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Effect of Block Geometry on Carbon Emissions of Pumice Masonry Elements

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Highlights

- Replacing cement with fly ash at a 2.90 vol.% reduced the embodied carbon emission of 1 m³ of mortar by 31%.
- Solid block designs exhibited the highest embodied carbon emission values.
- Five-row hollow block configurations provided the lowest CO_2e emissions among all designs.
- Environmental sustainability of pumice aggregate masonry elements was assessed through life-cycle carbon analysis.

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Abstract

This study investigates the sources of CO_2 emission differences among lightweight aggregate masonry blocks with varying geometries and configurations, evaluated from an environmental sustainability perspective. Two dry-mix (zero-slump) mortar designs were considered: a pumice-only mixture (LWC-P) and a fly ash–modified mixture (LWC-PF) with 2.90% cement replacement by volume. To quantify embodied carbon, four different masonry block configurations were analyzed for each mortar type using literature-based emission factors. The CO_2e emissions of 1 m³ of LWC-P and LWC-PF mortars were found to be 128.2 and 88.66 $kgCO_2e/m^3$, respectively, indicating lower emissions for the fly ash–containing mixture. On a product basis, emissions ranged from 0.879–1.757 $kgCO_2e$ for LWC-P blocks and 0.608–1.215 $kgCO_2e$ for LWC-PF blocks. Among all configurations, the 5-row hollow block design exhibited the lowest carbon footprint, while solid block designs showed the highest emissions, demonstrating the significant influence of block geometry on embodied carbon performance.

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Blok Geometrisinin Pomza Agregasıyla Üretilen Duvar Elemanlarının Karbon Emisyonları Üzerindeki Etkisi

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Öne Çıkanlar

- Çimento ile hacimce %2,90 oranında uçucu kül kullanımı, 1 m³ harcın karbon emisyonunu %31 oranında azaltmıştır.
- Dolu blok tasarımları en yüksek karbon emisyon değerlerini sergilemiştir.
- Beş sıralı içi boş blok konfigürasyonları, tüm tasarımlar arasında en düşük CO_2e emisyonunu göstermiştir.
- Pomza agregasılı blok elemanlarının çevresel sürdürülebilirliği, yaşam döngüsü karbon analizi yoluyla değerlendirilmiştir.

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Anahtar Kelimeler

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Karbon ayak izi
Pomza
Kagir blok
Sera gazı emisyonu

Atıf

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*** Sorumlu Yazar**

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Özet

Bu çalışma, farklı geometrilere ve konfigürasyonlara sahip hafif agregalı kagir bloklarda CO_2 emisyon farklılıklarının kaynaklarını çevresel sürdürülebilirlik açısından incelemektedir. Çalışmada iki farklı kuru karışım (sıfır çökme) harç tasarımı ele alınmıştır. Bunlar, yalnızca pomza agregası içeren (LWC-P) karışımı ve %2.90 oranında hacimsel çimento ikameli uçucu kül içeren (LWC-PF) karışımdır. CO_2 emisyon değerlerini belirlemek amacıyla, literatürde tanımlanan emisyon faktörlerine dayalı olarak her iki harç türü için dört farklı duvar bloğu konfigürasyonu analiz edilmiştir. LWC-P ve LWC-PF harçlarının 1 m³ başına CO_2e emisyon değerleri sırasıyla 128.2 ve 88.66 $kgCO_2e/m^3$ olarak belirlenmiş olup, uçucu kül içeren karışımın daha düşük emisyona sahip olduğu görülmüştür. Ürün bazında CO_2 emisyonları LWC-P blokları için 0.879–1.757 $kgCO_2e$, LWC-PF blokları için ise 0.608–1.215 $kgCO_2e$ aralığında değişmiştir. Tüm konfigürasyonlar arasında en düşük karbon ayak izi 5 sıralı boşluklu blok tasarımında elde edilirken, en yüksek emisyonlar dolu blok tasarımlarında belirlenmiş ve blok geometrisinin karbon performansı üzerinde önemli bir etkiye sahip olduğu ortaya konmuştur.

1. INTRODUCTION

Sustainability is the process of producing products and services based on economic, environmental and social issues, taking into account the ecological balance, using resources that will not cause environmental pollution [1,2]. The practice of building, which is based on human consumption and has a significant impact on climate change and greenhouse gas emissions, is among the areas of study of sustainability [3,4].

Despite all the environmental problems caused by the construction sector, the concept of sustainability has continued to maintain its place on the agenda in the construction industry for many years [3,4,5]. The environmental, economic and social roles of the construction sector have made the sector indispensable and have led to the emergence of new ideas in order to ensure development in harmony with nature and show that the sector continues to be a major energy consumer [3,4]. Today, the concept of sustainability has gained importance in the construction process of buildings in order to prevent increasing environmental pollution and to ensure the protection of energy resources [1,6]. These ideas, gathered under the umbrella of the concept of sustainable construction, basically aim to reduce the burden of resource use in the sector by using construction materials that can be reused and consume less energy, taking into account the increase in costs, and as a result, to produce less waste [5]. In addition to paying attention to the fact that construction materials are of good quality, have good physical and thermal performance, are aesthetic and cost-effective, and are materials that do not harm the environment and human health and meet the necessary sustainability criteria [1,6].

Sustainable construction can be defined as the continuation of the usage process of the building without any change in the properties of the materials used in the construction of the building sections and without any decrease in the amount of material [1,7]. In this context, sustainable building materials are building materials that minimize energy consumption during the production and usage stages, and the waste that may occur during the raw material production, processing, usage, maintenance and repair stages does not have any harmful effects on the environment and human health [1,8]. Sustainable building materials have the characteristics of not containing components harmful to human and environmental health, being reusable by recycling, and being easily supplied from local sources [1].

One of the biggest reasons for climate change, global warming and the increase in world temperature is seen as the increase in carbon emissions [9]. This increase in carbon emissions has brought about a significant concern in many countries regarding greenhouse gas emissions worldwide [10]. The gradual decrease in limited resources and the carbon emissions resulting from the use of these finite resources cause irreversible effects on the environment [11]. Greenhouse gas emissions caused by the construction and use of buildings are a result of basic vital activities. In order to achieve Net Zero targets in the fight against climate change, it is extremely important to reduce greenhouse gas emissions from buildings to minimum levels [12].

Greenhouse gas emissions of buildings are generally evaluated in two ways. These are greenhouse gas emissions generated during the daily energy use of buildings such as lighting, heating and cooling, and can be analyzed as a group. The other evaluation is the greenhouse gas emissions generated during the production, transportation and construction site process of all types of materials used during the construction of the building [13]. The building life cycle in buildings analyzes the total energy consumed by each component that will form the building, starting from the raw material stage, including the production, use and demolition stages of the building. It concretely reveals the environmental impacts that are a result of the natural resources consumed for this energy. As a result of this analysis, the design can be renewed and the relevant analysis can be repeated, different alternatives can be produced and compared, and the most suitable option for the natural environment can be determined [14]. Various greenhouse gas emissions occur as a result of the energy consumed throughout the life cycle.

