the permafrost preservation. In summertime unprotected ground receive a lot of solar radiation that warms up the soil and provoke permafrost thawing. In winter time the ground freezes and layer of permafrost is expanding closer to the ground surface, that's helps to thaw less during the next summer. The insulation layer protects the permafrost from the heat in summer, however, it also prevents cold air going down to the soil to freeze it more. So, it is necessary to install the insulation during the winter time when the permafrost is closer to the ground to preserve it better.

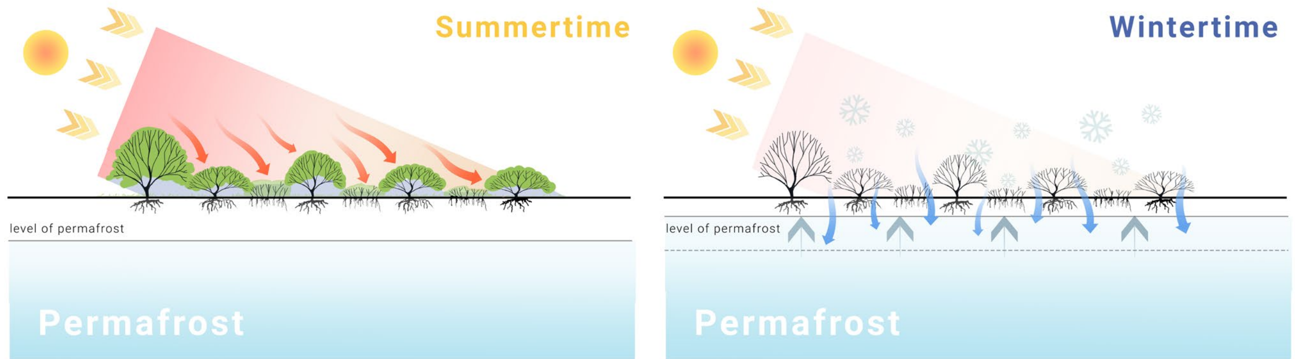


Figure 74: the scheme shows how vegetation can prevent permafrost degradation. Some species of vegetation, such as moss and lawns can play the role of natural insulation material. Moreover, bushes can create an additional shadowing to the ground and help to the permafrost preservation. During the winter time, due to the fall of leaves, the permafrost can freeze even more.

The negative effect of this strategy is that insulation works also during the winter time and does not allow the permafrost to freeze even more during the cold period of the year.

4.1.5. Natural - based solutions

Another way to solve this issue is the application of natural-based solutions, like lawns and bushes, that will expose the ground to cold during the winter time. There are some species that can survive the severe winter conditions and improve the permafrost situation.

Figure 75 (on the right): a section of the hill with different materials. This composition might help to prevent permafrost from thawing.

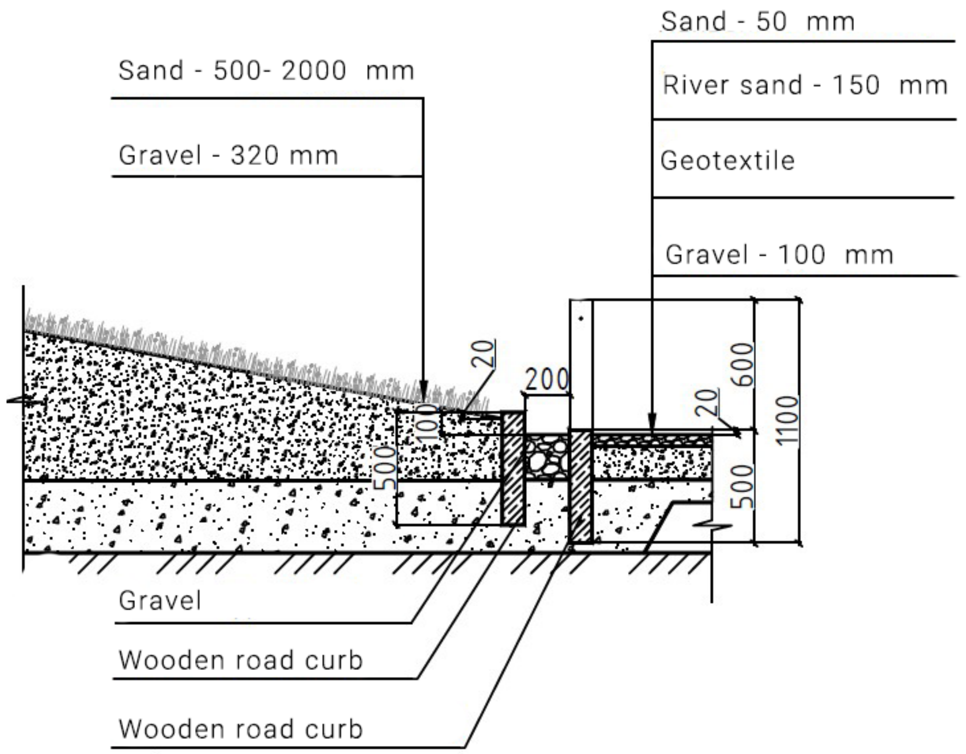


Figure 76 (on the right): a photo from the park shows the natural-based solution for permafrost protection. The hill is completely covered with vegetation that creates natural insulation layer and the pine trees will create extra shadowing for the ground when the trees will be big enough.

We can see a good example of vegetation as a barrier to the solar radiation and permafrost protection in Yakutsk. Where the garden was made with use of materials adapted for permafrost. Architects created a new landscape with a artificial hills, covered by vegetation. The hills are covered entirely by vegetation, creating a natural insulation layer. Moreover, as an extra measure for permafrost protection, conifers were planted on the hills. That creates extra shadowing during all the year.

4.1.6. Drainage and water management

Another negative aspect is water. Arriving with the rain, or due to the snow thawing in the spring it penetrates deep to the ground and melts permafrost. Moreover, the water can fall to the ground due to technical accidents in the hot-water pipes because of extreme weather conditions.

It is important to provide sustainable water management on the district scale it can be done in several ways. On the district scale, impermeable materials can be used to avoid water penetration where it can be dangerous and where it can provoke permafrost thawing. Also, it is important to provide a quick drainage system and proper water collection by slopes and water tanks.

4.1.7. Light - coloured materials

The use of light-colored materials could potentially protect permafrost from thawing. The BBC mentioned that the use of light-colored road materials and shielding the road embankment under a wooden shed have some positive results in preventing roads, built on permafrost areas in Alaska from deformation. Light-colored road materials or materials with high albedo absorb less solar radiation hence having less warming effect on the ground (see figure 77)

4.1.8. Cooling devices

As we can see from the research, using cooling devices could help us to protect the permafrost. Nowadays, this strategy could be considered the best in terms of permafrost protection. It could work both as adaptation strategy by implementing it above the existing buildings to improve the soil stability and save the structure of the building from damage and even collapse. And also, as a mitigation strategy, by implementing this technology in new construction. That can reduce the negative effect from the building on permafrost.

This strategy is quite expensive and that the main reason, why it is not so popular nowadays. However, more and more existing buildings are at risk of damage due to the permafrost thawing, so they demand cooling devices. Since sooner or later most of the buildings will reach same conditions, it would be better, if we start to use these devices since the beginning of the construction, to avoid the further degradation.

