The Utilization of Renewable Energy Sources in the Construction and Maintenance of Transport Infrastructure

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Abstract. The article deals with the utilization of renewable energy sources in the construction and maintenance of transport infrastructure. In the introduction of the article, the authors present a brief introduction to this issue. The authors present a system that utilizes renewable energy sources, specifically solar energy, called the Solar Road System. The article describes the functionality of this system and selected advantages and disadvantages over conventional methods of winter road maintenance. In the third chapter, the authors point out the possible use of the solar road system in the wider scope of transport infrastructures, specifically the chapter focuses on the possibilities of using the system in airport construction, where the authors show this principle using a conceptual model of the airport. This chapter briefly describes the winter maintenance of airport operating areas. At the end of the article, the authors point out the possible directions that the development in this area will take and the issues that will need to be addressed in the future.

Keywords: Transport infrastructure · Solar road system · Renewable energy

1 Introduction

It is a well-known fact that a black surface has a high tendency to absorb sunlight and its rays. This absorption is manifested by a heated black surface. In the summer, we can observe and physically feel heat waves radiating from the overheated concrete. It is therefore not surprising that there have been some attempts to recover or utilize this heat accumulated in the concrete layer [1]. Initial efforts deal with the construction of roads from solar panels, as roads and transport infrastructure occupy a large area and the direct use of radiation by these panels. However, a problem arose with the load-bearing capacity and durability of these panels [2]. The panels would not be able to support the weight of heavy machinery and would not be able to support the weight of multitone aircraft at all. This ruled out the use of solar panels in an airport as well as road construction, as the use of thicker and more durable solar panels did not solve the problem either. Therefore, efforts to use the thermal energy accumulated in concrete and asphalt have

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been partially halted, but this alternative to using a renewable energy source has not been forgotten. In 2011, the UK government approved the budget, launching phase one in the ICAX project [3]. ICAX is an acronym that means Interseasonal Collection and Exchange. This project has focused and still is, on the use of renewable energy sources. It is therefore an environmental project that deals with the use of thermal energy from concrete. ICAX later joined the global organization E-Hub, which has the same focus as ICAX, i.e. the use of renewable energy sources, but on a global scale.

It is a combination, use, and improvement of roads, transport infrastructures so that, in addition to the primary task, they also provide the possibility to use their area for the collection of energy from renewable sources through the integration of technologies [4]. These technologies, we call them heat-collecting, were developed within this project. Specially to collect and accumulate energy. The concept of using infrastructures to collect solar energy is called Solar Road System. In several countries around the world, this system has been fully used in some places, such as car parking lots, since 2016. One of the countries is, for example, Switzerland or Denmark. At that time, it was approved after testing in external conditions and after fulfilling all the conditions and tests specified in the technical standards of the countries. The technology used to collect and collect solar energy is called an inter-season thermal transformation system [5].

1.1 Inter-season Thermal Transformation System

It is a complex system of heat collecting pipes, incorporated between the individual layers of the road, or other transport infrastructure. The first part of these pipes is located just below the top, bearing layer of the road, from where it directly absorbs the heat that was absorbed by the black surface. The second part is called thermobank. It is the part where the heat energy is dissipated by the pipes. This energy is also stored in this component of the system. It is the same as the first part made of pipes. It is an accumulator of thermal energy, where energy is stored until it is necessary to reuse it to heat the road [6]. The pipes are made of polyethylene and are placed and fixed on steel grids. The thermobank is located in the bottom layer and is embedded in sand or other material that would provide insulation from the environment. Above it is a layer of polystyrene, which serves as insulation. Above the polystyrene, insulating layer, there is also a layer of granular material, which has the task of absorbing water. This is so that it does not get into the next layer and does not cause any damage. Unlike conventional devices where any type of energy is stored, a thermobank can contain heat, thermal energy for several months. With conventional equipment, large heat leaks could occur [7].

For the earth, the surface of the earth is characterized by the fact that heat moves through the earth only very slowly. The speed of movement can be set at approximately 1 m/month. ICAX uses this knowledge to be able to store and insulate heat deep in the ground in the summer months and to use road heating from the thermobank during the winter. It is practically winter maintenance of the road. This heat transfer system was initially used to heat residential buildings during the winter months without the use of fossil fuels [8]. This has proven to be very effective, as in the hot summer months the concrete can heat up to 15 °C higher than the ambient temperature. During these months, the thermobank can be heated from its natural temperature of 10 °C to a temperature of more than 27 °C. The thermobank is controlled exclusively by a sophisticated computer system.

