



Technology of Concrete and Asphalt Construction Works under Winter Conditions

Nazim Manić^a, Veis Šerifi^a, Emir Maslak^a, Alema Mašović^a, Berna Krbuzlić^a

^a State University of Novi Pazar, Novi Pazar, Serbia

ARTICLE INFO

DOI: 10.31075/PIS.72.03.03
Original Scientific Paper
Received: 19.06.2026.
Accepted: 24.07.2026.
Corresponding author: nmanic@np.ac.rs

ORCID ID

Nazim Manić: 0000-0001-8346-8255
Emir Maslak: 0009-0004-2189-4282
Veis Šerifi: 0000-0002-2639-9203
Alema Mašović: 0009-0008-4381-7359
Berna Krbuzlić: 0009-0000-6915-0718

Keywords:

concrete
asphalt mixtures
low temperatures
thermal protection
heat losses
winter construction conditions

ABSTRACT

Concrete and asphalt construction works under low-temperature conditions represent significant technological and energy-related challenges due to the adverse effects of winter conditions on cement hydration, early-age concrete strength development, and the proper placement and compaction of asphalt mixtures. This paper analyzes temperature regimes during the production, transport, and placement of concrete and asphalt mixtures, as well as thermal protection methods applied under winter conditions. Special attention is given to the energy requirements for heating concrete components, including heat balance calculations and the influence of curing temperature on the development of relative concrete strength. Thermal protection methods, including the thermos method and the application of thermoactive formwork systems, are also analysed. For asphalt works, heat losses during the transport and placement of asphalt mixtures were investigated using the "MultiCool" software package. The results indicate that winter conditions lead to intensified cooling of asphalt mixtures and a reduction in the available time for adequate layer compaction.

1. Introduction

Concrete and asphalt construction works under low-temperature conditions represent a significant technological and energy-related challenge in modern construction practice. Reduced temperatures adversely affect cement hydration, early-age concrete strength development, as well as the proper placement and compaction of asphalt mixtures. Therefore, during winter conditions, the implementation of appropriate protection measures, temperature control, and optimization of technological processes during the production, transportation, and placement of materials is essential [1, 2, 3]. In concrete works, low temperatures slow down the processes of cement setting and hardening, while temperatures below the freezing point may cause freezing of water within fresh concrete mixtures, negatively affecting the strength, durability, and resistance of the structure [3, 4, 5]. At the same time, accurate prediction of temperature development within the concrete mass plays an important role in determining the energy requirements for heating concrete components and selecting appropriate thermal insulation measures [6].

In asphalt works, the dominant issue is the rapid cooling of asphalt mixtures during transportation, placement, and compaction, which reduces the available time for achieving the required layer density [6, 9]. Low air and pavement temperatures increase the risk of cracking, reduce the quality of the surface layer, and negatively affect the long-term durability of pavement structures [7, 8]. Previous studies have shown that proper transportation organization, temperature regime control, and the application of low-temperature asphalt paving technologies can significantly reduce heat losses and improve the quality of constructed pavement layers [9, 10]. The aim of this paper is to analyze the technological and energy-related aspects of concrete and asphalt construction works under winter conditions, with particular emphasis on heating concrete components, methods of fresh concrete protection, and heat losses of asphalt mixtures during transportation and placement. The paper analyzes the influence of temperature conditions on the quality of constructed structures, including characteristic energy calculations and an analysis of temperature regimes during construction operations.