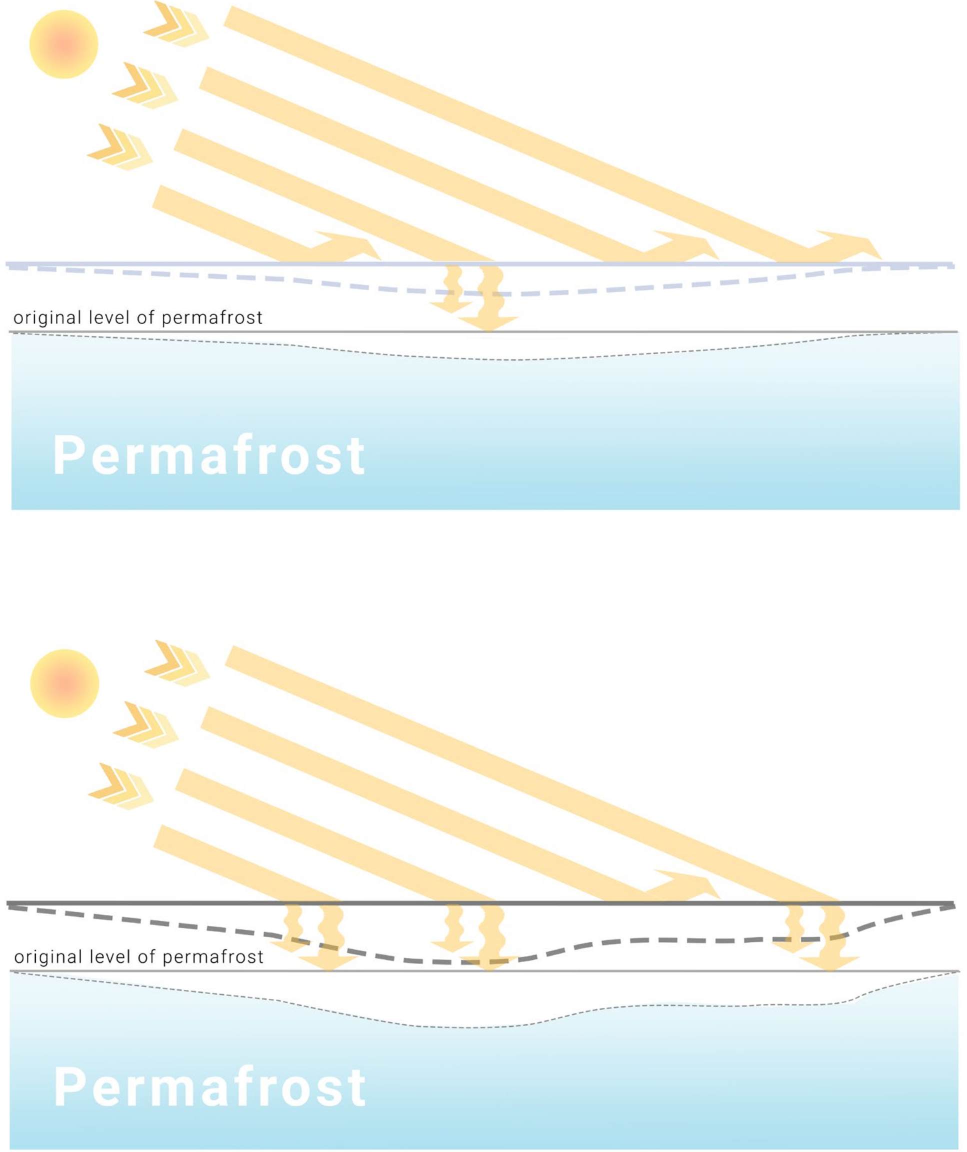


Figure 77: The scheme shows the difference between light-coloured and dark-coloured materials. The pavement with light-coloured material reflects the sun and says cooler than the pavement from dark- coloured materials that absorb the solar radiation and warm up the ground. We can see that light- coloured pavement helps to preserve permafrost better than the dark-coloured one.

5 CASE STUDY

5. CASE STUDY

As it was mentioned before, Yakutsk is the biggest city ever built in permafrost. Its location and specific characteristics make it very vulnerable to climate change. Hence it could be a perfect case study to apply our strategies.

Recently, the municipality proposed a competition on the new master plan that could define key points for the future development of the city and also help the city move towards sustainability. This competition allowed us to receive some important maps and choose the area for the application of the strategies. From the available analyses from this competition, we can find a map of all zones in Yakutsk that are preserved by the municipality as areas for future development (see figure 78). Yakutsk is constantly growing and changing. The constant growth of population, mostly thanks to migration from the rural areas, demands a lot of new residential areas. On the map from the figure 78. We can see that there are already several areas that will be turned into residential districts shortly. Like areas number 1, 2, 22, and 25. For the implementation of our strategies, I selected area number two.

First of all, this territory is included in the resettlement program that already was mentioned in Chapter 2. That means that the municipality is planning to demolish almost all of the residential buildings in this area and rebuild them. For us, it could be an interesting opportunity to analyze a nowadays situation, an approved project, and some projects from a design competition for this territory from the point of view of permafrost preservation.

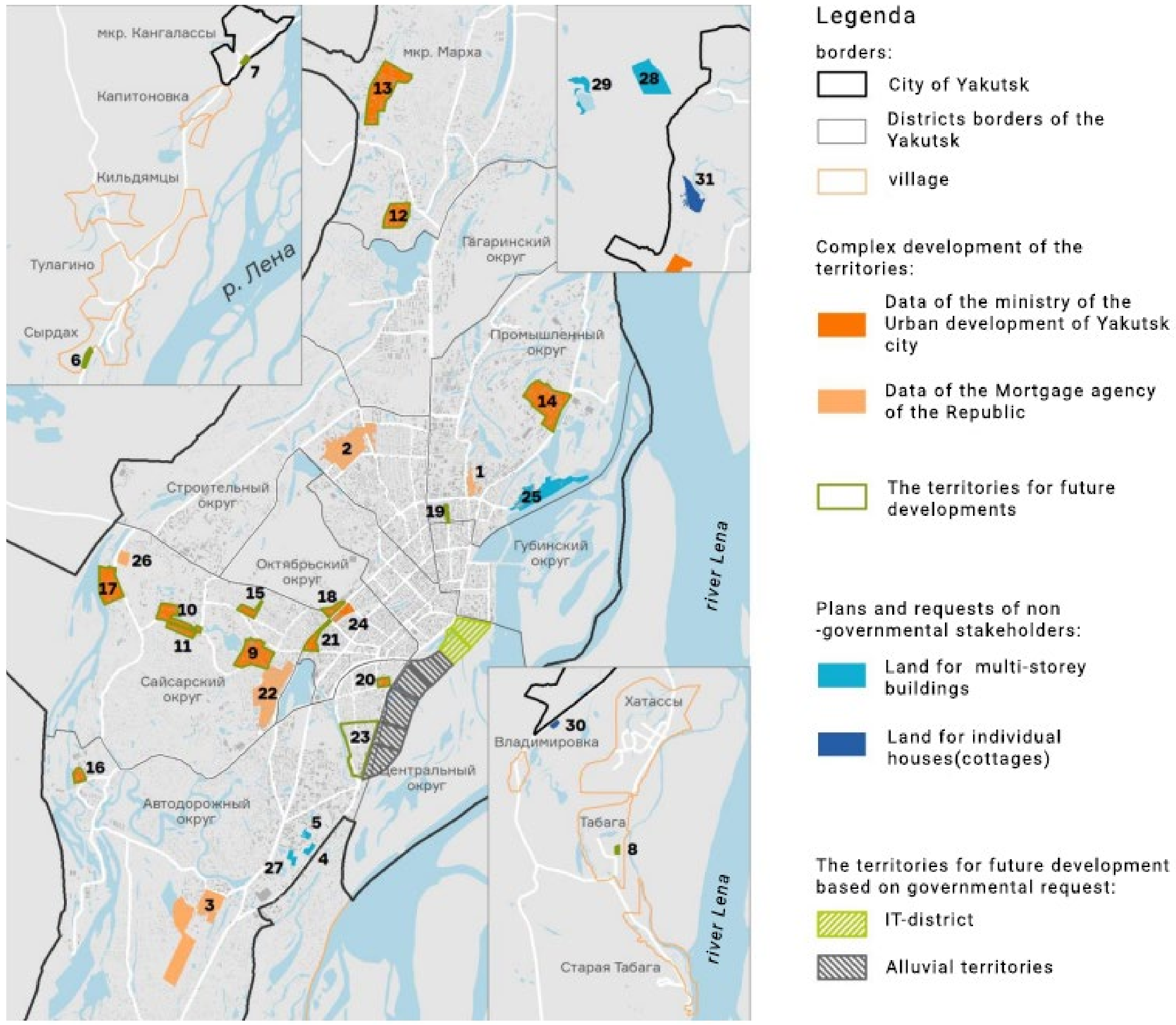


Figure 78: The map shows the areas in Yakutsk that are reserved for the future development (the scheme was taken from the «masterplan» competition materials available at www. masterplan-yakutsk.ru)

Secondly, nowadays the territory is in devastating conditions (see figures 80 and 81). It is one of the worst areas of the city both for the comfort of the population and permafrost preservation. From the available online photos, news, and Google Maps street views we can observe different signs of permafrost degradation such as buildings' deformation and sinkage, cracks and pits on the roads, and huge paddles, the area and houses there often get flooded. Horrible living conditions beget criminality and make the district unsafe also for the locals. It is important to improve the condition of this area both for the people and for the permafrost.

5.1. *ANALYSIS OF CHOSEN STIE*

The selected area is called "17kvartal" or the "district №17". However, in reality, it consists of several areas: 2a, 2b, 2g, 4a, 4b, 4v, and 17 (see figure 79). It is predominantly a residential area, most of the buildings were built in the middle of the XX century and present typical two-floor wooden buildings (chapter 3.1.4.). As it was already mentioned, nowadays these houses are in devastating conditions, and it is dangerous to stay in most of them.