In the construction industry, lightweight concrete masonry block elements obtained by using natural porous aggregates such as pumice rock in order to reduce building dead loads and also to contribute to the thermal insulation value of the building are one of the most widely used building materials to meet the housing needs today [15, 16]. Currently, its use in buildings is gaining importance with an increasing trend in many geographical regions where global climate change is felt. In this context, the increase in the usage trend naturally increases the amount of pumice rock consumption and the sustainability of lightweight aggregate masonry block elements as a building material is gaining more and more importance [17].

Life cycle assessment of cement-based lightweight aggregate masonry block elements with different design and configuration features can be performed according to the 2006 dated TS EN ISO 14040 [18] and TS EN ISO 14044 [19] standards, which are included in the ISO 14000 standard family that includes environmental management issues. According to ISO 14040/44 standards, the life cycle assessment of a product (LCA - Life Cycle Assessment) is an assessment method that calculates, measures, reports environmental impacts throughout the entire life cycle, starting from the acquisition of raw materials for a service or a process, to processing, production, use, end of life and disposal, and provides information including resource efficiency and waste generation (Figure 1). LCA generally starts from the acquisition of raw materials for materials and includes production, transportation, use, and end of life stages. Evaluating products throughout their life cycles provides an understanding of the real environmental impacts of the decisions made. According to DIN EN 15978 [20], whole life consideration requires considering all life cycle phases of a building, from the product phase (A1-A3, from cradle to door), through the construction process phase (A4-A5, handover) and the use phase (B1-B7) [4].

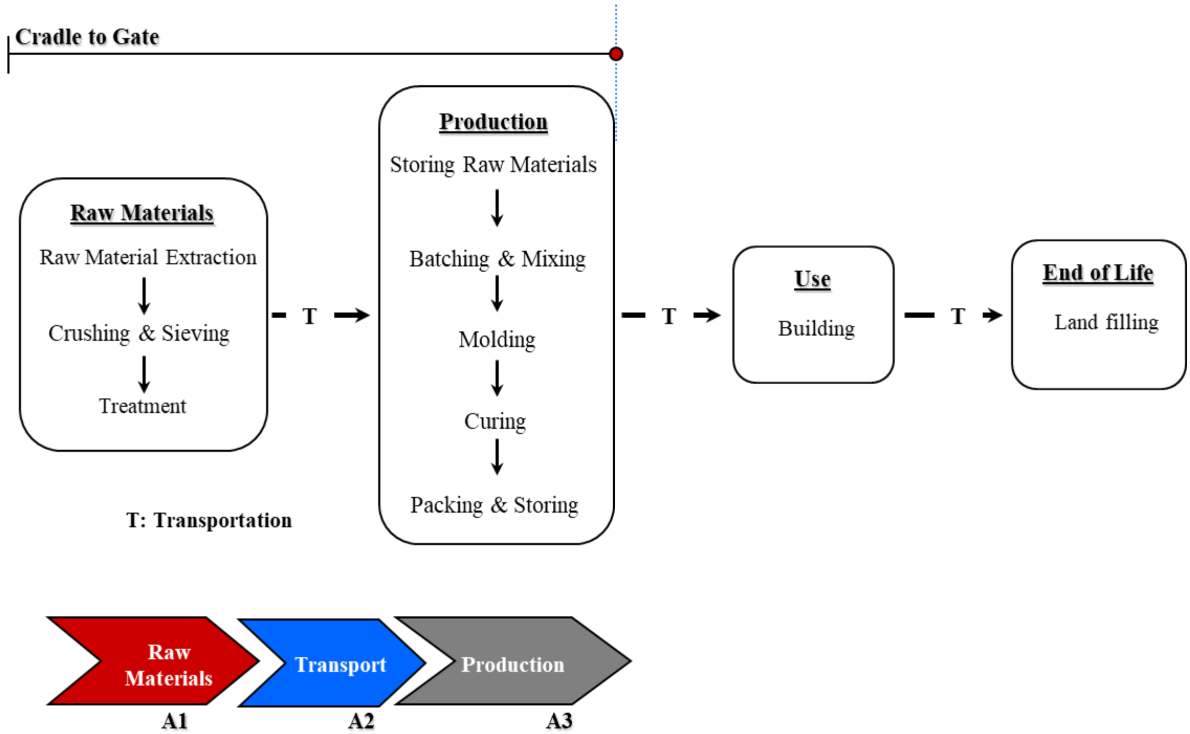

Figure 1. Life Cycle Assessment of Lightweight Aggregate Masonry Block Product

The concept of Carbon Footprint of Products is the carbon dioxide equivalent (CO_2e) of greenhouse gases released into the atmosphere due to the activities of people or organizations and is increasingly taken into consideration today as a life cycle assessment that focuses only on one environmental impact category - for example: climate change - [4]. The process analysis method is taken into account in determining the carbon dioxide equivalent (CO_2e) value in the life cycle assessment of the carbon footprint of lightweight aggregate masonry block elements. In this method, the “Cradle to Gate” approach is taken as the basis in the block production process, starting from the level of extraction of raw material from the quarry to pumice. Cradle to Gate refers to the carbon dioxide equivalent or carbon emissions starting from the stage of extraction of pumice as raw material from the quarry (cradle), transportation to the factory stock area where block production will take place, block production in the factory and the product stock area (the factory gate of the final processing operation) to be offered for sale as a product. In other words, it includes quarry mining, raw material extraction and preparation, processing and block production. Lightweight aggregate block elements, which are widely used in buildings, especially in non-bearing structural sections and infill wall applications, may offer different values for the carbon dioxide equivalent of greenhouse gases released into the atmosphere during the A1-A3 cradle-to-door production process, depending on the design and material components. In this context, choosing block elements that provide minimum emission values in the selection of block elements for the structural section is an important factor in achieving Net Zero targets in the fight against climate change. In addition, it is important to examine all material components used in the production of masonry block elements in a similar scope and to be able to present alternative material options.

In this study, an evaluation was made in terms of environmental sustainability by revealing the sources of CO_2 emission differences between lightweight aggregate masonry block elements with different appearances and configurations. This analysis aimed to make a significant contribution to understanding the environmental impacts of lightweight concrete masonry block elements made of pumice aggregate and to optimize the selection of materials and masonry block designs with the aim of lower carbon footprint.

2. MATERIALS AND METHODS

2.1. Materials Used And Mixture Design

ASTM Type I (42.5 MPa) cement type was used in all mixtures in this study and the chemical properties of the cement are given in Table 1.

