WHITE CEMENT CONCRETE AS AN ELEMENT OF SUSTAINABLE BUILDING

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Summary: *The effect of materials on the temperature of the localized atmosphere is a rapidly expanding research area. Basic research in this area is directed at the color and composition of materials and their ability to reflect or absorb (and emit) solar radiation. The color and composition of the materials greatly affects the temperature of the material exposed to solar radiation. Heat energy from absorbed solar radiation will eventually enter the surrounding atmosphere, causing localized heating. Smog levels have also been correlated to temperature rise. Thus, as the temperature of urban areas increases, so does the probability of smog and pollution. One of the materials reducing, among other things, the aforementioned negative effects on the environment is white concrete. White concrete made of white cement is popular with architects thanks to its pure and uniform appearance. The paper presents the properties of white cement, white concrete and benefits of using it as an element of sustainable building practice.*

Keywords: *white cement, white concrete, sustainable building practice*

1. INTRODUCTION

There is a large number of papers which demonstrate that the daytime temperatures of large cities are higher than their suburbs.

The term "heat island" describes built up areas that are hotter than nearby rural areas. The annual mean air temperature of a city with 1 million people or more can be 1–3°C warmer than its surroundings. In the evening, the difference can be as high as 12°C [1]. This "urban heat island" (UHI) effect is a problem in warm climates in the summers because it exacerbates the demand for electricity for air conditioning and increases the concentration of smog.

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The higher temperatures in urban centers can cause the following adverse impacts:

- accelerate the chemical reactions that produce ground level ozone and smog that potentially threatens public health and effects comfort of residents,
- higher urban temperatures can amplify extreme weather events such as heat waves that impact urban residents and may cause heat stroke, especially in the elderly,
- they may result in the increased cooling costs and the associated use and generation of electricity [1].

Some of the causes of the UHI are difficult to remedy (e.g., restricted airflow because of buildings, necessary human activities that release thermal energy), but some are within our easy control [2,3,4].

The heat island effect as shown in Fig. 1.

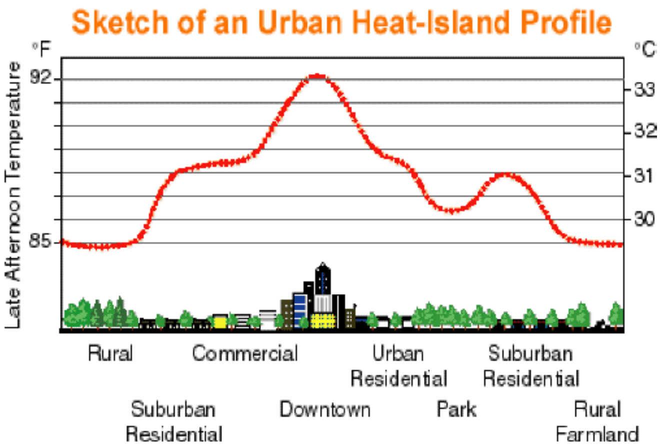

Figure 1. Urban Heat Island Profile [5].

What is the Albedo effect?

Albedo is the percentage of incoming radiation reflected off a surface. An albedo of 1 means that 100% of incoming radiation is reflected (no radiation is absorbed); an albedo of 0 means that 0% of incoming radiation is reflected (all radiation is absorbed).

Why is the Albedo effect important? The more radiation reflected the less global warming that occurs. It is known how the ice caps reflect solar radiation and hence why their melting is such a big issue. Fresh snow has an albedo of approximately 0.9 [6].

A composite index called the solar reflectance index (SRI) is used by the U.S. Green Building Council and others to estimate how hot a surface will get when exposed to full sun. The temperature of a surface depends on the surface’s reflectance and emittance, as well as solar radiation. The Solar Reflectance Index (SRI) is used to determine the effect of the reflectance and emittance on the surface temperature, and varies from 100 for a standard white surface to zero for a standard black surface [5].