However, despite the horrible conditions of the district, we surprisingly,

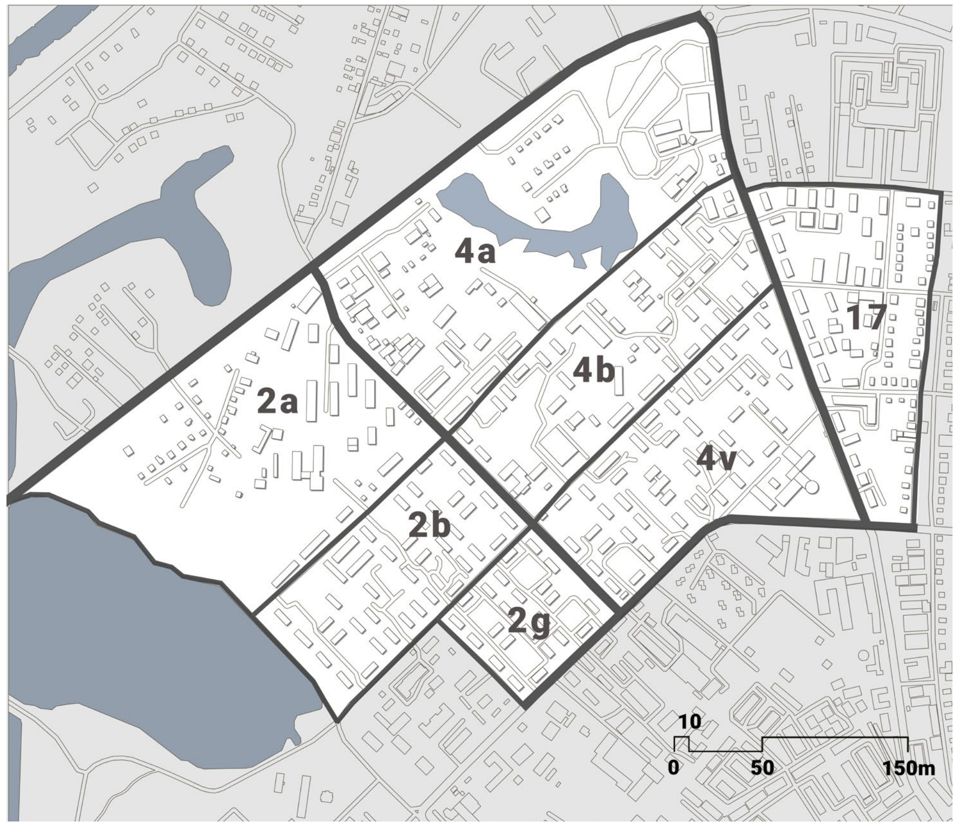


Figure 79 (on the left): district distribution in the 17kvartal

Figure 80: The view from the Google Maps street view shows the condition of the streets of the area. As we can see, some of the streets that lead to the heart of the district do not have any pavement. Rainwater goes down to the ground and provokes permafrost degradation. Uneven ground, pits, and paddles are the signs of permafrost degradation. Moreover, as we can see poor management of the district creates heaps of garbage around the areas. The area is built predominantly with two floors of wooden buildings (we can see them on the right part of the photo and its background). On the sides of the road, we can see garages that are used by locals not only for the cars but also for the storage of the goods.

Figure 81: The view from the Google Maps street view shows the condition of the main streets of the area. Despite the devastated condition of the houses, the area is reach with vegetation. Here we can see how existing engineering communications that are located above the ground for permafrost protection, create arches to let locals pass through them. Even though these streets are covered with asphalt we could see the accumulation of dust and sand on them.

have a huge diversity of services in it. On the northeast of the zone, we have a very important for the whole city building supplies market (see map 82) where you can buy everything you need to build anything you want starting from raw building materials like cement or wood and finishing with kitchen furniture. There are a lot of grocery stores, bars, and restaurants. We have some water tank centers where you can buy drinkable water (remember that some of the residential buildings of this area are not connected to the sewage and water systems of the city). Most of the stores are small and look more like kiosks than an actual building. The area has a school, a kindergarten, and a sport school, several pharmacies, and a hospital. An interesting point of this analysis was the discovery of several hotels with saunas in this area, despite being located far enough from the city centre and lack of attractions nearby.

The area has several lakes but there is no sign of urban planning or design. The research did not find any data about using these lakes as recreation areas for the population. So, we can suppose that these lakes are presented just as a part of the landscape and are not used by locals.

The south-west border of the district leads to the north entrance to the public park of the city which from this side presented as an urban forest. The North and East borders of the district are attached to another residential area that is presented by individual houses with private gardens. The south border of the area is also a predominantly residential area, however, that was built later, during the Soviet period, and presented by multi-story buildings on stilt foundations that were described in chapter 3.1.5.

5.2. ANALYSIS OF EXISTING PROJECTS

An approved project of the area is presented in figure 84. From the scheme 83 we can see that the project proposes to demolish almost all existing residential buildings due to their conditions and since it is not possible to renovate them.

The project consists of modular buildings located north-south. It helps to receive maximum daylight; Predominant winds in winter in Yakutsk go from North and North-east directions. So, this location of the building

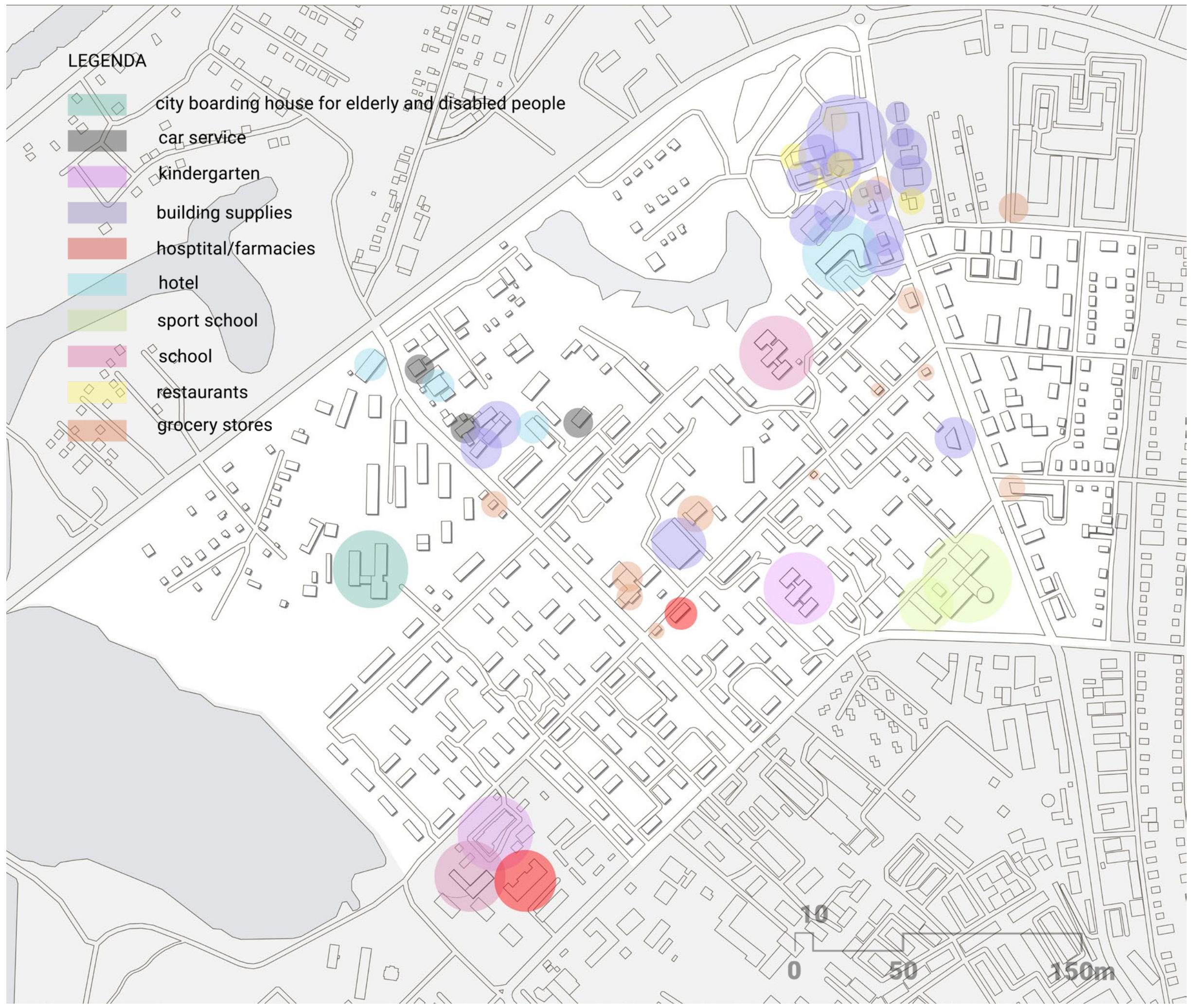


Figure 82: The map shows the distribution of services in the area. As we can see, the area is full of different services.

exposes public areas to the cold winds. However, there is an advantage to this placement. In the Northern regions, wind could play an important role in the snow management of the territories. At extreme cold, like the one we have in this area in winter, snow loses its qualities and turns into something close to the sand consistency. So, for example, it is not possible to make snowmen or play with snowballs anymore, however, it makes it easier to manage the snow inside the district since it can be done with the help of the wind circulation.