Pumice stone is a volcanic-origin inorganic lightweight aggregate with a natural porous structure that is widely used in the construction industry today in the production of masonry block elements for the purpose of non-bearing and insulation contribution [21]. Pumice aggregates exhibit different physical, chemical and mechanical properties depending on the formation mechanism and volcanic origin [22-24]. The pumice rock used in the study was supplied from quarries in the Central Anatolia Region of Türkiye, preserving its natural form. The pumice aggregates supplied were stored in nylon-based bags in order to preserve their natural moisture. In the laboratory, they were crushed in a primary crusher while preserving this natural moisture and subjected to size-milling process. After the crushing process, the pumice aggregate samples were classified in three different size fractions as 0-4 mm, 4-8 mm and 8-12 mm size ranges. In the study, these aggregate materials were used by coding them as PUM-0/4, PUM-4/8 and PUM-8/12. The general appearance of pumice aggregates is given in Figure 2.

Figure 2. General View of a) Fly Ash; b) 0/4 mm Pumice Aggregate; c) 4/8 mm Pumice Aggregate; d) 8/12 mm Pumice Aggregate

The present moisture contents of the sized pumice aggregate samples calculated according to TS EN 1097-5 standard are 28% for PUM-0/4, 32% for PUM-4/8 and 37% for PUM-8/12, respectively. The sized pumice aggregate samples were then dried in an oven at 105 ± 5 °C for 24 hours until reaching a constant mass to determine the dry bulk density values. The bulk density tests of the pumice aggregates were conducted in accordance with TS EN 1097-3, and the bulk densities were determined as 640 kg/m^3 for PUM-0/4, 610 kg/m^3 for PUM-4/8, and 515 kg/m^3 for PUM-8/12, respectively. The chemical properties of the pumice sample, determined by XRF analysis, are given in Table 1.

Table 1. Chemical properties of cement, pumice and fly ash samples

Component (%)	Cement	Pumice	Fly Ash
SiO_2	20.23	69.88	45.71
Al_2O_3	5.83	14.72	23.67
Fe_2O_3	4.31	3.02	4.47
CaO	62.35	3.36	17.16
Na_2O	0.16	3.78	0.40
K_2O	0.86	2.64	1.26
MgO	2.71	0.92	1.58
LOI	1.51	1.68	0.87

Fly ash is an important by-product that is collected in cyclones or electrofilters by being carried by the flue gases resulting from the combustion of pulverized coal in thermal power plants. The molten material resulting from the combustion of coal at high temperatures cools down and turns into partially or completely spherical ash particles with the gas flow. These ash particles are very fine and are called fly ash because they are dragged by the flue gases [25]. According to the ASTM C 618 standard, fly ash is divided into classes F and C. Class F fly ash is an ash produced from bituminous coal with a SiO_2+Al_2O_3+Fe_2O_3 percentage greater than 70% and a CaO percentage less than 10%, which is also called low-lime. They have pozzolanic properties. Class C fly ash is produced from lignite or semi-bituminous coal and the total SiO_2+Al_2O_3+Fe_2O_3 amount is greater than 50%. Since CaO > 10%, they are called high-lime fly ash. Class C fly ash has binding properties as well as pozzolanic properties [25, 26]. The highest potential use of fly ash in terms of quantity is in various civil engineering fields. Research conducted for approximately 60 years has shown that the use of fly ash in cement, concrete, aerated concrete, brick and lightweight aggregate production, soil stabilization and filling production gives positive results [27]. Especially with the use of fly ash in cement production, benefits such as less clinker use, reduced greenhouse gas emission, reduced energy consumption and less pollution of nature due to waste use can be achieved. In the study, fly ash from Manisa-Soma thermal power plant (Figure 2) was supplied and used in the prepared lightweight aggregate mortar mixtures. The chemical analysis results of fly ash are given in Table 1 [28]. According to these features, Soma fly ash, which belongs to Soma thermal power plant and is used in concrete mixtures, falls within the scope of "Calcareous Fly Ash" according to TS EN197-1 due to the reactive lime amount being over 10%. In addition, it meets the 70% requirement required in TS 639 for the SiO_2+Al_2O_3+Fe_2C>3 amount [27].

Within the scope of the study, two different designs of dry mix consistency (zero slump value) mortar mixture were evaluated. These are: mortar design obtained by using only pumice aggregate (LWC-P), and the other design is fly ash incorporated (LWC-PF). The components and mortar densities of both mix designs are given in Table 2.

Table 2. Lightweight aggregate mortar mix proportions and densities.

Mixture	Cement (kg/m^3)	PUM-0/4 (kg/m^3)	PUM-4/8 (kg/m^3)	PUM-8/12 (kg/m^3)	FLY ASH (kg/m^3)	Water/ Solid Ratio (w/s)	Fresh Mortar Density (kg/m^3)	Hardened Mortar Density (kg/m^3)
LWC-P	150	163	381	132	0	0.28	1057	805
LWC-PF	102	163	381	132	24	0.28	1027	782

In LWC-P and LWC-PF designs, equivalent amounts of sized pumice aggregate were used. The water/solid ratio (w/s) was kept constant at 0.2. However, in LWC-PF design, fly ash was added to the mixture by replacing the cement in LWC-P design with 2.90% of the volume of the cement used in LWC-P design. In this mixture, due to the pozzolanic activity of fly ash material, it was aimed to minimize the cement usage rate in lightweight aggregate mortar mixture. In LWC-P and LWC-PF designs, lightweight aggregate concrete samples were cast in laboratory environment with dry mix zero slump consistency. In order to determine the final density and block element manufacturability properties of the mixture compositions, these samples were first cast in 100×100×100 mm^3 cube molds as trial samples with the help of a manual casting machine with vibration-compression feature available in laboratory environment. After filling-vibration-placement and pressure pressing functions in casting press, the mixture samples were immediately removed from the mold and left to cure in laboratory under normal ambient air condition for 28 days. After 28 days of curing, the hardened mortar densities were measured without any drying process. When the measured hardened mortar densities were used in the production of full-size masonry block elements within the scope of this study, they were used as the main parameter in determining the unit weight value of the final block element by taking into account the areal and volumetric fullness and void ratios in the configuration of the masonry block element.

2.2. Masonry Block Design

Within the scope of the study, in order to determine the CO_2 emission values of the masonry block elements with different design values made of LWC-P and LWC-PF mortars with pumice aggregate, 4 different configurations of masonry block designs were analyzed. These are:

1. Single row hollow masonry block elements,
2. Three row hollow masonry block elements,
3. Five row hollow masonry block elements,
4. Solid form masonry block elements.

These block elements are coded as SRHB, TRHB, FRHB and SLDB in the study, taking into account the void row form. The design and general forms of all masonry block elements are shown symbolically in Figure 3.