Heat transport is ensured by the fluid with which the individual pipes are filled. The reason why the fluid has been used as a transport medium is that water absorbs well and retains heat in an isolated environment. This cycle, the transport of heat from the concrete surface to the thermobank and vice versa, is ensured by the heat pump [9]. Such a heat pump can be powered by different types of energy. Solar-powered pumps are used, mainly because they can be powered directly by energy obtained directly from the road. It is sufficient for the computer to program the dissipation of a certain part of this energy for the needs of the heat pump. However, air-powered pumps are often used, which operate on a similar principle as air conditioners. As mentioned, pumps based on the principle of using solar energy are most often used in this system. Compared to others, such pumps are much more efficient in the winter, when they are most needed. They also produce very little noise, so they are quieter than otherwise driven pumps. The biggest advantage of solar-powered pumps is their long service life, which requires minimal service [10].

2 The Functionality of the Solar Road System

The solar road system has many uses, but it has two main functions. These functions can be summarized as heating and cooling functions. The cooling function is used in summer when the concrete or asphalt is overheated and no longer can absorb additional solar energy. Then this function is used, which does not cool the concrete in the direct sense with cold water or air but helps the concrete to cool by transferring the accumulated heat through pipes to a thermobank, where heat and heat energy are stored until the winter months. Therefore, the concrete is cooled by removing heat, and the concrete thus regains the capacity to store thermal energy, and this cycle is then repeated until the thermobanks are filled. However, this rarely happens as several are being built. In the summer months, the obtained solar energy can be used as a power supply for some buildings. In the case of an air-driven pump, which, as we have mentioned, works on a similar principle as air conditioning, the effect of an air-conditioning device can be achieved by reversing the operation of the pump. In the case of the second function, the heating, the name implies that it is used in the winter months. The heat stored in the thermobanks is used to heat the road with it. Such heating during the winter months, in the presence of a layer of snow on the road, can reliably dissolve this layer and ensure that it is safe without the use of sanding salts or other techniques. The integration of such a system into transport infrastructures was inspired by underfloor heating in residential buildings. This system has a promising future but is currently in a phase of continuous development. Its use in transport infrastructure around the world is being tested.

2.1 Advantages and Disadvantages of the System

The advantages of this system are that it draws energy from a renewable source, so there is no need to consider the possibility of its depletion. This system has no or minimal negative impact on the environment. Since it uses solar thermal energy obtained from the surrounding environment for its proper operation, technical failures are minimal. Therefore, minimal service interventions are also required to ensure the life of the system. Also, heat pumps used to transport energy from one point to another have the advantage that their use is broad-spectrum. Assuming that solar-powered pumps are used, their service life is considerably longer than for other pump types. It is also advantageous that in the summer months when there is an excess of thermal, solar energy, it is possible to use this energy exclusively to power pumps and other necessary elements of the system. It can also be used to power the systems of adjacent residential complexes, thus reducing overall overhead costs. For the winter maintenance of roads, as well as to reduce the snow layer and the formation of ice, not only heavy equipment is used, but also the method of sprinkling roads with salt.

However, this method has a negative impact on the road itself as well as on the vehicles that use it. The sanding salt helps to break down the road structure, supports the formation of various defects, as well as corrosion of the top layer of the road. As far as vehicles are concerned, sanding salt also causes corrosion of metal parts of vehicles. With the help of a solar road system, it is possible to manage winter maintenance in a way that is harmless compared to conventional means of ensuring winter maintenance. And even for vehicles using these roads. Regarding the influence of this system on the cement concrete structure itself, we also get to the disadvantage of this system. Cement concrete, but especially asphalt surfaces are prone to temperature changes. This means that in winter, during low temperatures, they shrink, and in summer, when temperatures rise, they expand. For this process not to affect the operating condition of the roads, expansion joints will be created during the construction of the road. Their task is to provide space for this expansion and contraction by the heat.