Snow management plays an important role in permafrost protection since the accumulation of the snow creates an insulation layer that prevents permafrost from freezing during the winter and in the spring, when it thaws it penetrates inside the ground and melts the permafrost. That is why this position of the buildings could have a good point, even though may be uncomfortable for the locals in some periods of the year.

There is no available data about the details of the proposed buildings, however, we could suppose that all buildings will have stilt foundations and are uplifted above the ground to provide natural ventilation and prevent permafrost thawing from the building heat transfer. Since it is the most common nowadays technological solution in this region.

The project put all educational zones in the centre of the district, creating a common area for the school and kindergartens. The project adds some services such as a hotel and a sport centre, locating them on the bank of the lake in the western part of the district (see figure 85).

A positive aspect of this project includes vegetation in the area. The project adds new green corridors in the main streets and greenery inside each quartier. Vegetation plays an important role in permafrost preservation this solution with proper selection of species could significantly improve nowadays condition of permafrost.

Another project in this area, presented by the winner of the competition “Masterplan” in Yakutsk, is a project of the “Institute Genplan Moskvi” (Институт Генплан Москвы). Their master plan proposes to create a green corridor from the lake throw the district. The project keeps the existing services and only improves their shape.

Their project presents more interesting solutions for residential buildings in case of shape development, use of materials, and design. It divides the area into districts with an inner garden inside.

The figure 86 shows the master plan of the project. We can see the main green corridor, that splits the area into two parts. The project has similar functions as the previous, however, instead of hotel it proposed mall and waterpark.

As with a previous project, the technological solution is unknown. From the renders we can see that there is a parking in the ground floor, located on the same level with the ground. If render represented the real solution, it could mean that the building foundation is not adapted to the permafrost and could cause its degradation.

Both projects have strategies to protect permafrost from thawing. However, they are based on technologies of the past and do not use modern solutions. In this thesis I would like to try to implement the strategies for building on permafrost, defined in previous chapters, taking a piece of this district 200

Figure 83 (on the right): The map shows which of the existing buildings have already recieved an emergency state and will be demolished (map is taken from https://ysia.ru/proshloe-nastoyashhee-i-budushhee-17-kvartala-yakutska-istorii-starozhilov-i-novyj-oblik-mikrorajona/)

Figure 84: The render of the designed area. As we can see all residential buildings have modular structure (picture is taken from https://ysia.ru/proshloe-nastoyashhee-i-budushhee-17-kvartala-yakutska-istorii-starozhilov-i-novyj-oblik-mikrorajona/)

Figure 85: Schematic distribution of the main functional zones in the new district (map is taken from https://ysia.ru/proshloe-nastoyashhee-i-budushhee-17-kvartala-yakutska-istorii-starozhilov-i-novyj-oblik-mikrorajona/)

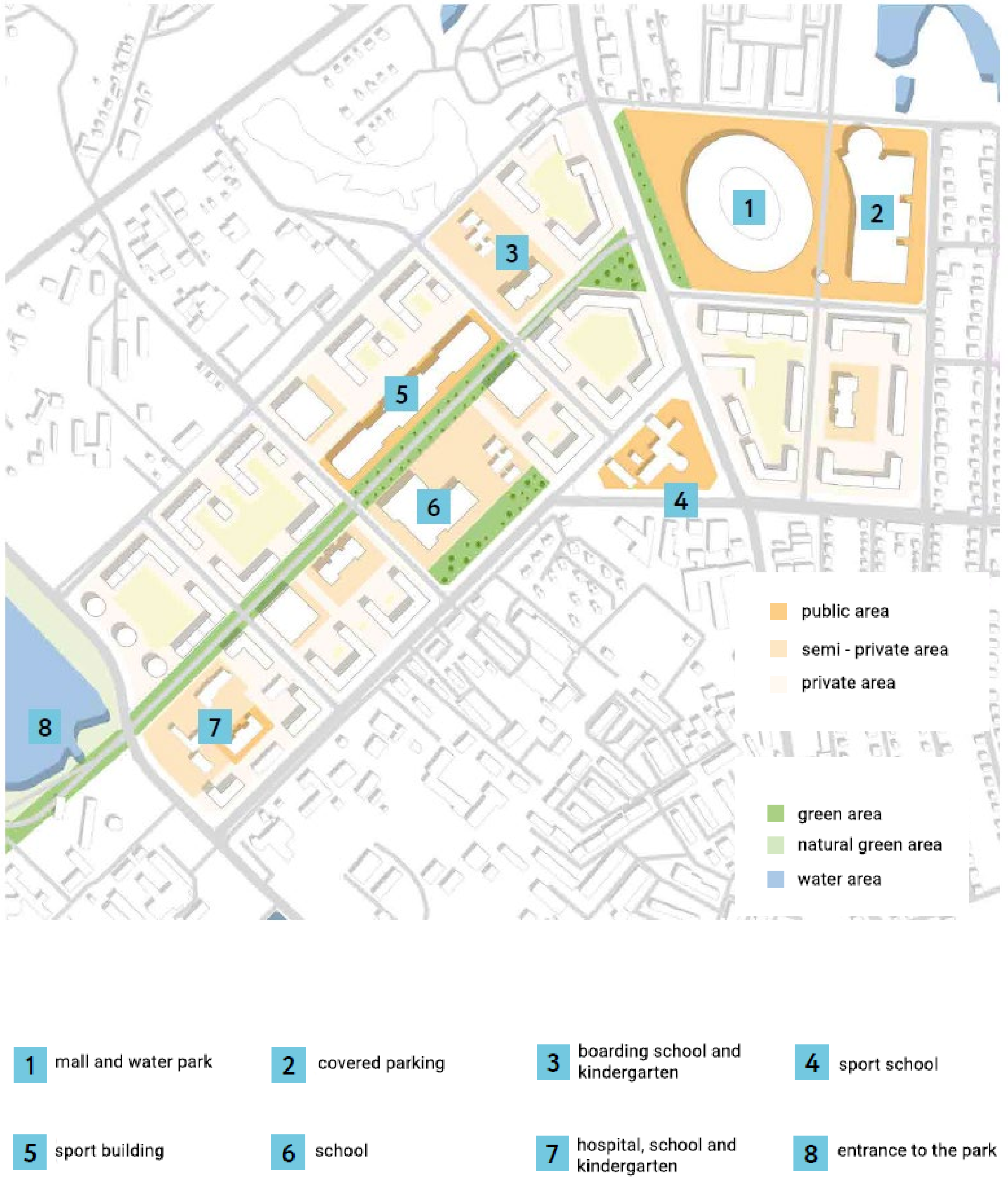


Figure 86: Schematic distribution of the main functional zones in the new district (the map is taken from the https://genplanmos.ru/project/master-plan-yakutska/)

Figure 87: A render of the residential area of the district (the picture is taken from the https://genplanmos.ru/project/master-plan-yakutska/)

Figure 88: A render of the residential area of the district (the picture is taken from the https://genplanmos.ru/project/master-plan-yakutska/)

per 200 meters, as a field for this experiment. I would take an approved project as a base for our case study and try to implement the strategies on the first residential lot in the west part of the district (the one in front of the lake).

5.3. STRATEGIES APPLICATION ON THE CHOSEN BLOCK

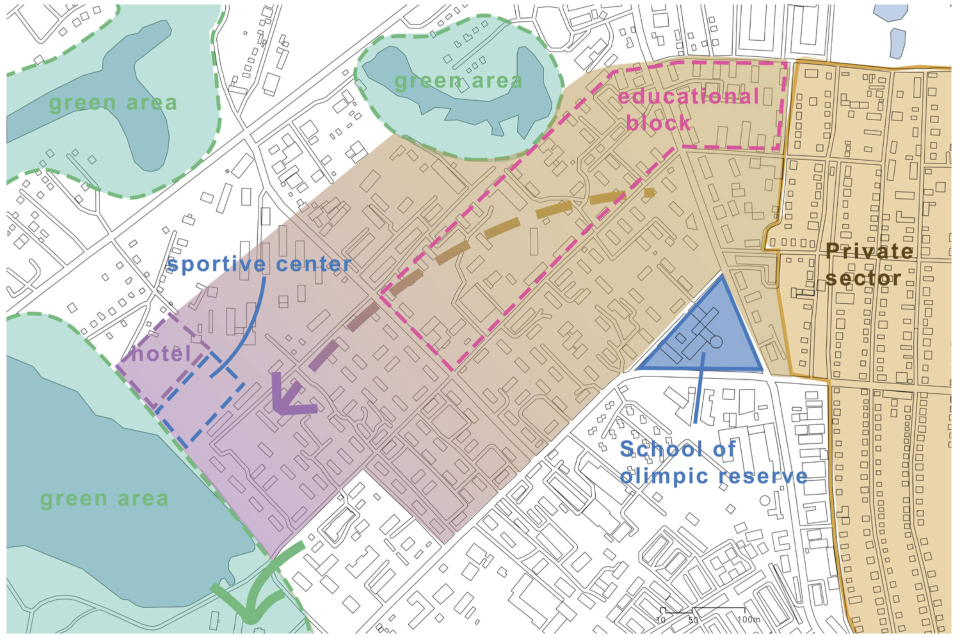
5.3.1. Strategies application on urban scale

For the implementation of our strategies, we will use the approved project of the area.