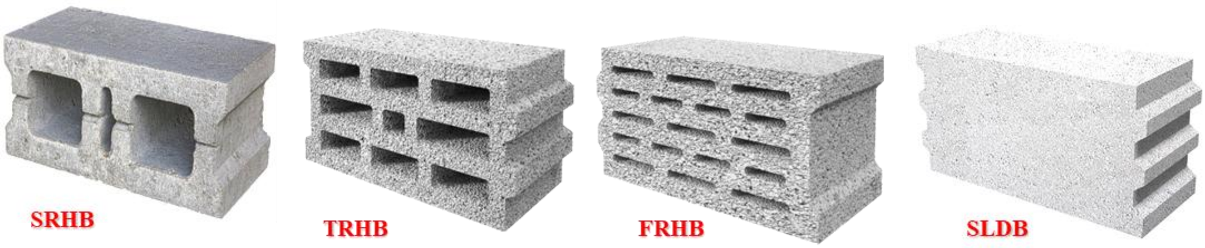

Figure 3. General View of the Designs of Lightweight Aggregate Masonry Block Elements

All the masonry block samples used in this study are in interlaced (tongue-and-groove) form and have nominal dimensions of 190×390×190 mm (width×length×height). The configuration properties of the masonry block elements with different designs are given in Table 3.

Table 3. Configuration properties of masonry block elements

	Block Form	Width (mm)	Length (mm)	Height (mm)	Areal Fill Rate (%)	Volumetric Fill Rate (%)	Solid Volume (cm^3)
SRHB	Single row hollow block	190	390	185	54.33	66.40	9102
TRHB	Three rows hollow block	190	390	185	61.94	72.00	9870
FRHB	Five rows hollow block	190	390	185	60.04	60.04	6859
SLDB	Solid block	190	390	185	100.00	100.00	13709

During the study, the unit weight value of each block element was calculated separately, with the principle that the hardened mortar densities of the samples poured for the mortar mixture design, measured without any drying process after 28 days of curing, are represented as the mortar that will form the solid part of the block element. In this calculation, the solid volume value of the block element is especially important. The value obtained by multiplying the amount of each mixture component used in 1 m^3 mortar in the mortar design with the solidity ratio of the block element represents the amount of material required for block production for that component. The sum of all components represents the final weight value of the block element.

In order to determine the CO_2e value of block elements, the emission values of all material components in the mortar design to be used in block production in the value of "$kgCO_2e/kg$" are needed. These values, literature review for each material type, and CO_2 emission values determined by different researchers were used as reference values within the scope of this study. The CO_2 emission values of the material components used in the LWC-P and LWC-PF designs are given in Table 4.

Table 4. CO_2 emission values of the material components used in the LWC-P and LWC-PF designs

Material	CO_2 emission ($kgCO_2e/kg$)	References
PUM-0/4	0.0020	[29, 30]
PUM-4/8	0.0020	[29, 30]
PUM-8/12	0.0020	[29, 30]
FLY-ASH	0.0270	[29, 31-33]
OPC	0.8460	[29, 31, 34-36]
Water	0.0003	[29, 35,36]

Afterwards, the emission values in the unit of "$kgCO_2e$" corresponding to the weight of each material type used in the design of the block element are determined separately, and the sum of the emission values represents the CO_2e value of the block element by weight on a product basis (from cradle to gate). Using this methodology, the CO_2e values of the SRHB, TRHB, FRHB and SLDB block elements to be produced in the LWC-P and LWC-PF mix designs were analyzed with the calculation method briefly described here.

3. RESULTS AND DISCUSSION

3.1. Carbon Factor Analysis

Within the scope of the study, carbon dioxide (CO_2) emission values formed for 1 m^3 production of lightweight concretes with dry mix consistency belonging to LWC-P and LWC-PF mortar designs were calculated and evaluated. CO_2 emission analyses were carried out considering the environmental impacts of lightweight aggregate concrete components in the production processes. The emission contribution of each of the cement, pumice aggregate, fly ash and water components in the mix designs were calculated using emission coefficients obtained from the existing literature. In the life cycle analysis of 1 m^3 lightweight aggregate mortar created in LWC-P and LWC-PF designs, the determination of the average CO_2e value from cradle to door covering the A1–A3 stages was determined depending on the typical embodied carbon factor values of the materials defined in the literature and the evaluation findings are given in Table 5 and Table 6.

Table 5. Determination of CO_2e emission value of 1 m^3 lightweight mortar of LWC-P design

Material	Amount (kg/m³)	Embodied Carbon Factor (kgCO₂e/kg)	Embodied Carbon Emission (kgCO₂e/m³)	Percentage value by weight (%)
PUM-0/4	163	0.0020	0.3256	0.25
PUM-4/8	381	0.0020	0.7625	0.59
PUM-8/12	132	0.0020	0.2639	0.21
FLY-ASH	-	-	-	0.00
OPC	150	0.8460	126.7572	98.89
Water	231	0.0003	0.0694	0.05
		Total:	128.2	100.00

Table 6. Determination of CO_2e emission value of 1 m^3 lightweight mortar of LWC-PF design

Material	Amount (kg/m³)	Embodied Carbon Factor (kgCO₂e/kg)	Embodied Carbon Emission (kgCO₂e/m³)	Percentage value by weight (%)
PUM-0/4	163	0.0020	0.3256	0.37
PUM-4/8	381	0.0020	0.7625	0.86
PUM-8/12	132	0.0020	0.2639	0.30
FLY-ASH	24	0.0270	0.6558	0.74
OPC	102	0.8460	86.5828	97.66
Water	225	0.0003	0.0674	0.08
		Total:	88.66	100.00

As seen in this evaluation, it is clearly seen that the highest embodied carbon emission value in both mortar designs is created by the cement component. In order to reduce the carbon emission of the mortar design, it is inevitable to reduce the amount of cement to the lowest possible rate. In lightweight mortar combinations designed in dry mix consistency for masonry block production, the use of fly ash as a replacement with cement as an alternative application shows a feasible feature due to its high pozzolanic value. In this study, the fly ash additive added as a replacement with cement at a rate of 2.90% by volume caused the embodied carbon emission value of 1 m^3 mortar to decrease by 31% due to the decreasing cement ratio.

When masonry blocks with different geometric designs are produced with pumice aggregate and pumice+fly ash added mortar mixtures, how the type and amount of aggregate in the mixture will affect the embodied carbon emission values of the masonry element brings up an important issue in terms of examining the life cycle process of the products. In this context, the extent to which both the use of pumice aggregate alone and the fly ash reinforcement affect the CO_2e values of the block product were analyzed and evaluated for block elements with 4 different designs within the scope of this study. The CO_2e values calculated from cradle to gate covering the A1–A3 stages in the life cycle analysis of the masonry block elements in SRHB, TRHB, FRHB and SLDB configurations obtained using LWC-P and LWC-PF mortar mixtures are given in Table 7–Table 10, respectively.