2. General Remarks on Concrete Works under Low-Temperature Conditions

The production and placement of concrete under low-temperature conditions represent a specific technological process due to the significant influence of temperature on cement hydration, early-age strength development, and concrete curing. According to the recommendations of the American Concrete Institute (ACI 306R-16), cold weather conditions are defined as a period of at least three consecutive days during which the average daily air temperature does not exceed 5 °C, while the temperature remains below 10 °C for more than 12 h per day [1, 3]. During cement hydration, heat is released, which may contribute to protecting fresh concrete from freezing in the early stages of curing. However, under extremely low temperatures or sudden temperature drops, freezing of water within the pores of fresh concrete may occur, causing microcracking and permanent damage to the cement matrix. Such damage results in reduced strength, watertightness, and long-term durability of the structure [3, 4, 5]. Concrete resistance to frost action depends on the level of strength developed at the time of exposure to low temperatures. In practice, concrete is generally required to achieve at least approximately 5 MPa of early-age strength in order to prevent damage caused by freezing of pore water, while more critical structures are recommended to reach approximately 70% of the design strength before prolonged exposure to frost conditions [1, 5]. A decrease in temperature significantly slows down cement hydration. At temperatures below 5 °C, strength development proceeds much more slowly, while at temperatures around -10 °C the hydration process is almost completely stopped [4, 5]. Therefore, during winter conditions it is necessary to ensure an adequate temperature of the fresh concrete mixture prior to placement, as well as the application of protective measures after concreting. A particular problem is represented by heat losses during the transportation and placement of concrete, where the cooling intensity depends on ambient temperature, transportation duration, and structural geometry. Consequently, practical measures include heating of water and aggregates, thermal insulation of formwork, protective covering of exposed surfaces, and the use of chemical.

3. Temperature Regimes during the Production and Placement of Concrete

Concrete production under low-temperature conditions requires the application of specific technological measures in order to maintain an adequate temperature of the fresh concrete mixture and prevent ice formation within the concrete structure. During winter conditions, the majority of additional energy consumption is associated with heating water and aggregates to ensure uninterrupted cement hydration and proper early-age strength development [1, 3]. In the case of dry aggregates without the presence of ice, the required temperature of the fresh concrete mixture is generally achieved by heating the mixing water. However, at ambient temperatures below approximately -4 °C, additional heating of aggregates is also necessary in order to maintain the prescribed mixture temperature during transportation and placement [3]. The recommended maximum temperature of fresh concrete produced by heating its components is approximately 32 °C, while controlled heating procedures and avoidance of sudden temperature variations between individual concrete batches are required [1].

When the water temperature exceeds approximately 80 °C, the sequence of mixing concrete components must be adjusted to prevent localized overheating of cement and undesirable effects during hydration. In practice, heated water is first mixed with coarse aggregate, followed by the addition of fine aggregate and cement. Furthermore, heating aggregates above 15 °C is generally unnecessary if the mixing water is heated to approximately 60 °C [3]. Energy losses during the winter period are also influenced by seasonal variations in aggregate temperature. During autumn, aggregate temperature may be higher than ambient air temperature, whereas the opposite situation is commonly observed during spring. The application of water and aggregate heating systems increases the overall cost of concrete production by approximately 10–15%, representing a significant factor in planning construction activities under winter conditions [3].