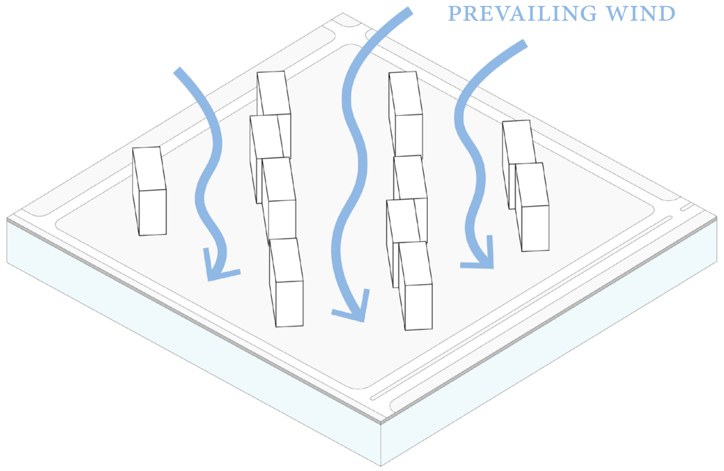
The distribution of the functions inside the district looks good. Public areas with a hotel and sport center are located in the western part of the area, closer to the park and the lake. This could help us to create a common area and connect it to the city in a way that people will have the possibility to enter the city park and have a walk around the lake.

Then, from the west to the east part of the area, functions have a gradual change from public to semi-public and private space (see figure 89). Also, the residential area has transitioned from multi-story buildings in the west part (closer to the public part) to individual houses in the east part of the area.

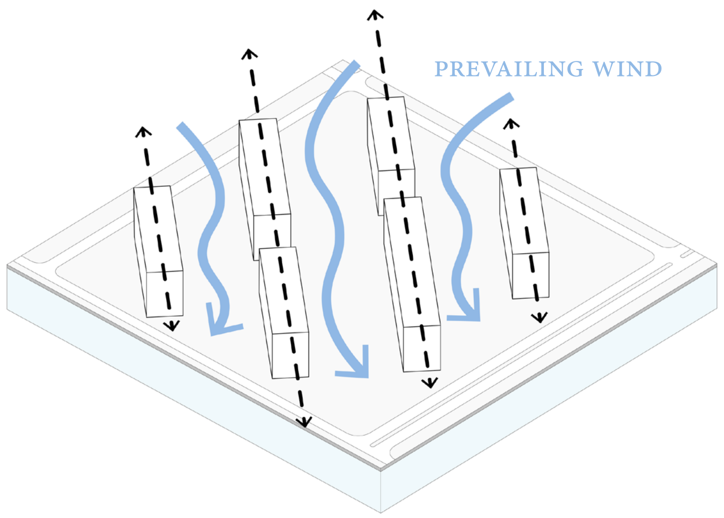
Figure 89 (on the right): The concept of the district. A gradual transition from the public zone on the left (next to the park and green area) to private areas.



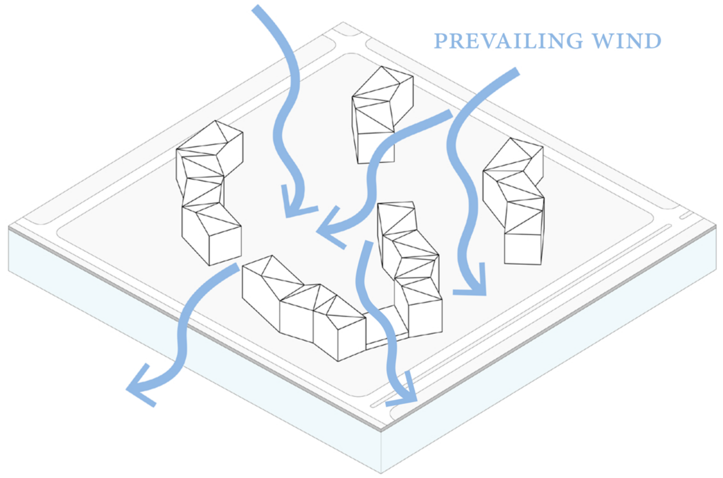
DRAINAGE AND WATER (SNOW) MANAGEMENT



The approved project of the area.



The approved project has a good positioning of the buildings in terms of wind circulation.



The shape development of the block. New shape provides good wind circulation which is important for the snow management.

Figure 90 (on top): The shape development of the block. Blue arrows represent wind circulation inside the quarter.

Drainage and water (snow) management

Let's focus on the one quarter in the western part of the district to apply all the strategies we have learnt during the research. The district is completely residential. The approved project put modular buildings oriented north-south. The predominant winter wind blows from the North and the North-east directions. This location of the buildings could help us with snow management during the long winter period. After certain negative air temperatures, snow loses its typical characteristics, becomes crumbly like sand, and can be easily moved by wind. Locating buildings in this direction would help to remove snow mass from the area and help with snow management inside the block.

As we remember, that snow could cause significant damage to the permafrost during the springtime, when snow masses are thawing and the water goes down and warms up the permafrost. Efficient snow management is important for those regions and wind could help us with that.

To make the shape of the district more interesting and dynamic, we turned existing lines into a zigzag. In this way, the quarter still has proper wind circulation but creates a more interesting design solution. The building shape development is shown in the figure 91.

Natural - based solutions

The second important strategy that we are going implement in our design on an urban scale is different natural-based solutions main purpose of which is to mitigate the effects of global warming on climate change and keep permafrost frozen during the summer time.

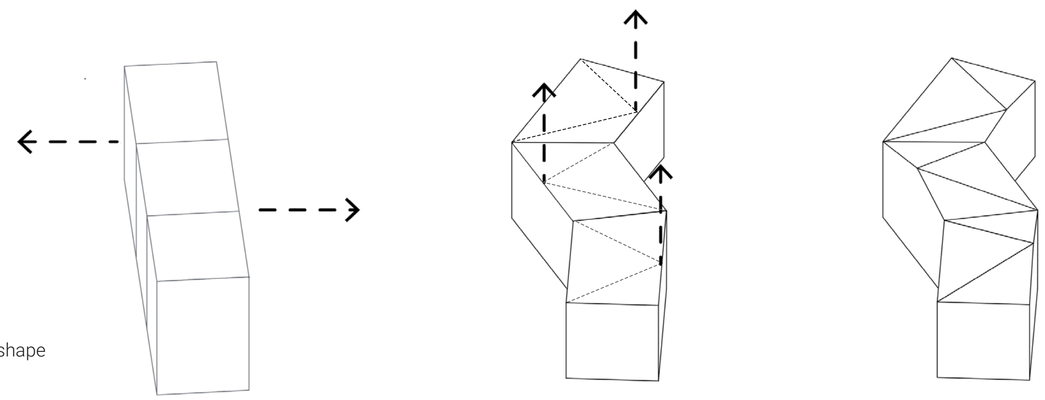
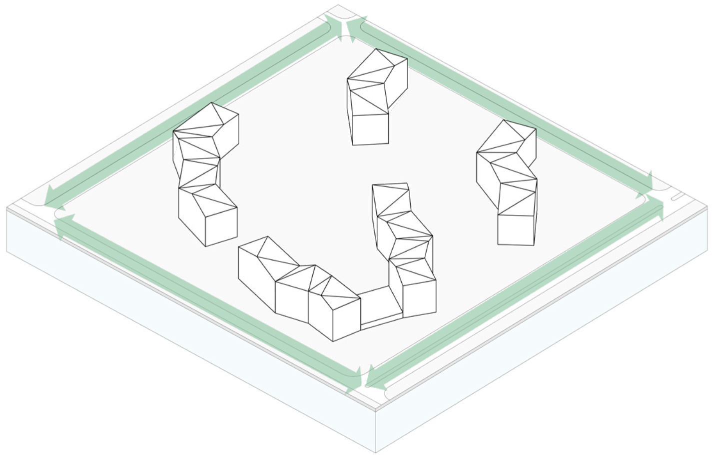


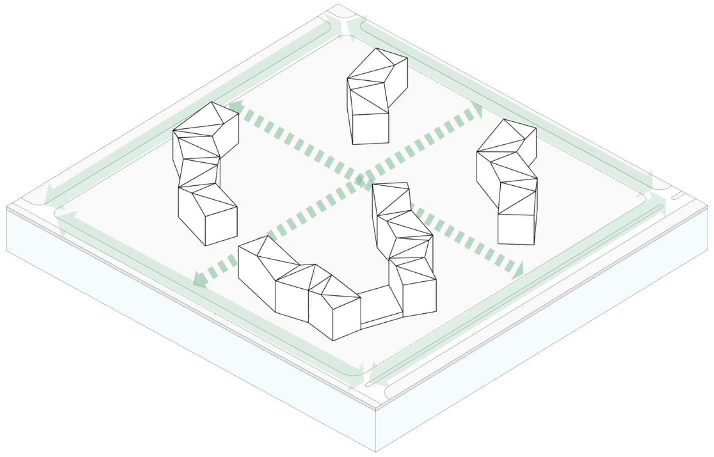
Figure 91 (on the right): The shape developpment of the building.