Table 7. CO_2e emission value of the masonry block element in the SRHB configuration

		with LWC-P		with LWC-PF	
Material	**Embodied Carbon Factor ($kgCO_2e/kg$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**
PUM-0/4	0.0020	1.48	0.0030	1.48	0.0030
PUM-4/8	0.0020	3.47	0.0069	3.47	0.0069
PUM-8/12	0.0020	1.20	0.0024	1.20	0.0024
FLY-ASH	0.0270	0.00	0.0000	0.22	0.0060
OPC	0.8460	1.36	1.1537	0.93	0.7881
Water	0.0003	2.10	0.0006	2.05	0.0006
	Total:	9.62	1.167	9.35	0.807
		ECF for product = 0.121 ($kgCO_2e/kg$)		ECF for product = 0.086 ($kgCO_2e/kg$)	

ECF: Embodied Carbon Factor

Table 8. CO_2e emission value of the masonry block element in the TRHB configuration

		with LWC-P		with LWC-PF	
Material	**Embodied Carbon Factor ($kgCO_2e/kg$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**
PUM-0/4	0.0020	1.61	0.0032	1.61	0.0032
PUM-4/8	0.0020	3.76	0.0075	3.76	0.0075
PUM-8/12	0.0020	1.30	0.0026	1.30	0.0026
FLY-ASH	0.0270	0.00	0.0000	0.24	0.0065
OPC	0.8460	1.48	1.2511	1.01	0.8546
Water	0.0003	2.28	0.0007	2.22	0.0007
	Total:	10.43	1.265	10.14	0.875
		ECF for product = 0.121 ($kgCO_2e/kg$)		ECF for product = 0.086 ($kgCO_2e/kg$)	

Table 9. CO_2e emission value of the masonry block element in the FRHB configuration

		with LWC-P		with LWC-PF	
Material	**Embodied Carbon Factor ($kgCO_2e/kg$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**
PUM-0/4	0.0020	1.12	0.0022	1.12	0.0022
PUM-4/8	0.0020	2.61	0.0052	2.61	0.0052
PUM-8/12	0.0020	0.91	0.0018	0.91	0.0018
FLY-ASH	0.0270	0.00	0.0000	0.17	0.0045
OPC	0.8460	1.03	0.8694	0.70	0.5939
Water	0.0003	1.59	0.0005	1.54	0.0005
	Total:	7.25	0.879	7.05	0.608
		ECF for product = 0.121 ($kgCO_2e/kg$)		ECF for product = 0.086 ($kgCO_2e/kg$)	

Table 10. CO_2e emission value of the masonry block element in the SLDB configuration

		with LWC-P		with LWC-PF	
Material	**Embodied Carbon Factor ($kgCO_2e/kg$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**	**Amount (kg)**	**Carbon Emission due to Material ($kgCO_2e$)**
PUM-0/4	0.0020	2.23	0.0045	2.23	0.0045
PUM-4/8	0.0020	5.23	0.0105	5.23	0.0105
PUM-8/12	0.0020	1.81	0.0036	1.81	0.0036
FLY-ASH	0.0270	0.00	0.0000	0.33	0.0090
OPC	0.8460	2.05	1.7377	1.40	1.1870
Water	0.0003	3.17	0.0010	3.08	0.0009
	Total:	14.49	1.757	14.08	1.215
		ECF for product = 0.121 ($kgCO_2e/kg$)		ECF for product = 0.086 ($kgCO_2e/kg$)	

The CO_2 emission values of pumice aggregate masonry block elements produced with lightweight mortar having equivalent mix design varied between 0.879 - 1.757 $kgCO_2e$ (see Table 7-10) on a product basis. The lowest emission value was obtained in the 5-row hollow masonry element design (Table 9). The reason why the emission value in this block design is lower than the others is that it is the block element produced with the lowest mortar usage with 6859 cm^3 filled volume and 60.04% fill rate (Table 3). The highest emission value was obtained in the SRHB block design in solid form and is due to its 13709 cm^3 filled volume and 100% fill rate (see Table 3 and Table 10). According to the emission value of the block element in SLDB form, it is seen that the CO_2 emission value of the SRHB block design decreased by 33.6% (see Table 7 and Table 10). Similarly, it was seen that the TRHB and FRHB block designs decreased by 28% and 50%, respectively, compared to the CO_2 emission values of the solid block design (see Tables 8-10). This simple comparison is important in terms of seeing that when an equivalent mortar is used in masonry block elements, the block design significantly affects the CO_2 emission values of the final product. In cases where it is desired to minimize CO_2 emission values in a masonry block design, it is important to be able to produce that block element with the minimum possible mortar use, provided that other technical features stipulated in the standards are met. Moreover, in order to reduce emissions in masonry construction, there is a growing shift toward interlocking dry-stack block systems and low-carbon masonry unit designs. These innovative approaches significantly reduce or entirely eliminate the use of cement-rich mortars, thereby contributing to a substantial decrease in the embodied carbon footprint of structures [37, 38]. The CO_2 emission values of the masonry block elements formed with 1 m^3 lightweight aggregate mortar in the LWC-P and LWC-PF designs are shown comparatively on a product basis in Figure 4.