When using a solar road system, care must therefore be taken to ensure that the road and its surface heat up gradually and smoothly. If the cement concrete pavement heats up too quickly and suddenly, it could suffer a thermal shock due to sudden temperature changes. This could result in cracking of the concrete surface or other types of road defects. Therefore, care must be taken when using such a system, but it is still true that, when used correctly, it is the most effective way to maintain roads during the winter months. Another disadvantage is the increased cost of building such an area, where this efficient system would be integrated. The tubular system that forms the basis of the entire system is made of polyethylene, which is essentially a thermoplastic. The integration of such pipes costs on average 115 euros/m^2. Thus, the initial costs will increase, but these costs will ultimately be many times higher than the savings in winter maintenance.

This system with small modifications can also fulfill the power function, when it supplies energy to residential complexes, for example in the form of electricity. Another disadvantage is that in the event of a fault on the road, its repair will be considerably more difficult. This is because this pipe system is located below the surface layer of the cement concrete pavement, and thus care must be taken not to damage the pipes during the repair process, for example during milling. In the event of damage, the transport medium, in this case, the fluid, could leak, which would also mean a loss of stored energy and a total system failure. In the winter months, constant circulation of the liquid must be ensured to prevent the pipes and liquid from freezing. This could cause the pipe system to rupture. This solar road system during the installation phase of the collecting pipes can be seen in Fig. 1.

Fig. 1. Installation of solar road system collecting pipes

The circulation of this complex system is ensured by heat pumps. These pumps, therefore, play a key role in the proper functioning of the whole system. Therefore, their faultless operating condition must be ensured. The complexity of this system can be considered both an advantage and a disadvantage. However, the fact remains that with the correct use and maintenance of a flawless operating system, the system has no competition in the field of road or airport construction.

3 The Utilization in Airport Construction

The use of this system in airport construction represents a really wide range of possibilities. The biggest benefit would be this system in the winter months, during the winter maintenance of airport movement areas. With the arrival of winter, airports are entering a period when airport staff must be constantly prepared for what may happen. A lot of snow is needed to completely close an airport, but thanks to modern chemicals, huge snow removal facilities, and good planning, airports manage to keep runways (RWY) and taxiways (TXY) in a condition sufficient for safe takeoffs and landings of aircraft. However, the highest priority is to prevent ice formation at the RWY. Snow and rain can be dealt with relatively easily, as opposed to how difficult it is to get rid of an ice layer of an airfield if it is formed. It requires constant readiness and a lot of hard work. If an airport is caught in a snow event, all work on it will slow down. Runways, where aircraft on average take off regularly every 45 s, can ensure the take-off of one aircraft every 90 s in this state.

Workers must move on the tracks with increased caution due to increased sliding conditions and the RWYs must be closed regularly to clean and secure the road surface. Also regularly check the coefficient of friction to make sure that the runway is safe for the aircraft. This means that during a snowstorm, the airport"s ability to handle aircraft arrivals and departures can be reduced by up to 50%, i.e. by half. In the worst-case scenarios, even more, which is the reason for most canceled flights. Therefore, procedures and techniques like those used to ensure the condition of roads in road construction are used to ensure the operational condition of tracks.

As already mentioned, salt-based chemicals are used on roads to remove the ice layer, which is effective but causes corrosion of vehicles and roads. This must not be used at airports, as there must be no corrosion of runways or parts of the aircraft. Therefore, chemicals with special formulations are used at airports, but they are very expensive. On the other hand, they do not cause corrosion. On roads, they use snowplows to clear snow, with blades with steel edges. Such blades are cheaper, but they are not gentle on the road surface. For obvious reasons, potholes and various other failures cannot occur on the runways, so blades made of polyurethane are used. They are more expensive but much gentler on the surface of the tracks.

The airport, as well as its staff who provide winter maintenance for the airport, must consider the climatic conditions in which the airport is located and provide the means to carry out winter maintenance. A winter maintenance plan will also be drawn up, outlining the individual operations and the intervals at which they are performed. The use of cement concrete runways with an installed solar road system would therefore mean a revolution in the field of winter maintenance of the airport. In contrast to the expensive methods and means used to ensure safe and operational runways, runways with a solar system would be an effective solution to save in this area. The system is computer-controlled, so workers and machines would not have to enter the tracks, and thus the tracks would not have to be closed as in the normal procedure. Workers would only have to check computer-displayed information about individual tracks and their status. Then focus the system's attention on the individual problems accordingly. The tracks could then be heated by this system according to the set parameters. The use of the solar road system in practice on parts of the airport runway can be seen in Fig. 2.