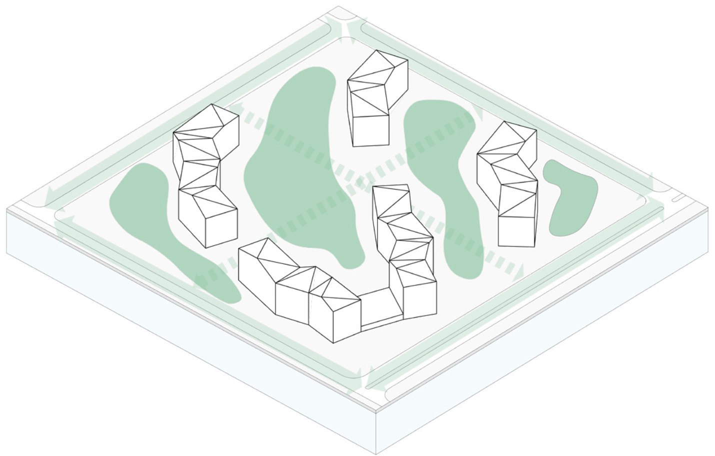
NATURAL-BASED SOLUTIONS



Four main green corridors around the block.

Two small green corridors inside the block.





Inner gardens and semi-private green areas.

Green roofs

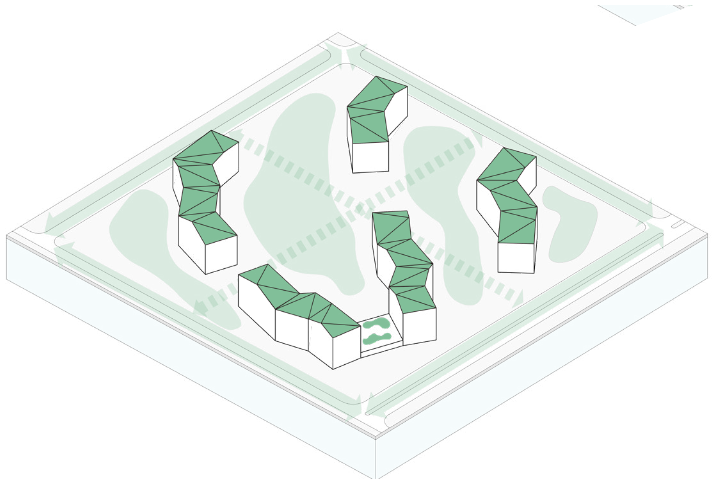


Figure 92 (on the left): The implemenation of natural-based strategies on the urban scale.

We start with implementing 4 new green corridors. These corridors are located on the main roads on the perimeter of the quartier. Green corridors with deciduous conifers could help to reduce the heat of the ground during the summertime due to the tree canopy and will create extra insulation during the spring, the most dangerous time for the permafrost, since the ground is fully exposed to solar radiation. In the case of deciduous conifers, that lose their litter in autumn, the litter layer will create a perfect thermal insulation, that could protect permafrost from thawing till the new tree canopy is formed.

An artificial insulation material such as extruded polystyrene could be used on the roads as an additional protection for these greed corridors. And light-coloured materials both for the roads and pedestrian paths.

The next step is the creation of another two green corridors, that are smaller and that are located inside of the quartier. These corridors will be predominantly used by locals for entering the quarter. The same strategies like light-coloured materials, trees chosen and artificial insulation could be used here as well.

The third step is the creation of inner gardens and public and semi-private green spaces. These areas will provide rest for locals and their structure could help to mitigate global warming effect on permafrost. The idea is to create a new landscape in these zones by creating artificial "hills". According to some research, this type of landscape could help to protect the permafrost. It is also important to use light-coloured materials for playgrounds and pedestrian ways, as well as to use insulation where it is not possible to plant trees (for example, in areas too close to the buildings). Insulation of the ground could be artificial, like we did for roads with layers of extruded polystyrene, or natural, by use of moss.

Insulating ground with moss could have a positive effect on permafrost and provide permafrost protection during the year, protecting permafrost from thawing during the summer and allowing it to freeze even more during the winter time.

The last natural-based solution will be applied on a building scale, however, could affect the microclimate of all the quartier. Green roofs with low

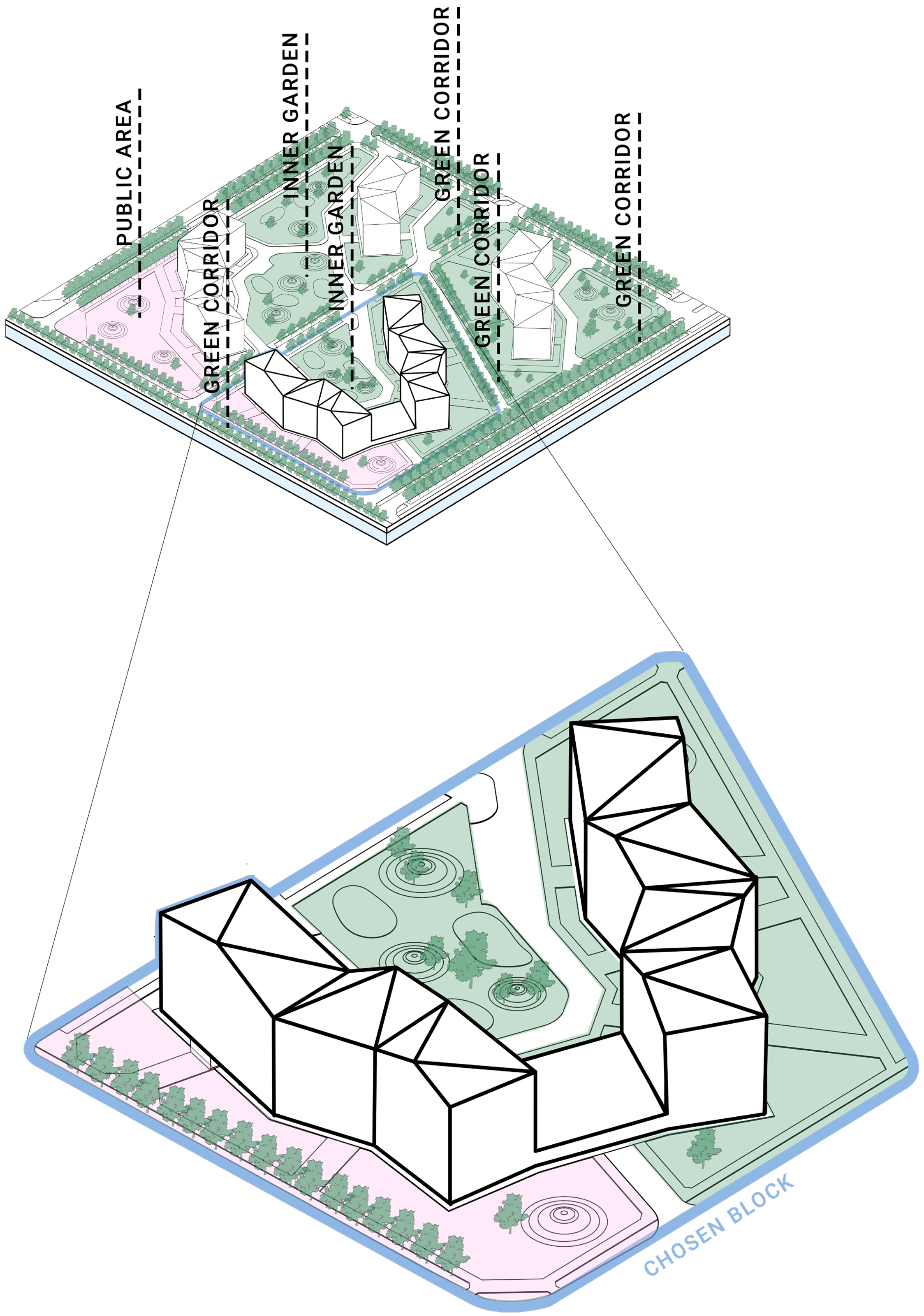


Figure 93 (on top): An urban proposal for the residential block in the 17kvartal district.

vegetation, like moss, could be a perfect solution for this region. It would reflect sun radiation and at the same time provide an extra insulation layer for the building. Moreover, moss does not require high maintenance during the lifespan of the building.