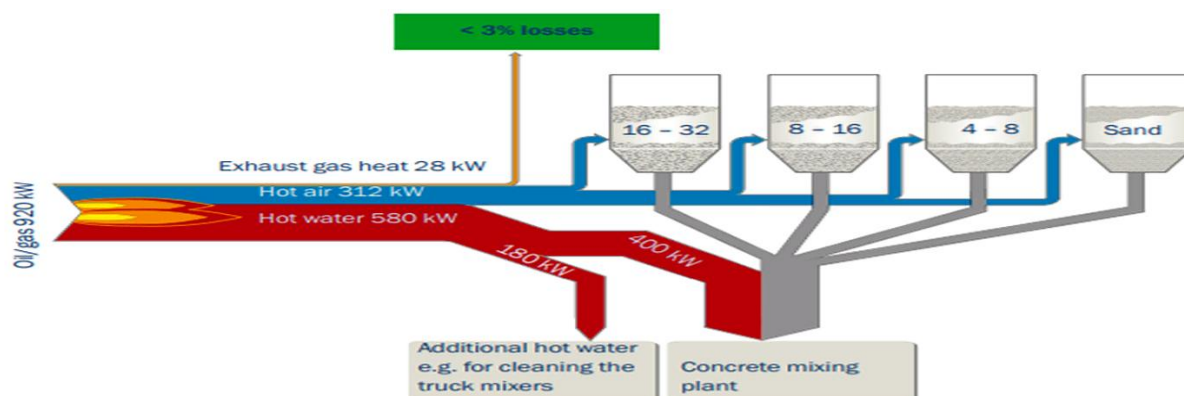


Figure 1. Schematic Representation of a Concrete Component Heating Plant

3.1. Energy Requirements for Heating Concrete Components

Under winter concrete production conditions, it is necessary to ensure an adequate temperature of the fresh concrete mixture in order to prevent water freezing within the concrete and to enable proper cement hydration. The calculation of the required heating temperature of concrete components is based on the heat balance principle of the fresh concrete mixture, taking into account the mass and specific heat capacity of all concrete components, in accordance with the recommendations of ACI 306R-16 [1] and the analyses presented by Carino [3].

Table 1. Input Data for the Heat Balance Calculation of the Concrete Mixture

Parameter	Symbol	Value
Required concrete temperature after mixing	t_{sprav}	15 °C
Aggregate and moisture temperature	$t_{ag} = t_{vl}$	-15 °C
Cement temperature	t_{cem}	0 °C
Water temperature before heating	t_v	1 °C
Water temperature after heating	t_{vgr}	80 °C
Aggregate quantity	Q_{ag}	2145 kg
Aggregate moisture content	—	5.64 %
Cement quantity	Q_{cem}	300 kg
Total water quantity	Q_v	180 kg
Specific heat capacity of aggregate	S_{ag}	0.84 kJ/kg°C
Specific heat capacity of water	S_v	4.2 kJ/kg°C

Source: (authors')

Table 1 presents the input parameters adopted for the heat-balance calculation. The low initial aggregate temperature and its moisture content significantly affect the energy required to achieve the specified concrete temperature.

Table 2. Results of the Heat Balance Calculation

Quantity	Expression	Result
Quantity of water contained in the aggregate	$Q_{vl} = 2145 \cdot 0,0564$	≈ 121 kg
Added water quantity	$Q_{v,dod} = 180 - 121$	59 kg
Required aggregate heating temperature	t_{ag}	16,62 °C
Energy required for water heating	$Q_v = 4.2 \cdot 59 \cdot (80 - 1)$	19576,2 kJ/m ³
Energy required for heating aggregate with moisture	$Q_{ag+vl} = 0,84 \cdot 2145 \cdot 31,62 + 2,1 \cdot 121 \cdot 15 + 335 \cdot 121 + 4,2 \cdot 121 \cdot 16,62$	≈ 109765,7 kJ/m ³
Total required energy	$Q_{en} = 19576,2 + 100539,6$	129341,9 kJ/m ³
Total required energy	$Q_{en} = 129,341.9 / 1000$	≈ 129,3 MJ/m ³

Source: (Authors' calculations)

As shown in Table 2, most of the calculated energy demand is associated with heating the aggregate and its moisture. The total energy requirement of approximately 120.1 MJ/m³ confirms the dominant influence of aggregate heating on winter concrete production. The obtained results indicate that the energy required for heating concrete components increases significantly with decreasing ambient temperature, with the largest portion of the total energy consumption associated with aggregate heating. In addition to energy requirements, the curing temperature directly affects the development of early-age concrete strength, as presented in Table 3. Table 3 presents the influence of curing temperature on the relative strength development of concrete produced with different types of cement. The results show that lower temperatures significantly slow down early-age strength development, particularly during the initial curing period.