Fig. 2. The utilization of solar road system in practice

It is obvious that the road where the solar road system is used has a clean surface, i.e. it is without the presence of a snow or ice layer. Elimination of ice formation is the most important factor in the efficiency of this system. The problem with the use of this system could arise in terms of the carrying capacity of the airport area, as gigantic machines, aircraft, move around the airport movement areas. This problem is currently being addressed, there is a certain effort by the E-hub organization to improve the load-bearing capacity of the road by using another, progressive cement-concrete mixture enriched with carbon fibers. This increases the flexibility and overall load-bearing capacity of this material.

Thermobanks can be near the collecting pipes, or they can be located remotely, for example, due to the use of geothermal options for better conservation of thermal energy. If excess heat accumulates in thermobanks during the summer months, this thermal energy can also be used in other ways than exclusively for heating airport runways. Buildings located at the airport, such as terminals, a hangar, or various airport workplaces, must be heated with fossil fuels during the winter months. When using a solar road system, part of the obtained thermal energy can be used to heat these mentioned buildings. This energy can also be used, for example, to heat water. In this case, it uses "clean" accumulated energy from renewable sources and also saves the cost of heating these buildings with fossil fuels. Such a three-dimensional conceptual model can be seen in Fig. 3.

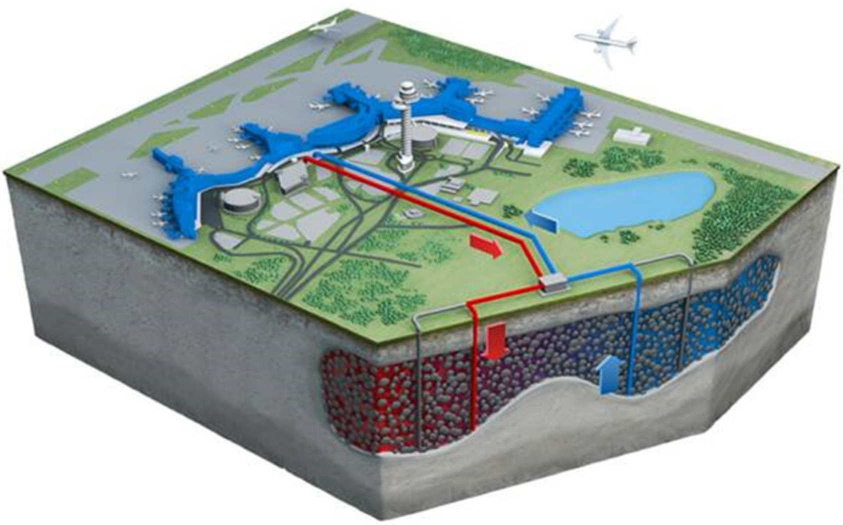

Fig. 3. 3D model of an airport with a fully integrated inter-seasonal exchange system

The location of thermobanks in the locality with geothermal activity can be seen. If the geothermal site is used correctly, the time for which thermal energy can be stored can be extended. The heat obtained through collecting rods from the airport runways utilizing another system of pipes is received from the terminal, in the direction of the arrows, to the heat pump, which ensures the circulation of the liquid. From there it gets to the thermobanks, where it can be stored. With the correct adjustment of the pump, the pump can function as an air conditioning device in the summer months, and therefore, instead of heating the terminals and adjacent buildings, it will cool them. It is more than likely that this system will have a place in the construction of airport movement areas soon. However, it still needs to be adapted to meet the specific needs of airports.

3.1 Practical Application of the System

In the case of winter maintenance of airports, the priority is to ensure the smooth and safe operation of the airport. Any operational irregularity may pose a potential threat to the smooth operation of the airport. This potential is even greater during the winter months. Therefore, the constant development in this area is noticeable in aviation. Each new technology can help airport staff and ensure its smooth operation. In aviation, safety always comes first. The department responsible for winter maintenance as may differ depending on the organization of the airport. Those winter maintenance workers at most airports with a normal hierarchy fall under the technical section of the airport. The scope and planning of winter maintenance is an important step in preparing for the winter months. It is necessary to determine the number of materials, personnel and equipment that will be used to secure it.