Table 1 shows the reflectance, emittance and SRI of some common building materials.

Table 1. Solar reflectance (albedo), Emittance, and Solar Reflective Index (SRI) of select material surfaces [5]

Material surface	Solar Reflectance	Emittance	SRI
Black acrylic paint	0.05	0.9	0
New asphalt	0.05	0.9	0
Aged asphalt	0.1	0.9	6
“White” asphalt shingle	0.21	0.91	21
Aged concrete	0.2 to 0.3	0.9	19 to 32
New concrete (ordinary)	0.35 to 0.45	0.9	38 to 52
New white portland cement concrete	0.7 to 0.8	0.9	86 to 100
White acrylic paint	0.8	0.9	100

The use of light colored exposed concrete in our urban areas and roadways can aid in the overall energy savings, safety, comfort and ambience of the general public. This is a guiding principle of Low Impact Development (LID).

Light colored concrete absorbs less heat and reflects more light than dark-colored materials, therefore maintaining a low surface temperature.

High albedo concrete has been demonstrated to have a positive impact on the localized ambient temperatures and can reduce energy requirements to cool buildings.
Light colored pavements also require less site lighting to provide safe night-time illumination levels, whether on parking lots, driveways or sidewalks. Less sighte lighting requires less energy.

Although not always an indicator, materials with a light color have a high albedo, where materials that appear darker typically have a lower albedo. A material’s ability to reflect infrared light is directly proportional to a material’s ability to reflect heat from the surface [7].

2. WHITE CEMENT - PROPERTIES

White Cement takes artistic expression to new heights, allowing architects, engineers and contractors the freedom to choose from an unlimited range of colors, textures, shapes, sizes and patterns to accommodate a multitude of applications [8][3][9].

AALBORG WHITE® meets the demands that most countries make on rapid-hardening cement and is made of particularly pure white chalk and finely-ground sand. The content of substances that might color the cement is thus limited to a minimum. The small quantities of colored substances that are always present in raw materials are bound and their coloring effect eliminated through the use of a special flame-cleaning technique.

AALBORG WHITE® has a very low alkali content and high sulphate resistance. It is therefore ideal for concrete used in passive as well as aggressive environments (e.g. bridges or structures in contact with sulphated ground water).

Concrete made with AALBORG WHITE® quickly gains relatively high compressive strength and its ultimate strength is far higher than that of concrete in which ordinary grey Portland cement is used. AALBORG WHITE® carries a product certificate and fulfils the requirements of EN 197-1 and the American ASTM C 150.

High reflection white concrete has a higher reflection of light than grey concrete. Where grey concrete has a reflection corresponding to a Hunter L value of 40, white concrete has a reflection corresponding to a Hunter L value of up to 85.

When the concrete surfaces are wet the difference is larger. With wet concrete the Hunter L value of grey concrete can fall to approx. 20 where the value for white concrete can fall to approx. 70 [10].

Product characteristics for Aalborg white cement – Portland cement CEM I 52.5 is shown in table 2.

Table 2. Product characteristics for Aalbort white cement “Portland cement CEM I 52.5” [11]

Cement designation		To EN 197-1		ASTM C 150	
Type		Portland cement			
Designation		CEM I 52.5		I II III V	
Strength class		52.5			
Content of clinker minerals a.o. in %					
C_3S	C_2S	C_3A	C_4AF	Na_2O eqv.	$CaSO_4$
62	25	4	1	0.2	3-5
Density and setting					
Absolute density		kg/m3		3150	
Bulk density		kg/m3		1100	
Setting time, initial		100 minutes			

In table 3. is shown declaration of performance Aalbort white cement “Portland Cement CEM I 52,5 R - SR5”, Aalborg, Denmark, used in the preparation of concrete and mortar etc [11].