Table 3. Influence of Curing Temperature on the Relative Strength Development of Concrete

Cement Type	Number of Curing Days	Average Concrete Temperature during Curing					
		1°C	5°C	10°C	15°C	20°C	25°C
		Relative Concrete Strength (%)					
Portland Cement 30	3	12	17	24	33	40	44
	5	20	26	35	45	50	56
	7	27	35	42	52	59	66
	10	37	45	53	64	72	78
	15	47	57	68	77	85	92
	28	65	79	90	100	-	-
Portland Cement 40	3	14	21	30	37	45	52
	5	21	30	38	47	56	63
	7	27	37	47	55	64	72
	10	36	47	57	67	75	83
	15	49	60	72	83	92	97
	28	70	80	91	100	-	-
Portland Cement 50	3	17	22	29	34	47	52
	5	26	34	40	47	57	64
	7	35	43	52	61	68	75
	10	46	55	65	75	82	87
	15	57	70	80	89	99	-
	28	75	86	95	100	-	-

Source: (Authors' compilation based on [1, 3])

The analysis of the results presented in Table 3 indicates that an increase in curing temperature significantly accelerates the development of relative concrete strength. At temperatures between 1 and 5 °C, strength development is considerably slower compared to curing conditions at 15–25 °C, confirming the necessity of applying thermal protection measures during winter conditions.

3.2. Thermal Protection Methods for Concrete under Low-Temperature Conditions

Maintaining adequate temperature conditions during curing represents one of the key requirements in concrete construction under winter conditions.

3.2.1. Thermos Method

The thermos method represents one of the most commonly applied concreting techniques under low-temperature conditions. The method is based on providing an adequate initial temperature of the fresh concrete mixture and preserving the heat generated during cement hydration through the application of thermal insulation measures. According to the recommendations of ACI 306R-16, concrete should achieve approximately 70% of its design strength before the concrete temperature falls below 0 °C [1]. For massive and moderately massive structures with a surface modulus lower than 8 m⁻¹, additional heating of the concrete mass is often unnecessary because the heat generated by cement hydration is sufficient to maintain the required temperature. In contrast, slender and segmented structures experience more intensive heat losses, requiring the application of additional heating and more efficient thermal insulation measures [1, 3]. To estimate the duration for which concrete can be maintained above the minimum allowable temperature, a heat-balance analysis of the concrete element is required. Under the assumptions of uniform concrete temperature, constant ambient conditions, and constant thermal properties, the approximate duration of the protection period may be estimated using the following expression [1]:

$$Z = \frac{(\rho_{con} \cdot C_{con} \cdot (T_{initial} - T_{final}) + m_c \cdot H_h)}{M_s \cdot U \cdot (T_{avg} - T_{amb})} \quad (1)$$

where: Z - estimated duration of the concrete protection period (s); ρ_{con} - density of concrete (kg/m³); C_{con} - specific heat capacity of concrete (J/(kg·K)); $T_{initial}$ - initial concrete temperature (°C); T_{final} - minimum allowable concrete temperature at the end of the protection period (°C); m_c - cement content per unit volume of concrete (kg/m³); H_h - effective heat of cement hydration released during the considered period (J/kg); M_s - surface modulus of the structural element (m⁻¹); U - overall heat transfer coefficient (W/(m²·K)); T_{avg} - average concrete temperature during the protection period (°C); and T_{amb} - ambient air temperature (°C).

$$U = \frac{1}{R_{si} + \sum_{i=1}^n \frac{d_i}{\lambda_i} + R_{se}} \quad (2)$$

where: U - overall heat transfer coefficient (W/(m²·K)); R_{si} - internal surface thermal resistance (m²·K/W); R_{se} - external surface thermal resistance (m²·K/W); d_i - thickness of the i-th insulation layer (m); λ_i - thermal conductivity of the i-th insulation material (W/(m·K)); and $\sum_{i=1}^n \frac{d_i}{\lambda_i}$ - total thermal resistance of the insulation layers (m²·K/W).