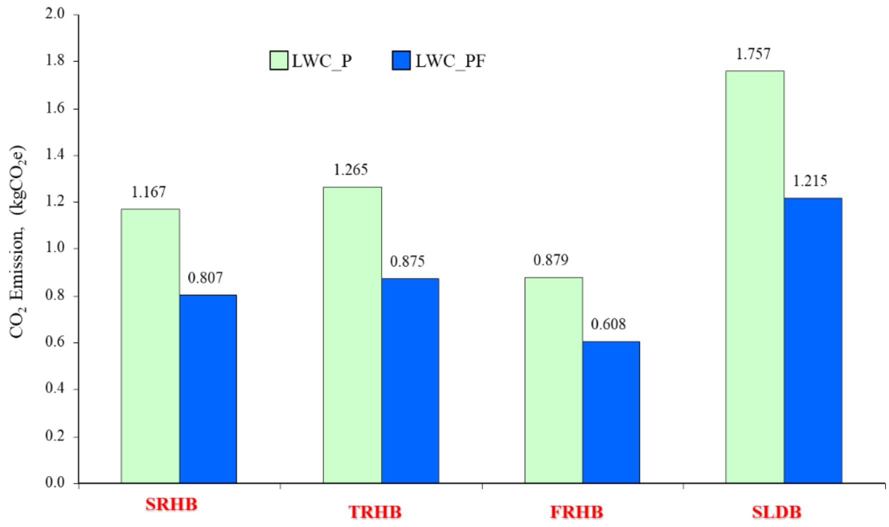

Figure 4. CO_2e Emission Values for Masonry Block Designs

When Figure 4 is examined, the CO_2 emission values of the pumice + fly ash added masonry block elements produced with lightweight mortar with equivalent mixture design also vary between 0.608 - 1.215 kgCO_2e on a product basis. The lowest emission value was obtained in the 5-row hollow masonry element design as in the pumice aggregate mortar design, and the highest emission value was obtained in the solid form SRHB block design. According to the emission value of the block element in the SLDB form, it is seen that the CO_2 emission value of the SRHB block design decreases by 33.6%. Similarly, it is seen that the TRHB and FRHB block designs decrease by 28% and 50%, respectively, compared to the CO_2 emission values of the solid form block design. When the CO_2 emission values of all block designs in this study are considered, a 30.8% reduction is observed between the LWC-P and LWC-PF mortar mixtures used in block production, indicating that the incorporation of fly ash decreases the CO_2 emission value of the block element by 30.8%.

Another investigation within the scope of the study is the determination of the CO_2 emission value created by the block elements to be used in 1 m^2 of wall construction. The CO_2 emission values of the masonry block elements created with the LWC-P and LWC-PF designs in 1 m^2 of wall construction are shown comparatively on a product basis in Figure 5.

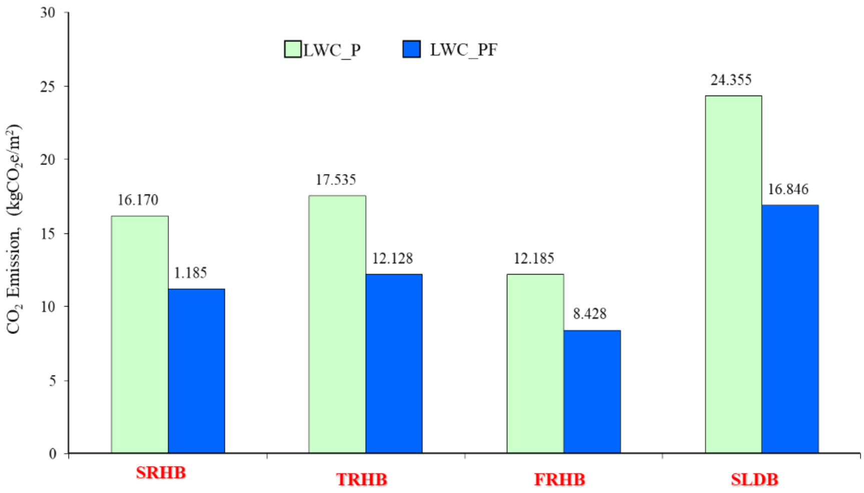

Figure 5. CO_2e Values of Masonry Block Elements In 1 m^2 Of Wall Structure

When Figure 5 is examined, with the LWC-P mix design, the CO_2e values of the masonry block elements in 1 m^2 of wall construction varied between 12.185 and 24.355 $kgCO_2e/m^2$. With the LWC-PF mix design, the CO_2e values of the masonry block elements in 1 m^2 of wall construction varied between 8.428 and 16.846 $kgCO_2e/m^2$. The lowest emission value for the block elements in both different mortar designs was obtained in the 5-row hollow FRHB masonry element design. It was determined that a 30.8% reduction in CO_2 emission value per m^2 of wall construction occurred between both LWC-P and LWC-PF designs in terms of the mortar mixture to be used in block production.

3.2. Carbon Factors-Density Analysis

The unit weight value is an important parameter due to the fact that it affects the dead weight of the building formed by the wall units formed with the masonry block elements. Reducing the dead weight of the buildings can generally be considered as an important evaluation criterion in terms of both earthquake systematics and insulation evaluations of the building. In this context, the use of low-density masonry block elements is important. The densities of the masonry block elements are generally represented by their gross unit volume weights. Within the scope of the study, the gross unit volume weights of the masonry block elements obtained with the LWC-P mixture design were obtained as 547, 598, 499 and 824 kg/m^3 for SRHB, TRHB, FRHB and SLDB, respectively. Similarly, the gross unit volume weights of the masonry block elements obtained with the LWC-PF mixture design were obtained as 533, 576, 481 and 802 kg/m^3 for SRHB, TRHB, FRHB and SLDB, respectively. As can be seen here, the fly ash addition reduced the unit weight value of the block element, albeit to a small extent. The relationship between the gross unit weight changes obtained with the LWC-P and LWC-PF mortar designs of the block elements and the CO_2e values of the block is given graphically in Figure 6 and Figure 7.

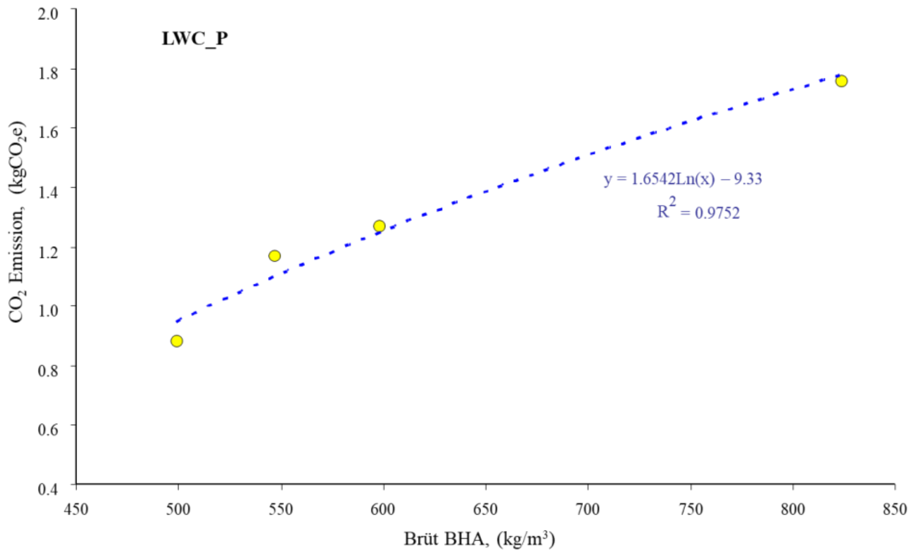

Figure 6. Masonry Block Gross Unit Weight – CO_2e Relationship (LWC-P Mortar Design)