The weather has the biggest impact on the operation of the airport. Depending on the expected situations that may occur, scenarios are planned in advance that must be followed in order to ensure the smooth performance of winter maintenance. The staff responsible for winter maintenance must be thoroughly acquainted with these operating procedures so that, in the event of a specific scenario, each worker knows exactly what their role is. The effects of weather can vary, from heavy snow, storms and rain to icing. Each of these effects has different consequences and poses a specific threat to airport operations. To give an example of the use of a solar road system in practice, we will focus on icing.

As the riskiest stage of the flight is the take-off and landing of the aircraft, which is performed on the runway of the airport, it is necessary to ensure its fit. Any deviation from the eligible condition is a problem for smooth operation, because in the worst cases, the entire runway will be closed to restore operability, which will of course be reflected in the delay or cancellation of many flights. This type of operational irregularity can cause a so-called domino effect, where the cancellation or delay of a flight at one airport can cause operational irregularities at the airport at the destination. Regarding icing on the runway, it is necessary to define the basic factors affecting the operability of the runway. Sufficient coefficient of friction is required for correct and adequate landing braking. Briefly, the coefficient of friction is a numerical expression of the time horizon required for a complete stop of an aircraft wheel from the moment braking begins. Specific conditions are also required for the formation of icing, namely temperatures below -3 °C.

If icing forms on the runway, the coefficient of friction is significantly reduced, and thus the time required for the aircraft to come to a complete stop is increased exponentially. Another problem is that when braking, the wheel may deviate from the assumed trajectory because it loses traction with the road. At large hub airports, special sensors are installed on the runways that monitor the runway surface as well as meteorological conditions. If the conditions for the formation of icing are met and if the sensors detect its formation, an alert is immediately sent to the airport coordination department. This is usually the airport dispatching department. At small regional airports, the monitoring function is performed by so-called meteorological offices. These are airport departments, which report directly to the main meteorological office of the state, or to an office at the supranational and international level. Therefore, if the conditions for icing are met and the airport does not have sensors, the dispatcher must check the coefficient of friction on the road to determine whether the safety of operation is not endangered. To give a specific example of the use of a solar road system in the airport infrastructure, we chose an airport model with a system of sensors installed to detect icing phenomena on the runway.

Therefore, the usual procedure assumes that after detecting icing and confirming a reduction in the coefficient of friction, technical staff are sent, under the guidance of a winter maintenance master, to eliminate icing on the road. This is ensured by sprinkling the road with chemicals, usually urea. Road salt is not used at airports, as it causes corrosion that is unacceptable on aircraft. It also destroys the road surface. Upon completion of this operation, the coefficient of friction on the road shall be checked again and, if within the specified range, the road shall be declared operational. If this is not the case, it is not necessary to repeat the road surface again. These activities are very time consuming. Time is a key factor in winter airport maintenance. Every action must be taken as quickly and thoroughly as possible. Any restriction on the runway results in an increased possibility of operational irregularity. For large airports, where one aircraft lands, for example, every 10 min, time is of the essence. Failure to ensure the operability of the runway is a huge problem. It should be noted that any operational irregularity has a negative impact on passenger satisfaction, but the reputation of the airport will have a negative impact on finances, where operational irregularities cause losses not only to the airport but also to the air carrier. However, experienced teams of workers under the leadership of the master of winter maintenance, i.e. the main coordinator, manage this task. However, it is not always possible to handle this situation. If a solar road system were implemented in this process, the whole process would be significantly streamlined, either in terms of time or in terms of the use of human resources.

To demonstrate the effectiveness of this system, the airport model with re-installed runway sensors for icing detection is re-selected. If the sensor detects the formation of icing, an alert is sent to the dispatching department. It is reasonable to assume that the coefficient of friction always decreases with the occurrence of icing. Subsequently, the solar road system can be started either automatically, when the system starts automatically after receiving an alarm from the sensor system, or it can be switched on manually by the person responsible for the operability of the track. These methods can be configured according to the client's requirements. In any case, after switching on the track heating using the solar road system, icing is eliminated. It is then necessary to check the coefficient of friction, and if it is sufficient, the track is declared operational. This procedure significantly saves the time required to sprinkle the track with chemicals. Another significant advantage is the minimized environmental impact of winter maintenance. When using common chemical agents to eliminate icing on the road, these agents have a negative impact on the environment. The use of a solar road system minimizes this impact. The methodology of elimination of icing phenomena using a solar road system is shown in Fig. 4.