Table 4. Time required to achieve the design strength at different curing temperatures

Average Concrete Curing Temperature (°C)	Time Required to Achieve 70% of the Design Strength (days)
-10	Hydration Almost Completely Stopped
-5	> 35
0	28
5	22
6.9	19
10	14
15	10
20	7
25	5

Source: [1, 3]

T

Table 4 presents the time required to achieve approximately 70% of the design strength at different concrete curing temperatures. The obtained results indicate that an appropriate selection of thermal insulation measures and proper control of temperature regimes can provide sufficient curing time for concrete under low ambient temperature conditions [1, 3].

3.2.2. Application of Thermoactive Formwork Systems

Thermoactive formwork systems represent one of the most efficient concreting methods under low-temperature conditions, particularly in cases where rapid development of early-age concrete strength is required. The method is based on the use of formwork equipped with integrated heating elements, which enable controlled heating of the concrete mass and reduction of heat losses during the curing process [1, 3]. The application of thermoactive formwork enables faster achievement of the required concrete strength compared to conventional protection methods, allowing concrete to reach approximately 60–70% of its design strength within a shorter period of time [2]. This method is particularly suitable for slender and segmented structures with a high surface-to-volume ratio, where intensive heat losses occur. In practice, thermoactive formwork systems are most commonly applied for structures with a surface modulus greater than 6 m⁻¹. For more massive structures, low-temperature heating regimes are generally applied, with an average concrete temperature of approximately $t_{b,sr}=40^{\circ}\text{C}$.

The energy consumption of thermoactive formwork systems depends on the thermal characteristics of concrete, structural geometry, dimensions of heating panels, and ambient temperature. According to literature data, thermoactive formwork systems used at an ambient temperature of $-20\text{ }^{\circ}\text{C}$ achieved heating capacities ranging from 0.4 to 1.5 kW/m^2 , while the corresponding energy consumption was approximately:

- 45 kWh/m^3 for massive walls,
- 35 kWh/m^3 for isolated footings,
- 25 kWh/m^3 for slab girders [11].

The obtained data confirm that thermoactive formwork systems represent an efficient solution for concrete construction under low-temperature conditions, particularly for structures requiring accelerated curing with reduced heat losses.

4. Temperature Regimes during the Production and Placement of Asphalt Mixtures

4.1. Temperature Regimes of Asphalt Mixtures

Asphalt paving operations under low-temperature conditions represent a significant technological challenge, since weather conditions directly affect the proper placement and compaction of asphalt mixtures. Air and pavement temperatures, wind speed, and transportation duration have a considerable influence on the cooling rate of the mixture, the quality of the constructed pavement layer, and its long-term durability [7, 8, 12]. During transportation, placement, and compaction, it is necessary to maintain the asphalt mixture temperature within the prescribed temperature range. Under unfavorable weather conditions, accelerated cooling of the mixture occurs, reducing the available time required to achieve the specified layer density. Insufficiently compacted asphalt mixtures may result in increased porosity, reduced resistance to water penetration, cracking, and accelerated deterioration of pavement structures [8, 13, 14].

According to recommendations for asphalt paving operations, both air and pavement temperatures must satisfy minimum requirements in order for asphalt mixture placement to be permitted. For binder and base layers thicker than 30 mm , a minimum temperature of $5\text{ }^{\circ}\text{C}$ is recommended, while for wearing courses thinner than 30 mm , a minimum temperature of $10\text{ }^{\circ}\text{C}$ is recommended [12, 15]. These limitations are particularly important for thin asphalt layers due to increased heat losses caused by a higher surface-to-volume ratio. The cooling intensity of asphalt mixtures during transportation depends on ambient temperature, wind speed, transportation duration, layer type and thickness, the protection method of transport vehicles, and the thermal properties of the mixture. If the mixture temperature falls below the minimum allowable value before compaction is completed, the quality of the constructed layer may be significantly impaired [7, 9, 10, 12].