Table 3. Declaration of performance Aalbort white cement, “Portland cement CEM I 52,5 R - SR5” [11]

Essential characteristics	**Performance**	**Requirements in EN 197-1**
1 day strength	21 - 27 MPa	None
2 days strength	39 - 47 MPa	≥ 30 MPa
7 days strength	53 - 65 MPa	None
28 days strength	66 - 76 MPa	≥ 52.5 MPa
Initial setting time	110 - 160 min	≥ 45 min
Loss on ignition	≤ 2 %	≤ 5.0 %
Insoluble residue	≤ 0.3 %	≤ 5.0 %
Sulphate content SO_3	1.8 - 2.3 %	≤ 3.5 %
Chloride	≤ 0.04 %	≤ 0.10 %

Alkali content	≤ 0.3 %	None
Water soluble chromate	≤ 2 mg/kg	≤ 2 mg/kg *(Claims in EU Directive 2003/53/EC)*
Y-Reflection, (DIN 5033)	85 - 89.5 %	None
Specific density	3090 - 3190 kg/m3	None

3. WHITE CONCRETE

White concrete is synonymous with light, clear colors and beautifully consistent surfaces – whether on large or small buildings, or in facilities of any size. Constructions automatically look more elegant and slim when they are created using white concrete.The light-reflecting property of white concrete is particularly useful as a practical function in the manufacture of kerbs, road markings, tunnel ramps and paving stones, in-situ constructions, mortar and paints, terrazzo [12].

Albedo reflectance of different pavement surfaces is shown in table 4.

Table 4. Albedo: Reflectance of Pavement Surfaces

Albedo: Reflectance of Pavement Surfaces	
Asphalt	0.05–0.10 (new)
	0.10–0.15 (weathered)
Gray Portland Cement Concrete	0.35–0.40 (new)
	0.20–0.30 (weathered)
White Portland Cement Concrete	0.70–0.80 (new)
	0.40–0.60 (weathered)

The infrared image, figure 2, demonstrates that the light colored concrete remains cooler than the darker colored asphalt road. It can easily be appreciated that a city with darker roads and roofs would become much hotter leading to local heat island effects and wider global warming effects. The local heat island effect can have significant cost implications.

Figure 2. The infrared image demonstrates that the light colored concrete remains cooler than the darker colored asphalt road.

Figure 3. illustrates that there is a reduced requirement for artificial lighting when surfaces are lighter colored. These two images are of similar shopping centers with the same degree of artificial lighting.

The difference in luminescence is because at one centers the car park is asphalt and in the other it is lighter colored concrete. Because of the increased visibility as a result of the lighter colored concrete there is a considerable safety benefit.

Using lighter colored surfaces can result in up to a 30% reduction in energy usage because reduced artificial lighting is required to achieve a similar brightness [13].

Figure 3. The difference in luminescence between asphalt and lighter colored concrete.

Furhter is provided an example of experimental testing of white concrete in aggressive environements is shown in the paper “White Concrete for Aggressive Environment AALBORT WHITE“ [13].

Besides the reference concretes, each series contained concretes with the following powder combinations:

- one concrete based on 100% Aalborg White (AW) with no other powder;
- one concrete based on 95% AW and 5% silica fume;
- one concrete based on 100% AW with 2 kg zinc stearate per m3 concrete;
- one concrete based on 95% AW and 5% silica fume with 2 kg zinc stearate per m3 concrete;
- one concrete based on 70% AW and 30% blast furnace slag.

The concretes had a slump of 150±30 mm and an air content of 5.9-7.0%. It should be noted that there was no great effect of powder composition on slump or air content. However, it was necessary to double or triple the quantity of air-entraining agent used in the mix designs containing zinc stearate (i.e. hydrophobic agent) [13].