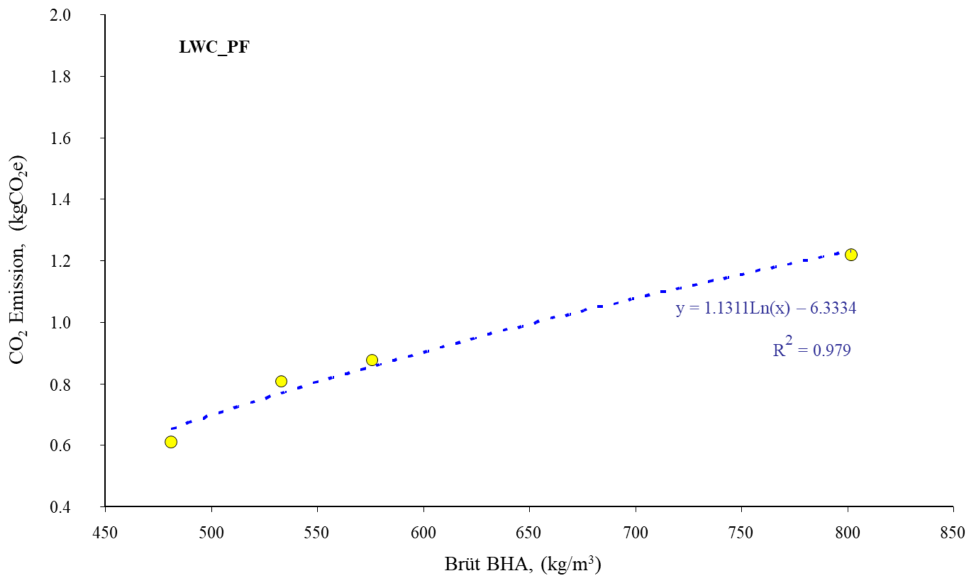

Figure 7. Masonry Block Gross Unit Weight – CO_2e Relationship (LWC-PF Mortar Design)

For LWC-P and LWC-PF mortar designs, as the unit volume weight of the masonry block elements increases, the CO_2e values increase with a trend that can be considered linear. In other words, when the unit weight of the masonry block product produced with an equivalent mixture design increases due to the change in geometric design, size and/or configuration, the CO_2e value on a product basis also increases. In this context, minimum density gains importance in the production of low-emission block elements. Within the scope of the study, in the block elements produced with LWC-P mortar, the unit volume weight change in the blocks obtained with the highest density (SLDB) and the lowest density (FRHB) was 1.65 times, while the change in CO_2e values was 2 times. Similarly, in the block elements produced with LWC-PF mortar, the unit volume weight change in the blocks obtained with the highest density (SLDB) and the lowest density (FRHB) was 1.67 times, while the change in CO_2e values was 2 times.

4. RESULTS AND RECOMMENDATIONS

This study analyzed the carbon footprint of lightweight concrete masonry blocks by evaluating CO_2 emissions based on different mix designs and block configurations. The key findings can be summarized as follows:

1. The highest embodied carbon emission values in both mortar designs (LWC-P and LWC-PF) were attributed to the cement component. The replacement of 2.90% cement by volume with fly ash in the LWC-PF design resulted in a 31% reduction in the total embodied CO_2 emission value per cubic meter of mortar.
2. The CO_2 emission values of pumice-based masonry blocks varied between 0.879 and 1.757 kgCO_2e per block, with the highest emissions observed in the SRHB solid block design and the lowest in the FRHB hollow block design. This highlights the significant impact of geometric design on emission values, where reducing the amount of mortar used per block led to lower CO_2 emissions.
3. The incorporation of fly ash into the mortar mix reduced the CO_2 emissions of block elements by 30.8%. This reduction was consistent across different block designs and was also reflected in emissions per square meter of wall construction, where LWC-PF-based walls exhibited lower emissions compared to their LWC-P counterparts.
4. A nearly linear correlation was observed between the gross unit weight and CO_2 emissions of masonry blocks. Blocks with higher unit weights exhibited increased carbon emissions, emphasizing the importance of designing lightweight masonry units to achieve lower environmental impact.
5. The study demonstrates that using lightweight aggregates and supplementary cementitious materials like fly ash can significantly reduce the carbon footprint of masonry blocks without compromising performance. This finding supports the adoption of sustainable construction materials for reducing environmental impact in the building sector.

In conclusion, optimizing mix designs by incorporating fly ash and refining block geometries can serve as effective strategies for minimizing the carbon footprint of masonry block production. Future research can explore additional supplementary cementitious materials and innovative geometric configurations to further enhance sustainability in masonry construction.

REFERENCE

[1] Ali Çüçen, Adem Solak, "Sürdürülebilir Yapı Malzemeleri Üzerine Bir Araştırma", Teknik Bilimler Dergisi, 13(1), pp.1–8, 2023.

[2] Muhammed Zakir Tufan, Cengiz Özel, "Sürdürülebilirlik Kavramı ve Yapı Malzemeleri İçin Sürdürülebilirlik Kriterleri", Uluslararası Sürdürülebilir Mühendislik ve Teknoloji Dergisi, 2(1), pp.9–13, 2018.

[3] Philipp Rode, Ricky Burdett, Joana Carla Soares Gonçalves, "Buildings: Investing in Energy and Resource Efficiency", United Nations Environment Programme, Towards a Green Economy, pp.331–373, 2011.

[4] Betül Köksal, "Yapı Malzemelerinin Gömülü Karbon Miktarına Etkisi: Örnek Bir Yapı Üzerinden İnceleme", Yapı Bilgi Modelleme, 5(1), pp.14–25, 2023.

[5] Rasime Pamuk, Murat Kuruoğlu, "İnşaat Sektöründe Sürdürülebilirlik ve Bina İnşaatlarında Evrensel Uygulama Örnekleri", Beykent University Journal of Science and Engineering, 9(1), pp.161–177, 2016.

[6] Özlem Aydın, Didem Bayraktar Marangoz, "Mimaride Sürdürülebilir Malzeme: Bambu", Bodrum Journal of Art and Design, 1(1), pp.77–94, 2022.

[7] Luke A. Nicholson, "Integrating Sustainable Building Design and Construction Principles into Engineering Technology and Construction Management Curricula", ASEE Annual Conference, 2004.

[8] Zübeyde Sayar, Arzuhan Burcu Gültekin, Çiğdem Belgin Dikmen, "Sürdürülebilir Mimarlık Kapsamında Ahşap ve PVC Doğramaların Değerlendirilmesi", 5. Uluslararası İleri Teknoloji Sempozyumu (İATS'09), pp.2067–2072, Karabük, 2009.

[9] Kun Lu, Xiaoyan Jiang, Vivian W.Y. Tam, Mengyun Li, Hongyu Wang, Bo Xia, Qing Chen, "Development of a Carbon Emissions Analysis Framework Using Building Information Modeling and Life Cycle Assessment for the Construction of Hospital Projects", Sustainability, 11(22), pp.6274, 2019.