For hot mix asphalt concretes, the following temperature regimes are recommended [11, 12]:

- bitumen storage temperature: $130\text{--}160\text{ }^{\circ}\text{C}$,
- maximum allowable bitumen temperature: $175\text{ }^{\circ}\text{C}$,
- recommended asphalt mixture temperature at the asphalt plant outlet: $140 \pm 10\text{ }^{\circ}\text{C}$ to $170 \pm 10\text{ }^{\circ}\text{C}$,
- maximum asphalt mixture production temperature: $180\text{ }^{\circ}\text{C}$,
- recommended asphalt mixture temperature at the placement site: $130 \pm 10\text{ }^{\circ}\text{C}$ to $160 \pm 10\text{ }^{\circ}\text{C}$,
- minimum allowable asphalt mixture temperature before compaction: $90\text{ }^{\circ}\text{C}$.

Recent studies indicate that proper control of temperature regimes during the production, transportation, and placement of asphalt mixtures is essential for achieving the required density, durability, and resistance of pavement structures, particularly under low-temperature conditions [7, 8, 10, 13]. Furthermore, the application of asphalt mixtures designed for placement at lower temperatures may contribute to reduced energy consumption and improved organization of construction activities under unfavorable weather conditions [9, 10]. In order to analyze the time available for proper placement and compaction of asphalt mixtures, the "MultiCool" software package was used to simulate the cooling process of asphalt mixtures under different weather conditions and layer thicknesses.

Table 5. Influence of Air Temperature and Layer Thickness on the Available Time for Asphalt Mixture Compaction

Parameter / Temperature	3,81 cm	5,08 cm	7,62 cm
Available Time for Compaction (min)			
4.44 $^{\circ}\text{C}$	16	25	46
10.00 $^{\circ}\text{C}$	17	27	50
15.56 $^{\circ}\text{C}$	19	30	55
21.11 $^{\circ}\text{C}$	21	33	60
26.67 $^{\circ}\text{C}$	24	37	67

Source: [12, 16]

The analysis of the results presented in Table 5 indicates that an increase in air and subgrade temperature significantly extends the time available for proper compaction of the asphalt mixture. At an air temperature of $4.44\text{ }^{\circ}\text{C}$, the available compaction time for a 3.81 cm thick layer is only 16 min , whereas at a temperature of $26.67\text{ }^{\circ}\text{C}$ it increases to approximately 24 min . The influence of asphalt layer thickness is particularly pronounced. Thicker asphalt layers lose heat more slowly due to their greater thermal mass and lower surface-to-volume ratio. Thus, a layer thickness of 7.62 cm at an air temperature of $4.44\text{ }^{\circ}\text{C}$ maintains a temperature suitable for compaction for approximately 46 min , which is nearly three times longer than for a 3.81 cm thick layer.

The obtained results confirm that low-temperature conditions represent one of the key factors limiting the proper placement of asphalt mixtures. Therefore, during asphalt paving operations under winter conditions, it is necessary to:

- reduce transportation time,
- use thermally insulated transport vehicles,
- optimize paving and compaction operations,
- increase temperature regime control during construction activities [7, 9, 12, 14].

Based on the presented results, it can be concluded that controlling heat losses is one of the essential requirements for achieving adequate density, durability, and functionality of pavement structures under low-temperature conditions. The application of modern low-temperature asphalt paving technologies and improved transportation organization can significantly contribute to reducing heat losses and improving the quality of constructed pavement layers [9, 10]. In order to provide a clearer understanding of the influence of ambient temperature on the cooling process of asphalt mixtures, a comparison was performed between the results obtained under winter and summer paving conditions. The analysis was carried out using the “MultiCool” software package, while changes in asphalt mixture temperature over time after delivery to the construction site were monitored.

4.2. Heat Losses during Transportation and Placement

In order to analyze the cooling process of asphalt mixtures, the “MultiCool” software package was used to simulate the variation of asphalt mixture temperature over time under different ambient temperature conditions. The temperature changes of the asphalt mixture after 15 min of transportation and placement were analyzed for different ambient temperatures.