When using this system, there is no disturbance and degradation of the track surface, as is the case with the use of chemicals, such as urea. Finally, the money spent on the purchase of these funds, the technology needed to sprinkle the track is saved and financial losses are avoided, as the potential for operational irregularities is significantly reduced.

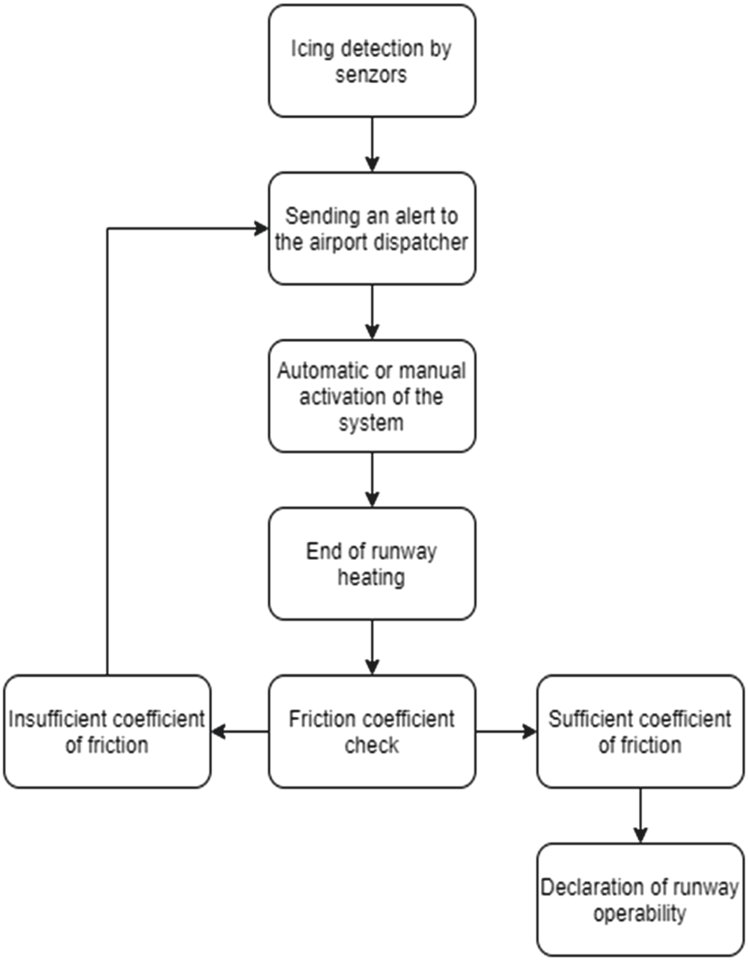

Fig. 4. The methodology of elimination of icing phenomena using a solar road system

The only problem is to ensure adequate bearing capacity of the track. However, this is the subject of current research, where it is possible to ensure the bearing capacity of the track by implementing carbon fibers in the overall structure of the road, and one of the possibilities is the implementation of nanoparticles. However, these methods require further research. It should be mentioned that the solar road system is a solution especially for the construction of new airports or the expansion of existing ones. Of course, it is also possible to modify and upgrade existing airport runways, but this would be much more costly. An adequate analysis is needed to decide on the implementation of this system into the airport infrastructure, when after its evaluation it is possible to determine the benefit of this system for a specific airport.

4 Conclusion

Technological progress is becoming more and more noticeable in everyday life. In order to improve the quality of life but also to ensure the protection of the environment and its preservation, constant development is also needed in this area. The concepts of wise cities and the ways to achieve this idea are especially at a time when the consequences of climate change are more noticeable than ever before, it is necessary to carefully assess and try to implement them. One of the components that could be to ensure sustainable development while preserving the environment in the field of transport infrastructure [11]. In the field of road and airport construction, continuous development is needed to meet the specific requirements of roads, as means of transport are constantly evolving, so are these specific means changing. One of the concepts of implementing a solar system in the roadway is that the energy collected would not be used only to ecologically ensure winter maintenance or partial supply of electricity to adjacent buildings. This concept presents the possibility of connecting the power supply of electric cars directly during their stay on the road when the accumulated solar energy would be transmitted directly to the electric cars using special panels on the road surface [12]. This could be ensured by the principle of wireless power supply, similar to the case of wireless charging of mobile phones. Such cross integration between these technologies is still the subject of future research.

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