Based on the tests of physical-mechanical properties on the aforementioned concrete mixtures, the following conclusions were drawn:

1. The ultimate strength of white concretes was similar to that of the reference concretes at both investigated water/powder ratios.
2. The initial strength of white concretes was higher than that of the reference concretes.
3. The initial heat development in white concretes without blast furnace slag was higher than that of the reference concretes.
4. Replacing 30% of Aalborg White cement with blast furnace slag reduced heat development in relation to concretes based mainly on pure Aalborg White cement.
5. Chloride diffusion coefficients similar to those of reference concretes were achieved by the addition of 5% silica fume.

6. The addition of zinc stearate did not affect the measured properties significantly.
7. All concretes were frost resistant, with the exception of Mix 10, containing 30% blast furnace slag and having a water/powder ratio of 0.45.
The overall conclusion of the examination is:

Concrete based on AALBORG WHITE® cement and silica fume has at least as good properties in respect to strength and durability as concrete normally used in constructions placed in an aggressive environment [13].

4. SUSTAINABLE BENEFITS OF WHITE CONCRETE

Thermal properties of concrete based materials can be far superior to other competitive materials. Reflectivity of light for use in flooring applications in malls, schools, airports and other large buildings, which reduces the requirement excessive lighting which in turn reduces energy costs.

Reduction of the heat island effect by using white based mix designs for the manufacture of rooftop pavers, light colored pavers in driveways, walkways, patios rooftop pavers, light colored pavers in driveways, walkway and around pools.

White cement can be pigmented to achieve various colors without the need for paint or stains thus eliminating VOCs (Volatile Organic Compounds - According to the EPA, some VOCs are suspected to cause cancer in animals and humans, while others are actually known human carcinogens). When concrete products reach the end of their long useful life they can be recycled and used in the manufacture of other product [14][15].

There is increasing interest in using white or colored concrete in aggressive environments.

5. CONCLUSION

The light color of Portland cement concrete has always been one of the material's most important attributes. However, white cement is not only being used for building facades – it is also finding growing acceptance in countertops, flooring, pavement, concrete masonry units (CMUs), mortar, grout, and site furnishings.

While aesthetics are the primary factor driving the use of white concrete its brilliance/reflectivity also contributes to energy efficiency, safety, and other functional considerations.

The enhanced reflectivity of white concrete can be used to conserve energy and meet criteria for sustainable conctruction. White concrete can also create floors that reflect more light, reducing the energy required for interior lighting by approximately 20 percent when compared to ordinary gray concrete floors.

Light colored concrete's inherent reflectivity also improves visibility and safety on roadways.The reflectivity is particularly striking in wet weather because gray concrete tend to darken when damp. For many started departments of transportations white concrete reduces the ongoing coasts of repainting highway barriers, bridge piers, parapets, median strips, and other structures, which are required to be white for safety reasons [16].

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BELI CEMENT BETON KAO ELEMENT ODRŽIVOG GRADITELJSTVA

Rezime: Uticaj materijala na temperaturu lokalne atmosfere je područje istraživanja koje se ubrzano razvija. Osnovno istraživanje na ovom polju je usmereno ka boji i kompoziciji materijala i njihovoj sposobnosti da reflektuju ili apsorbuju (i emituju) sunčevo zračenje. Boja i sastav materijala snažno utiču na temperature materijala izložene sunčevom zračenju. Toplotna energija nastala apsorpcijom sunčevog zračenja će u konačnom dospeti u okolnu atmosferu, izazivajući lokalno zagrevanje. Nivoi smoga u vazduhu su takođe u korelaciji sa porastom temperature. Stoga, kako se temperatura urbanih područja povećava, tako se povećava i mogućnost za nastanak smoga i zagađenja. Jedan od materijala koji smanjuje između ostalog i napred navedene negativne efekte po okruženje je i beli beton. Beli beton, spravljen od belog cementa je popularan kod arhitekata zahvaljujući svom čistom i jednoobraznom izgledu. U radu su prikazana svojstva belog cementa, belog betona i prednosti njegovog korišćenja kao elementa održivog graditeljstva.

***Ključne reči**: beli cement, beli beton, održivo graditeljstvo*