Table 6. Influence of Ambient Temperature on the Cooling of Asphalt Mixtures after 15 min of Transportation and Placement

Air Temperature (°C)	Initial Asphalt Mixture Temperature (°C)	Cooling Time (min)	Asphalt Mixture Temperature after 15 min (°C)
-10	160	15	88.420
-5	160	15	91.375
0	160	15	93.102
5	160	15	93.734
10	160	15	114.543
15	160	15	114.860
20	160	15	115.071
25	160	15	115.388
30	160	15	115.705

Source: [12, 14, 16]

The results presented in Table 6 indicate that asphalt mixtures lose heat significantly faster at lower ambient temperatures. A particularly pronounced temperature decrease occurs at temperatures below 0 °C, where the asphalt mixture temperature after 15 min may fall below the recommended values required for effective compaction. Based on the obtained results, a graphical comparison of the asphalt mixture cooling process under winter and summer conditions was performed, as presented in Figure 2.

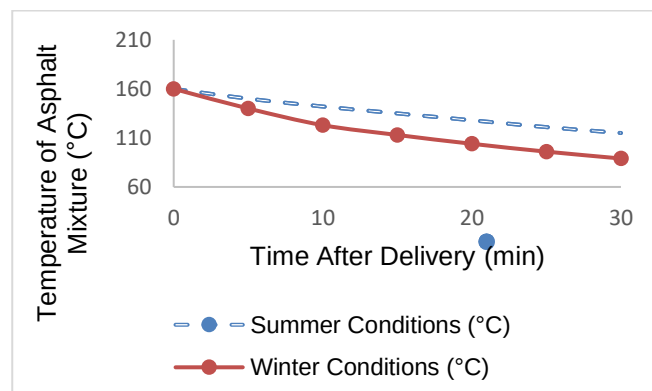


Figure 2. Influence of Ambient Temperature on the Cooling Process of Asphalt Mixtures

The analysis of the results presented in Figure 2 confirms that under winter conditions asphalt mixtures experience more intensive cooling, resulting in a reduction of the available time for transportation, placement, and compaction of asphalt layers.

4.3. Comparative Analysis of Results

The obtained results confirm the significant influence of ambient conditions on the cooling rate of asphalt mixtures. Under winter conditions, more intensive heat losses occur, significantly reducing the available time for transportation, placement, and compaction of asphalt mixtures. The analysis confirms that maintaining an adequate temperature regime during asphalt paving operations is essential for achieving the required pavement density, durability, and long-term performance under low-temperature conditions. Proper coordination of transport, paving, and compaction activities significantly reduces heat losses and improves construction quality. [7, 9, 14, 15]. The obtained results confirm that proper organization of asphalt paving operations and effective control of heat losses have a significant influence on the density, durability, and functionality of pavement structures, particularly under winter construction conditions [8, 9, 10].

5. Conclusion

Concrete and asphalt construction works under low-temperature conditions represent significant technological and energy-related challenges due to the adverse effects of low temperatures on cement hydration, early-age concrete strength development, and the proper placement and compaction of asphalt mixtures.

Therefore, during winter conditions it is necessary to apply appropriate protective measures and maintain adequate temperature control during the production, transportation, and placement of construction materials. The analysis of the energy aspects of concrete production showed that heating water and aggregates represents a significant portion of the total energy consumption under winter conditions. The calculations indicated that approximately 120 MJ of energy is required for heating the components of 1 m³ of concrete at an ambient temperature of -15 °C. The obtained results confirm the importance of proper temperature control of concrete components in order to prevent freezing of fresh concrete mixtures and ensure adequate early-age concrete strength development.

The analyzed thermal protection methods demonstrated that the thermos method and thermoactive formwork systems represent effective solutions for maintaining the required temperature conditions during concrete curing. By selecting appropriate thermal insulation measures and applying controlled heating regimes, it is possible to ensure sufficient curing time while reducing heat losses.