5.3.2. Strategies application on building scale

Let's move closer and see which strategies could be implemented in the building and its surroundings. The building for implementation is shown in the figure 93.

Temperature control

The buildings are 6 stories tall. They have 3 main functions: residential floors on the top, offices, and commercial areas on the first floor, and heated parking on the ground floor (it is important to have heated parking since cars cannot be turned on with these kinds of negative temperatures). This distribution of functions could have a positive effect in the case of permafrost preservation since the standard air temperature gets lower and lower as closer to the ground is located. For example, residential areas, usually have to have from + 22 to + 26°C inside, meanwhile, this parameter could be lower for the offices and commercial buildings - around + 20 - 21°C. Heated parking is usually required to have only + 5°C. These distributions

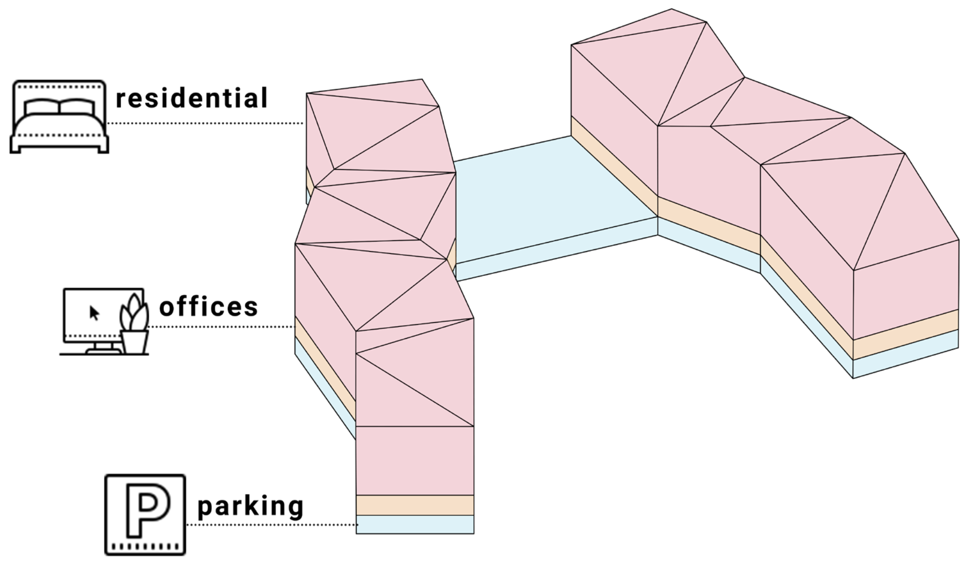


Figure 94 (on the right): The distribution of the functions inside the building.

of thermal zones in the building could help to reduce temperature closer to the ground.

Each temperature zone has to be properly insulated to avoid heat losses and provide an efficient building envelope to the building.

A stilt foundation without a ventilated floor and with thermosyphons was chosen for this building. This type of foundation showed wonderful results in terms of permafrost preservation and building stability in this region. The absence of a ventilated floor would help to protect the foundation from hot airflow during the summertime. Meanwhile, the thick insulation from extruded or expanded polystyrene and thermosyphons on the perimeter of the building would help to keep the ground frozen during the wintertime.

The stilt's foundation grid of 6 x 5 meters was perfect both for parking floor composition and flats on the top.

The width of the building is 18 meters, according to the research, it would require an insulation layer of 36 cm between the building and the ground.

This composition of the foundation should help to minimize heat losses, protect permafrost from thawing, and provide building stability even during global warming.

Moreover, the absence of a ventilated floor gives some benefits to the population with low mobility. This foundation makes buildings accessible to all types of the population.

Drainage and water (snow) management

The perimeter of the building has a slop for draining water away from the building. As we know water could cause permafrost degradation and should be drained away from the foundation, since in this case, it could provoke building instability.

Natural - based solutions

Green roofs could remind us of the building heritage of the past, create an extra insulation layer for the building, and help to reflect solar radiation during the summertime. Creating a roof with a rich variety of different

plants could be challenging in this region and expensive. Moss green roof could be an easier solution with great insulative qualities.

For the inner garden between the buildings, it is important to provide natural insulation. The best way would be to plant deciduous conifers, the ones that could create an extra insulation layer from the litter. The litter will stay during all spring and summer and help to protect permafrost during the most dangerous time of the year.

For the green areas where it is difficult or impossible to plant some trees, for example, too close to the building, it is possible to create moss lawns. Moss is a perfect insulation material. It could help to protect permafrost from thawing during the summertime and at the same time will not prevent it from freezing during the wintertime.

Artificial landscapes in the inner garden could also help to protect permafrost, creating extra zones for permafrost growth during the winter and vegetation that could protect it during the summer. Moreover, these artificial "hills" could be also used as playground elements for kids.

Light-coloured materials

It is recommended to use light-coloured materials for the pedestrian paths and playground, which could help to reduce overheating of the surfaces.

In the figures 95 and 96 you could see two sections that show how two buildings and their surroundings could work with the implementation of the mitigation and adaptation strategies. Wintertime analyses were made on the 21st of December at noon (with a sun angle of 4,35°), while summertime analyses were based on the reference day of 10th July, at the same time (with a sun angle of 49,97°).

A combination of these strategies should protect permafrost from thawing, improve building stability and provide citizens with the environment that suited for their needs.

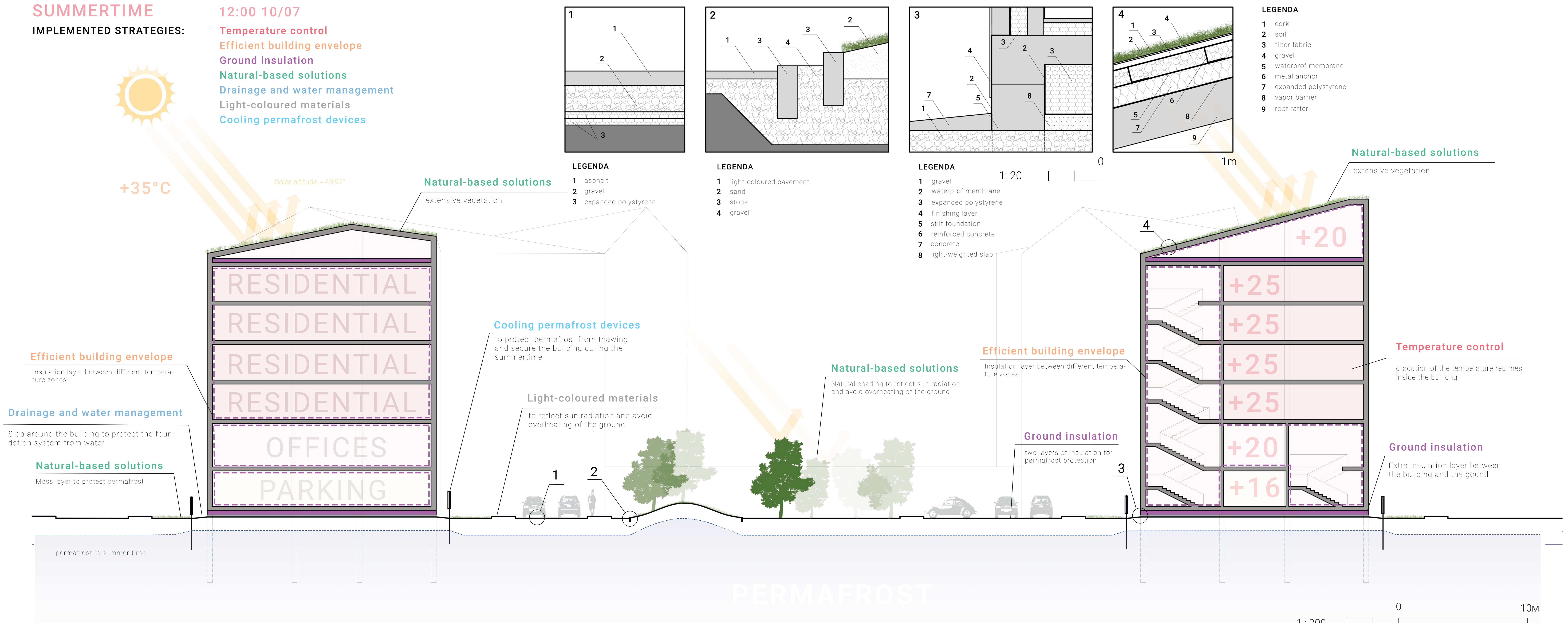


Figure 95 (on top): A section on scale 1:200 that shows implementation of the strategies on the building in the district and how do they work in the summertime