[10] Huijun J. Wu, Zengwei W. Yuan, Ling Zhang, Jun Bi, "Life Cycle Energy Consumption and CO_2 Emission of an Office Building in China", The International Journal of Life Cycle Assessment, 17, pp.105–118, 2012.

[11] Global Comission On Adaption, Global Commission on "Adapt Now: A Global Call For Leadership on Climate Resilience", Report, https://gca.org/reports/adapt-now-a-global-call-for-leadership-on-climate-resilience/ , 2019.

[12] UN, Causes and Effects of Climate Change, United Nations, https://www-un-org.translate.goog/en/climatechange/science/causes-effects-climate-change? , 2025.

[13] Global Status Report, UN Environment Programme, https://www.unep.org/resources/report/global-status-report-buildings-and-construction (Access Date: 16.03.2025), UN Environment Programme, "Global Status Report for Buildings and Construction", Report, 2024.

[14] Hatice Sena Azkur, Fatih Canan, "Farklı Taşıyıcı Sistemlerin Gömülü Enerji ve Gömülü Karbon Değerlerinin Müstakil Konutlar Bağlamında Karşılaştırılması", Süleyman Demirel University Journal of Natural and Applied Sciences, 26(1), pp.35–46, 2022.

[15] Fahriza, F., Saputra, D. S., Mislina, M., Afdhal, A., & Ramadhini, M. (2026). Lightweight Hollow Block Production Using Recycled Expanded Polystyrene and Coconut Coir: An Experimental Assessment. CIRCULIZER: Journal of Circular Systems, Innovation, and Technology, 1(1), 74-87.

[16] Hanuseac, L. G., Bejan, G., Mihai, P., Bărbuță, M., Panțiru, A., & Mihai, R. G. (2023, November). Lightweight Concrete with Wastes Used for Hollow Concrete Blocks. In International Scientific Conference Civil Engineering and Buildings Services (pp. 37-49). Cham: Springer Nature Switzerland.

[17] Gündüz, L., & Kalkan, Ş. O. (2020). Lightweight cellular hollow concrete blocks containing volcanic tuff powder, expanded clay and diatomite for non-load bearing walls. *Teknik Dergi*, *31*(6), 10291-10313.

[18] TS EN ISO 14040, "Environmental Management-Life Cycle Assestment-Principles and Framework", Türk Standardları Enstitüsü, Ankara, 2007.

[19] TS EN ISO 14044, "Environmental management — Life cycle assessment — Requirements and guidelines", Türk Standardları Enstitüsü, Ankara, 2007.

[20] DIN EN 15978, "Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method", Almanya.

[21] Lütfullah Gündüz, "İnşaat Sektöründe Bimsblok", Süleyman Demirel Üniversitesi Pomza Araştırma ve Uygulama Merkezi Yayını, Isparta, 2005.

[22] H. Ásgeirsson, "Léttsteypur úr vikri (Lightweight Pumice Concrete)", IBRI, 1984.

[23] Lütfullah Gündüz (Ed.), "Pomza Teknolojisi (Pomza Karakterizasyonu)", Cilt I, Isparta, 1998.

[24] O. Berge, "Lätt Isolerande Konstruktionsbeton med Isländsk Pimpsten som Ballast", Västra Frölunda, 1983.

[25] Gökhan Görhan, Erhan Kahraman, M. Serhat Başpınar, İsmail Demir, "Uçucu Kül Bölüm I: Oluşumu, Sınıflandırılması ve Kullanım Alanları", Yapı Teknolojileri Elektronik Dergisi, 4(2), pp.85–94, 2016.

[26] ASTM C618, "Standart Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete", ASTM Standards, 2000.

[27] Osman Ünal, Tayfun Uygunoğlu, "Soma Termik Santral Atığı Uçucu Külün İnşaat Sektöründe Değerlendirilmesi", Türkiye 14. Kömür Kongresi Bildiriler Kitabı, pp.311–321, Zonguldak, 2004.

[28] Pelin Türker, Bahadır Erdoğan, Fehime Katnaş, Asım Yeğinobalı, "Türkiye'deki Uçucu Küllerin Sınıflandırılması ve Özellikleri", TÇMB / AR-GE / Y03.03, Türkiye Çimento Müstahsilleri Birliği, Ankara, 2009.

[29] Ali Abbas, Mathura Mahadevan, Saru Prajapati, Bamdad Ayati, Fragkouils Kanavaris, "Development of Low-Carbon Lightweight Concrete Using Pumice as Aggregate and Cement Replacement", International RILEM Conference on Synergising expertise towards sustainability and robustness of CBMs and concrete structures. Cham: Springer Nature Switzerland, 2023.

[30] Lava Mining & Quarrying SA: Pumice Stone Environmental Product Declaration No. S-P-02521, 2021.

[31] Concrete 4Change, Barriers To Net-Zero Concrete – Fly Ash And GGBS Shortage. By C4C, October 23, 2022, https://www.concrete4change.com/post/barriers-to-net-zero-concrete-fly-ash-and-ggbs-shortage, Access date: 16.03.2025, 2022.

[32] Theradej Litsomboon, Pichai Nimityongskul, Naveed Anwar, "Development of Lightweight Aggregate Concrete Containing Pulverized Fly Ash and Bottom Ash", Key Engineering Materials, 400–402, pp.379–384, 2008.

[33] Rawaz Kurda, José D. Silvestre, Jorge de Brito, "Life Cycle Assessment of Concrete Made with High Volume of Recycled Concrete Aggregates and Fly Ash", Resources, Conservation and Recycling, 139, pp.407–417, 2018.

[34] Fragkoulis Kanavaris, Orlando Gibbons, Emily Walport, Ed Shearer, Ali Abbas, John Orr, Bryan Marsh, "Reducing Embodied Carbon Dioxide of Structural Concrete with Lightweight Aggregate", Proceedings of the Institution of Civil Engineers - Engineering Sustainability, 175(2), pp.75–83, 2022.

[35] UN Environment, Scrivener, K. L, John, V. M. & Gartner, E. M., "Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry", Cement and Concrete Research, 114, 2-26, 2018.

[36] Fragkoulis Kanavaris, Nuno Mesquita Ferreira, Bryan Kenneth Marsh, "Low Carbon Concrete: Specification and Practical Recommendations", Concrete (London), pp.35–37, 2021.

[37] Mohammadi, M., Atsbha, T. G., & Chen, Y. (2025). Comparison and Design of Dry-Stack Blocks with High Thermal Resistance for Exterior Walls of Sustainable Buildings in Cold Climates. Sustainability, 17(4), 1393.

[38] Asman, N. S. A., Bolong, N., Mirasa, A. K., Asrah, H., & Saad, I. (2020, April). Interlocking compressed earth bricks as low carbon footprint building material. In IOP Conference Series: Earth and Environmental Science (Vol. 476, No. 1, p. 012086). IOP Publishing.