For asphalt paving operations, it was determined that air and pavement temperatures, wind speed, and asphalt layer thickness have a direct influence on the cooling rate of asphalt mixtures and the available time for proper compaction. Simulation results showed that asphalt mixtures under winter conditions lose temperature significantly faster, increasing the risk of insufficient compaction of asphalt layers. A comparative analysis of winter and summer conditions revealed a temperature difference of approximately 22 °C after 15 min from the delivery of the asphalt mixture to the placement site. The obtained results confirm that temperature regime control, reduction of heat losses, and proper organization of construction activities are of crucial importance for the quality and durability of pavement structures. Based on the conducted analyses, it can be concluded that construction works under low-temperature conditions require additional energy investments; however, the proper application of protective and technological measures enables the preservation of structural quality and continuity of construction activities during the winter period. Modern thermal protection methods and temperature control systems can significantly contribute to improving construction efficiency and reducing the risk of damage caused by low-temperature effects.

References

- [1] American Concrete Institute. (2017). *Guide to cold weather concreting (ACI 306R-16)*. American Concrete Institute.
- [2] European Committee for Standardization. (2016). *EN 206: Concrete – Specification, performance, production and conformity*. CEN.
- [3] Carino, N. J. (2004). Cold weather concreting. *Concrete International*, 26(7), 48–55.
- [4] Nassif, A. Y., Suksawang, N., & Mohammed, S. (2013). Influence of cold weather during casting and curing on the stiffness and strength of concrete. *Construction and Building Materials*, 44, 161–167. <https://doi.org/10.1016/j.conbuildmat.2013.03.004>
- [5] Cui, J., Hama, Y., Taniguchi, M., & Katsura, O. (2022). Evaluation of applicability of minimum required compressive strength for cold weather concreting based on winter meteorological factors. *Materials*, 15(23), 8515. <https://doi.org/10.3390/ma15238515>
- [6] Kim, J. K., & Lee, C. S. (1998). Prediction of temperature development in concrete under cold weather conditions. *Cement and Concrete Research*, 28(3), 363–371. [https://doi.org/10.1016/S0008-8846\(98\)00002-8](https://doi.org/10.1016/S0008-8846(98)00002-8)
- [7] West, R., Rodezno, C., Julian, G., & Prowell, B. (2010). *Warm mix asphalt best practices*. Federal Highway Administration.
- [8] Ma, R., Zhang, Y., Liu, H., & Wang, F. (2024). Low-temperature cracking and improvement methods for asphalt pavements in cold regions: A review. *Buildings*, 14(12), 3802. <https://doi.org/10.3390/buildings14123802>
- [9] Kristjansdottir, O. (2006). *Warm mix asphalt for cold weather paving* [Master's thesis, University of Washington].
- [10] Nicholls, J. C., & James, D. (2012). Literature review of lower temperature asphalt systems. *Proceedings of the Institution of Civil Engineers – Construction Materials*, 165(1), 1–8. <https://doi.org/10.1680/coma.11.00051>
- [11] ASTM International. (2020). *ASTM C1064/C1064M-20: Standard test method for temperature of freshly mixed hydraulic-cement concrete*. ASTM International. [12] Federal Highway Administration. (2000). *Hot mix asphalt paving handbook*. U.S. Department of Transportation.
- [13] Timm, D. H., & Newcomb, D. E. (2006). Perpetual pavement design for flexible pavements in cold regions. *International Journal of Pavement Engineering*, 7(2), 95–102. <https://doi.org/10.1080/10298430500505320>
- [14] Huber, G. A., & Hughes, C. S. (1993). Effects of cooling on asphalt compaction. *Transportation Research Record: Journal of the Transportation Research Board*, 1417, 106–113.
- [15] Milić, M. (2016). Analiza parametara koji utiču na izvođenje asfaltnih radova. *Građevinar*, 68(4), 301–312.
- [16] Asphalt Institute. (Version 4.0). MultiCool: Program for simulation of asphalt mixture cooling during paving operations.