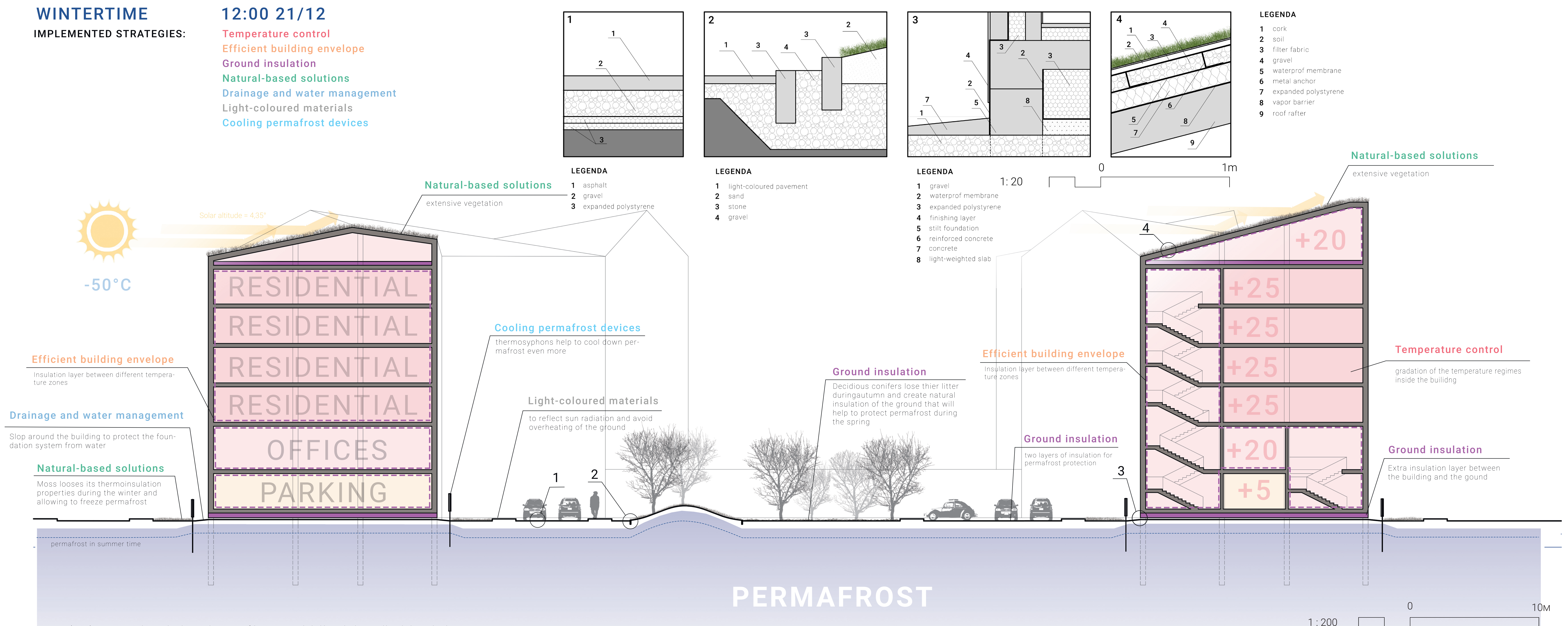


Figure 96 (on top): A section on scale 1:200 that shows implementation of the strategies on the building in the district and how do they work in the wintertime

6 CONCLUSIONS

6. Conclusions

There is not a lot of data and research about what has to be done to improve the situation with the permafrost thawing and climate change. Based on historical analyses of residential building construction in Yakutsk, existing building regulations of Canada and Russia, and available research papers, this thesis formed mitigation and adaptation strategies for permafrost regions. However, it shows only the concept of the implementation of building strategies and sketches of some technological solutions. Now it is important to continue this research, develop a detailed design for each of the building's parts, and test this solution with the help of different software.

All of the presented strategies are directly or indirectly oriented toward permafrost preservation. Most of them are based on the idea of thermal insulation during the summertime and extra cooling during the wintertime. On the building scale, permafrost and the structural part of the house present mutual danger to each other. The heat of the building thaws the permafrost beneath which as a response, challenges the structural safety of the building. That is why it is important to focus further research on the energy efficiency of the building envelope and the limitation of heat losses.

One of the research papers, that was analyzed during this thesis, claimed that there is a direct correlation between the height of the building and building envelope efficiency (Arkhangelskaya E.A., 2022), due to the increase of air pressure with the height of each floor. This could be an interesting topic to explore. Is it more difficult to avoid heat losses in the tall building? Does permafrost thaw faster beneath tall tower buildings than beneath 4-story buildings? And what height of the building could provide the best building envelope for permafrost protection?

Since we talk a lot about building envelopes, it would be an interesting opportunity to discover, which materials are the best for the extreme cold regions. What kind of material would be suitable for – 50°C in winter and at the same time for +35 °C in summer? Most of the research papers, examined for this thesis suggested that extruded or expanded polystyrene is the best insulating material. Are there any other materials that could work with the same efficiency? Are there any fully organic materials or is the use of plastic the only way for this region? What should be the thickness of thermal insulation for the floor, roof and walls?

Also, it is important to design a detailed solution for all building compounds. Since there are multiple ways how a building foundation on permafrost could be made, it could be interesting to model different designs and see through climate analysis software which of these solutions could be interchangeable and which has to stay in the past.

This thesis hasn't touched on the topic of the façade composition and especially the window/wall ratio. Living in places such as Yakutsk is challenging. The lack of sunlight during the wintertime makes this period of the year depressing and tiresome. However, enlarging the windows could cause heat losses that could lead to permafrost degradation. It could be a good opportunity to understand what is the best window/wall ratio that allows to maximize daylight in the building and the same time provides an efficient building envelope.

Urban scale also has things to explore. Most of the urban strategies presented in this thesis are an idea of how natural-based solutions could be implemented in Northern regions and how permafrost can benefit from them. There are a lot of research papers that talk about the interdependent relationship between permafrost and different species, explaining how ecosystems are affected by climate change, and which type of vegetation could help to preserve permafrost. However, there is not a lot of data on some urban actions that could be taken to mitigate global warming's effect on permafrost. It could be interesting to model and see which type of urban section is the best for the permafrost regions. What is the best way to design open areas like playgrounds or parks?

Moreover, are natural base solutions being enough for urban scale or some artificial strategies like extra insulation from extruded polystyrene always needed? Which of the proposed strategies could be improved for better results?

The thesis proposed the implementation of mitigation and adaptation strategies on residential blocks since it is the predominant type of construction in the region. In the case of Russia (which has the 60% of world permafrost territories), it is also a good opportunity to integrate these new strategies into the governmental resettlement programs and completely rebuild entire districts in these zones. The use of the strategies and their further development on a higher level of detail and research could help Russia move towards the Paris Agreement's goals, which were settled in 2015.

As always, one of the main reasons for the slow sustainable development of Far North is the budget. Nowadays, the most efficient technology for permafrost preservation and building stability is the implementation of thermosyphons. Which is also one of the most expensive technologies that was mentioned in this work. At first, it was implemented only on buildings with high-cost selling square meters, like hotels or malls. So, the investors could afford to spend their money on such a costly solution. Then, it was applied only if the building sinkage was already visible and could not be fixed in any other way. Unfortunately, not every project can afford to spend extra on the implementation of mitigation and adaptation strategies. Taking into consideration that most of the ongoing projects still use modular buildings and cheap materials to reduce the cost, so even with nowadays climatic threats, they are not going to pay more for "some strategies". It could be interesting to understand if there is a way to design a "permafrost-friendly" project that could be affordable or if these severe climate conditions will always require extra money.

This thesis is focused on residential blocks but there are other types of buildings as well. How much these strategies could change for schools, hospitals, stadiums, and other type of buildings? That is a thing that could be analyzed as well in future.

The sustainable development of the permafrost regions is a complex

topic that could challenge nowadays architects and researchers. The topic is quite new and unfortunately, there is not a lot of data that could tell what to do and how. However, it is important to start and continue to work in this direction since even in the best-case scenarios an increase in air temperature in these regions is terrifying and could give us tons of irreversible consequences. There are still a lot of aspects to research, analyze, and develop. This thesis could be considered as an introduction to the topic and a guide to discovering general strategies that might help to mitigate the situation. However, it is necessary to go deeper into the points that were mentioned above and provide some actual design solutions.

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